DEPARTMENT OF HEALTH AND HUMAN SERVICES

Public Health Service
Centers for Disease Control and Prevention (CDC)

Memorandum

Date: March 26, 2001

From: Roy M. Fleming, Sc.D., Director, Research Grants Program RMF
Office of Extramural Programs, NIOSH, D30

Subject: Final Report Submitted for Entry into NTIS for Grant 5 R01 OH003254-04

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment
cc: Sherri Diana, EID, P03/C13 w/attachment

List of Publications

Title: Risk Factors for Injury in Denver Airport Construction
Investigator: Judith Glazner, M.S.
Affiliation: University of Colorado
City & State: Denver, CO
Telephone: (303) 315-7939
Award Number: 5 R01 OH003254-04
Start & End Date: 9/30/1994–9/29/1998
Total Project Cost: $908,117
Program Area: Traumatic Injuries
Key Words:

Abstract:
Purpose - The principal objective of the study was to test hypotheses related to prevention of occupational disease and injury in construction workers. The purpose of the specific aim addressed herein was to estimate the morbidity impacts of an Owner-Controlled Insurance Program (OCIP) and state workers' compensation reform. Historically, construction has been the most hazardous industry and has only recently been surpassed by manufacturing. Study of construction worker morbidity has been hampered by the multiplicity of small employers, each with its own separate workers' compensation insurance plan, who are present on construction sites for variable and often short periods of time. Construction of Denver International Airport (DIA) provided a unique opportunity to describe the magnitude of injury on a major construction project for which complete data on injury and hours at risk were available for over 32,000 employees working 31 million hours.

For construction project owners and states wishing to reduce the incidence and burden of work-related injury and illness, knowledge about the effects of particular project organizational features, such as OCIPs, and of legal reform of workers' compensation systems upon injury and payment rates is important. These are potentially effective tools within the domains of project ownership and government.

Methods - Comprehensive payroll data for all workers, who were paid standard Davis-Bacon wages, allowed calculation of person hours at risk by job classification. Complete reporting, facilitated by a single workers' compensation plan covering all contracts and by an on-site medical clinic and designated provider system, allowed us to determine both total and lost-work-time (LWT) injury rates per 200,000 hours at risk. Workers' compensation payment rates were calculated and compared with expected loss rates, derived by the National Council on Compensation Insurance. All rates were calculated by relevant time periods.

Overall Results - An apparent lack of validity of nationally determined injury rates did not allow us to make meaningful comparisons with DIA rates, leaving unanswered the question of the effects of an OCIP on injury rates. Moreover, no similar data for a similar project without an OCIP with which to compare the DIA experience existed; we could therefore draw no conclusion about the effects of an OCIP on worker morbidity. Without information about the workers' compensation experience of similar projects in states

without legal reform during the same period, it is not possible to attribute the reduction in DIA payment rates we found for the pre-reform and post-reform periods to workers' compensation reform.

Publications

20000859 Glazner JE, Borgerding J, Bondy J, Lowery JT, Lezotte DC, Kreiss K: Contractor Safety Practices and Injury Rates in Construction of Denver International Airport. Am J Med, in press, 1999

20024052 Glazner JE, Borgerding J, Lowery JT, Bondy J, Mueller K, Kreiss K: Construction Injury Rates May Exceed National Estimates: Evidence from the Construction of Denver International Airport. Am J Ind Med 34:105-112, 1998

20024053 Lowery J, Borgerding JA, Zhen B, Glazner JE, Bondy J, Kreiss K: Risk Factors for Injury Among Construction Workers at Denver International Airport. Am J Ind Med 34:113-120, 1998

20024837 analysis of construction injury burden by type of work AMJ IND MED 37(4): 390-399 Feb. 2000

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Risk Factors for Injury in Denver Airport Construction

Summary Report: Specific Aims 1 and 2

December 28, 1998

Principal Investigator (9/94-9/96): Kathleen Kreiss, MD
Principal Investigator (10/96-9/98): Judith Glazner, MS

Project Coordinator: Jan T. Lowery, MPH
Investigators: Jessica Bondy, MSHA
Joleen Borgerding, MS
Dennis C. Lezotte, PhD
William Marine, MD, MPH
John Martyny, PhD

Sponsors: National Institute for Occupational Safety and Health
Grant Number R01 OH03254

List of Publications and Status

Glazner JE, Borgerding J, Lowery JT, Bondy J, Mueller K, and Kreiss K: Construction injury rates may exceed national estimates: Evidence from the construction of Denver International Airport. Am J Ind Med 34:105-112, 1998.

Glazner JE, Borgerding J, Bondy J, Lowery JT, Lezotte DC, Kreiss K: Contractor safety practices and injury rates in construction of Denver International Airport. Am J Ind Med., in press, 1999.

Lowery J, Borgerding JA, Zhen B, Glazner JE, Bondy J, Kreiss K: Risk factors for injury among construction workers at Denver International Airport. Am J Ind Med 34:113-120, 1998.

Lowery JT, Borgerding JA, Glazner JE, Bondy J, Lezotte DC, Kreiss K: Type-of-work analysis reveals wide variation in several measures of injury burden in construction workers. Submitted to Am J Ind Med.

Significant Findings

Specific Aim 1: To describe the magnitude of work-related injury and illness by trade and project

Relevant Publications.

Glazner J, Borgerding J, Lowery JT, Bondy J, Mueller K, and Kreiss K: Construction injury rates may exceed national estimates: Evidence from the construction of Denver International Airport. Am J Ind Med 34:105-112. (1998).

Lowery JT, Borgerding JA, Glazner JE, Bondy J, Lezotte DC, and Kreiss K: Type-of-work analysis reveals wide variation in several measures of injury burden in construction workers. Submitted to Am J Ind Med.

Significant Findings.

After analyzing comprehensive injury and payroll data (including both injuries and hours at risk for over 32,000 employees working 31 million hours), we found that Denver International Airport's (DIA) overall total injury rates were over twice those published by the Bureau of Labor Statistics (BLS) for the construction industry for each year of DIA construction. Most of the difference occurred for non-lost-work time (non-LWT) injuries; differences between DIA's and BLS's LWT rates were modest by comparison.

DIA's total injury rates were twice BLS's rates for all contractor sizes. The injury rate pattern by company size at DIA differed from BLS's in that small firms at DIA had injury rates that were higher than or comparable to most other size categories. BLS's rates for small firms were lower than its rates for all but the very largest (250 or more employees) contractors. DIA's total workers' compensation (WC) payment rate of $7.06 per $100 payroll was only 11 percent higher than the Colorado-specific expected loss rate ($6.35) calculated for the project using the method specified by the National Council on Compensation Insurance.

It is unlikely that the injury rate at the DIA site was substantially higher than in construction nationally. The project was large, but no component was unusual. A substantial safety infrastructure, not universally provided on construction projects, was in place. Its activities included requiring written safety plans and job hazard analyses, overseeing contractor compliance with safety rules, investigating incidents and accidents, and administering on-site safety programs. A likely explanation for the difference between DIA injury rates and BLS rates is that the latter do not reflect the true incidence of construction work-site injury and illness.

Complete reporting, facilitated by the existence of a single WC plan, an on-site medical clinic, and designated medical providers, is the more likely explanation for

DIA's higher injury rates. The relatively small difference between DIA's payment rates and expected loss rates suggests that the discrepancy between DIA's injury rates and national estimates is due primarily to underreporting of non-LWT injuries to the BLS. The burden of on-site work-related construction injury may be higher and more costly than has been evident from national data.

For more detailed reporting on these findings, see Glazner et al., 1998.

With respect to trade-specific injuries and illnesses, we have submitted a manuscript describing our findings to the American Journal of Industrial Medicine. The most significant findings follow.

Because claims and payroll data were recorded in DIA's administrative database according to job classification, we were able to analyze injury and payment data by type of work performed. Types of work were defined using National Council on Compensation Insurance job classifications.

Several types of work (elevator construction, metal/steel installation, conduit construction, glass installation, general concrete construction and carpentry) were associated with lost-work-time (LWT) injury rates more than 50 percent higher than average for DIA construction and more than twice as high as BLS-reported rates for the construction industry for 1993 (BLS, 1995). These same types of work were also associated with higher-than-average non-LWT injuries. Comparison of several types of work for which there were comparable categories in BLS reports revealed three- to five-fold greater injury risk for DIA workers.

For the project as a whole, the mean and median number of lost-work days for LWT injuries were 112 and 52 days, respectively. The days of work lost per injury, including estimated lost days for permanent total injuries and deaths, ranged from 4 to 10,179 days (approximately 39 years). The median number of lost-work days reported by BLS for construction for 1993 was 7 days (BLS, 1995). The DIA median was calculated based on Colorado's definition of lost time, i.e., more than three work days, while BLS's is based on a definition of a minimum of one lost work day. These differing definitions explain to some extent the large difference between medians. When we recalculated BLS's median to exclude the 1- and 2-day losses, we arrived at a median of 31 days. (We were unable to exclude the 3-day injuries because of the way in which BLS reports lost days.) The median lost days for several types of work (drivers/trucking-202; general concrete construction-91; and roofing –90) were considerably higher than for other types of work. These three types of work also accounted for the highest workers' compensation payment rates.

To compare safety performance at DIA with expected performance, we measured workers' compensation payment rates against expected loss rates for each type of work. Expected loss rates (ELRs) are a measure of prevailing risk calculated by the National Council on Compensation Insurance. They represent average workers' compensation claim payments per $100 of payroll among workers with the same job classification across industries. ELRs are explained in some detail in Glazner et al. (1998).

Payment rates for several types of work were notably higher than their ELRs, indicating that safety performance was poor compared with similar work performed across all industries in Colorado. In general, those types of work with payment rates exceeding their ELRs were also those with the highest payment rates at DIA. They included: drivers/trucking, metal/steel installation, and elevator construction. Roofing, which was associated with the highest payment rate, also had the second highest ELR, suggesting that its safety performance was average for that type of work. To determine whether payment rates that were higher than ELRs were explained by more complete reporting of non-LWT injuries, we calculated payment rates for LWT claims only and compared these with ELRs by type of work. While the exclusion of non-LWT claims naturally reduced the payment rates, in no case was the decrease sufficient to bring the payment rates that had been in excess of ELRs down to the level of ELRs.

Payment rates for a number of types of work, including iron/steel erection at levels below two stories, iron/steel erection at levels above two stories, insulation work, and concrete construction of bridges and culverts, were lower than their ELRs, suggesting that these types of work were performed more safely than expected.

Usefulness of Findings.

Construction worker morbidity has been difficult to study because of the multiplicity of employers with different workers' compensation insurance plans who are present on construction sites for variable and often short periods of time. The findings presented here, because they are based on complete numerator and denominator data, call into question national reports on the magnitude of construction injury as well as company-specific measures of safety, such as experience modification ratings, calculated by NCCI for all construction contractors. If such measures are underestimated, contractors and project owners will not correctly assess the magnitude and cost of work-related injury and may not target internal safety resources appropriately. National resources, too, may be misdirected if true construction industry injury rates are closer to DIA's rates than to BLS's, since construction could once again replace manufacturing as the riskiest industry.

Findings about injuries associated with types of work can guide safety professionals, project owners, and contractors in targeting their safety activities and resources to types of work at high risk for injury. Researchers performing trade-specific analysis have acknowledged that workers in specific trades may perform a wider range of construction work than their trades would suggest (Lipscomb et al., 1996; OSHA, 1992; Construction Safety Association of Ontario, 1995). Moreover, much construction work is performed by non-trade union workers. Injury prevention is the province of the employer, who must address risk of work type rather than trade-union-specific risk. Trade-specific analysis can illuminate the risks to which members of certain trades are exposed. But the results presented here provides information about the relative levels of risk faced when workers perform certain types of work. Such information is a necessary precursor to developing safety interventions specific to tasks or types of work performed and may be more useful than trade-specific analysis for such purposes.

Relationship of publications to specific aims.

The articles cited above describe the magnitude of work-related injury and illness, as reflected in injury rates and workers' compensation payment rates, occurring during construction of the Denver International Airport. We reported rates of injury and payment at both the project level and the type-of-work level. Because of the availability of an administrative database with complete reporting of injuries and complete payroll data (converted into person hours of work), we believe that the DIA experience described in these articles gives the best estimate available to date of the burden of on-site work-related injury and illness in construction workers as a whole and for specific types of construction work.

Specific Aim 2: To assess modifiable risk factors for construction-related health problems.

Lowery J, Borgerding JA, Zhen B, Glazner JE, Bondy J, Kreiss K: Risk factors for injury among construction workers at Denver International Airport. Am J Ind Med 34:113-120, 1998.

Glazner J, Borgerding J, Bondy J, Lowery JT, Lezotte DC, Kreiss K: Contractor safety practices and injury rates in construction of Denver International Airport. Am J Ind Med. in press, 1999.

Significant findings. The administrative database created by the owner-controlled insurance program for construction of Denver International Airport allowed for analysis of certain contract characteristics for their effects on injury rates. We used Poisson regression models to examine contract-specific risk factors for total, LWT, and non-LWT injuries, calculating rate ratios to signify the relative risk of injury for each level of each model variable, while controlling for all other variables in the model. The variables we investigated included construction domain, company size, contract status as prime, subcontract or higher order subcontract, contract start year, company SIC code, contract payroll size, and percent overtime payroll. We found that risk for total and non-LWT injuries was greater for building construction contracts, contracts for special trades companies (SIC 17), contracts with payrolls over $1 million, contracts of small and mid-sized companies, and those with overtime payrolls greater than 20 percent. Risk for LWT injuries was increased for site development contracts and contracts starting in the first year of construction. Using logistic regression, we found that contracts experiencing one or more minor injuries were four times as likely to have at least one major injury. Univariate analysis revealed that LWT injury rates were significantly higher in the first quartile of contract duration compared with all other quartiles. Moreover, both LWT and non-LWT injury rates were found to increase with worker age.

Expected loss rates (ELR), typically used within the insurance industry to set workers' compensation insurance premiums, were a significant predictor for all injuries. We found no correlation between injury rates among contracts held by the same company.

We investigated the effects of company and contract safety practices on injury rates by conducting a survey of contractors who built DIA. Using Poisson regression, we examined the association between contract injury rates and reported contract safety practices, controlling for variables previously shown to affect contract-level injury rates (Lowery et al., 1998). Two actions (1) disciplinary action always resulting when safety rules were violated and (2) always considering experience modification ratings when selecting subcontractors, were associated with lower LWT injury rates. Three actions or contract characteristics resulted in lower non-LWT injury rates: management always establishing goals for safety for supervisors, conducting drug testing at times other than badging or after an accident, and completing the DIA contract on budget, rather than over budget. Reported consistent use of a large number of safety practices, however, was associated with *significantly higher* injury rates in both bivariate and multivariate analyses.

Usefulness of findings. The analysis of risk factors suggests several approaches for targeting safety resources. The absence of correlation between injury rates among contracts held by the same company suggests that targeting safety resources at the level of the contract, as opposed to the company, may be an effective approach to injury prevention. Occurrence of minor injuries may be a useful trigger for assessment of safety practices and intervention to avert major injuries, as indicated by the association between minor and major injuries at the contract level. Limited safety resources can also be targeted to older workers, workers new to a site, contracts with sizable overtime payroll, and contracts belonging to small and mid-sized companies.

The pattern of counterintuitive results found in the analysis of reported contractor safety practices suggests that questions reflecting agreed-upon safety practices are likely to elicit normative responses. Research into company safety culture and practices will benefit from objective validation of reported safety practices, measures of both time at risk and outcome, and control for prevailing risk of the work performed.

Relationship of publications to specific aims.

The articles cited above describe the findings of the DIA construction injury study with respect to risk factors for injury at the contract level, including both objective factors, such as construction domain, SIC, and percent overtime, and reported use of safety practices, such as management providing safety leadership and companies providing safety training to all new or transferred workers. They satisfy specific aim 2 in its entirety and they add detail to the findings about project-wide injury rates (specific aim 1).

References

BLS (Bureau of Labor Statistics): Work Injuries and Illnesses by Selected Characteristics, 1993. Washington, DC: U.S. Department of Labor, 1995.

Construction Safety Association of Ontario: Injury Atlas, Ontario Construction. Toronto: Construction Safety Association of Ontario, 1995.

Lipscomb HJ, Kalat J, Dement JM: Workers' compensation claims of union carpenters 1989-1992: Washington State. Appl Occup Environ Hyg 11:56-63, 1996.

Occupational Safety and Health Administration (OSHA): Construction lost-time injuries: the U.S. Army Corps of Engineers database, 1984-1988. Washington, D.C. OSHA, 1992.

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Risk Factors for Injury in Denver Airport Construction

Technical Report for Specific Aim 3:

Specific Aim 3: To estimate the morbidity impacts of both an owner-controlled insurance program and workers' compensation reform in Colorado which occurred midstream in the airport construction

December 28, 1998

Principal Investigator (9/94-9/96): Kathleen Kreiss, MD
Principal Investigator (10/96-9/98): Judith Glazner, MS

Project Coordinator: Jan T. Lowery, MPH
Investigators: Jessica Bondy, MS
Joleen Borgerding, MS
Dennis C. Lezotte, Ph.D.
William Marine, MD, MPH
John Martyny, PhD

Sponsors: National Institute for Occupational Safety and Health
Grant Number R01 OH03254

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List of Abbreviations

DIA: Denver International Airport

ELR: Expected Loss Rate

LWT: Lost work time

Non-LWT: non-lost work time

NCCI: National Council on Compensation Insurance

OCIP: Owner-Controlled Insurance Program

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Significant Findings

The third specific aim of the study, "Risk Factors for Injury in Denver Airport Construction," addressed the effects of both workers' compensation legal reform and an owner-controlled insurance program on worker morbidity. That specific aim read as follows:

> To estimate the morbidity impacts of both an owner-controlled insurance program [OCIP] and workers' compensation reform in Colorado which occurred midstream in the airport construction.

To achieve the third specific aim, two questions were proposed to be answered.

> Question 1. Did this owner-controlled insurance plan result in better health and safety, as reflected in fewer workers' compensation claims and expenses per payroll hour, than the construction industry had in Colorado and the nation during the 1990-94 time period?
>
> Question 2. Did the legislative reform of the Colorado Workers' Compensation Act in 1991 result in lowering the medical, indemnity, or disability payments for comparable workers' compensation claims submitted from 7/91 through 8/94 compared to claims submitted from 12/90 through 6/91? Did this reform have any effect on prevention of work-related injury and illness at this project?

Effects of an Owner-Controlled Insurance Program. Earlier findings with respect to injury rates and payment rates (described in Glazner et al., 1998) led us to the conclusion that construction injury is underreported to the Bureau of Labor Statistics (BLS), perhaps to a considerable degree. Because of this, we felt that there was no adequate standard against which to measure construction injury rates for Denver International Airport (DIA). We cannot determine conclusively, therefore, whether DIA injury and payment rates were in fact lower or higher than injury and payment rates experienced elsewhere in the state or the nation.

Another approach to determining the relative effectiveness of an OCIP would be to compare DIA results with those of another, similar project without an OCIP. No construction projects similar in size and complexity were under way in the world at the time of DIA construction. Had there been such a project, however, it is unlikely that, in the absence of an OCIP, there would have been a centralized database on workers, payroll, injuries and workers' compensation claims. Researchers would have had to collect data on injuries from a multiplicity of private employers, not all of whom would have been cooperative about allowing access to such information. Furthermore, even when the information needed is made available, the likelihood that reporting and data ascertainment would differ among employers is high, leading to collection of non-comparable data from employer to employer.

Given the apparent lack of validity of nationally determined rates and the fact that similar data for a similar project with no OCIP with which to compare the DIA experience were available, we can draw no conclusion about the effects of an OCIP.

Effects of Workers' Compensation Reform. Workers' compensation reforms were passed by the Colorado legislature, but most provisions did not take effect until 1993. While both injury rates and payment rates at DIA declined between the pre-reform and post-reform periods, we were unable to isolate the effects of workers' compensation reform on either injury rates or payment rates from those of several other occurrences. Of particular concern for the usefulness of injury and payment rates in answering this question is the dramatic increase in the project's safety infrastructure (an increase from 5 to 41 employees), which occurred in early 1992, and which may have had an important effect on injury rates and therefore payment rates. Moreover, the work performed in the early years of the project (e.g., site preparation involving heavy machinery) was more dangerous than work performed later, as reflected by the difference in expected loss rates for the two time periods. Furthermore, we found that workers were more likely to be injured during the first quartile of their contract than in any later quartile (Lowery et al., 1998). By the final year of the project, many contracts were in their final phases, and the their injury rates would have declined. Given these competing explanations for the difference in rates, it is difficult to draw conclusions about the effect of workers' compensation legal reform on injury and illness rates.

During the early 1990s, changes in the practice of medicine were occurring, because of both medical advances and increasingly rapid movement to managed care as a mode of insuring and caring for patients in both the health insurance and workers' compensation domains. These could have had the effect of reducing the cost of providing care to injured workers or of reducing the amount of time (and therefore indemnity payments) lost from work. The differences in average payment for total and LWT injuries for the two periods are striking, however, (a 28% decline for all injuries and 15% for lost-time injuries between the two time periods), and these changes in the environment may not account for all of the differences. Without information about the workers' compensation experience of similar projects in states without legal reform during the same period, however, it is not possible to attribute the reduction in payment to workers' compensation reform.

Usefulness of Findings.

With respect to Specific Aim 3, which sought to estimate the morbidity impacts of both an owner-controlled insurance program and workers' compensation reform in Colorado, our findings are inconclusive. It is difficult to isolate the safety effects of particular organizational features of construction projects, such as an owner-controlled insurance program (OCIP), without conducting a prospective study using cases and controls. In the case of the recently completed study, only one project was analyzed, and there were no other similar projects anywhere in the world.

Because the structure of the workers' compensation arrangements at DIA, including the OCIP, contributed to more complete reporting and therefore apparently higher injury rates than would otherwise have been found, we cannot conclude that it resulted in better health and safety than was typical of Colorado and the nation at the time of DIA construction. The fact that workers' compensation payment rates were lower for DIA during 1992 and 1993 than would have been expected (based on expected loss rates) for Colorado, coupled with our belief that more complete reporting occurred, suggests that the project may have been safer than average. There are, however, competing explanations for greater safety at DIA, including a large and active safety program, which, while it was aided in its mission by the OCIP, could have existed simply as an arm of the project owner, whether an OCIP existed or not. We cannot, therefore, answer this question conclusively with the data available.

Certainly, an OCIP with a centralized database containing demographic information and claims information makes possible the type of study conducted for the DIA construction project. It enabled us to aggregate workers' compensation experience over hundreds of contractors on site, to obtain payroll denominator data and to control for comparable medical care delivery. Other OCIPs for large construction projects could likewise support such analyses, and such study would advance understanding of the burden of construction site injury. The analytic difficulties that an OCIP can solve, however, make study of the effects of the OCIP itself on injury experience nearly impossible, since OCIP construction projects would have to be compared with similar projects with no OCIP. These difficulties include the necessity of collecting demographic, payroll and workers' compensation claims data from the multitude of different employers usually found on large construction sites. These problems have hampered construction injury research for decades.

We also found that the data available to us did not support determining the effects of Colorado's workers' compensation reform on worker injury and illness. Workers' compensation reforms took effect in 1993, about 2/3 of the way through DIA construction. Clearly, it would be very useful for states and policy makers to know whether the reforms they have passed have had the desired effects. While our findings of significant declines in total and lost-work-time injury rates from the pre-reform period to the post-reform period are suggestive, numerous competing explanations for those declines make it impossible to attribute them to workers' compensation reform. A study of several states, with and without workers' compensation reform, would be useful in answering this question. Ideally, the study would examine several industries, not only construction. Such a study would have to measure compliance with the reforms passed and the effects on workers with respect to return to work, worker health outcomes, and medical and indemnity costs.

Abstract

Risk Factors for Injury in Denver Airport Construction

Purpose The principal objective of the study was to test hypotheses related to prevention of occupational disease and injury in construction workers. The purpose of the specific aim addressed herein was to estimate the morbidity impacts of an Owner-Controlled Insurance Program (OCIP) and state workers' compensation reform. Historically, construction has been the most hazardous industry and has only recently been surpassed by manufacturing. Study of construction worker morbidity has been hampered by the multiplicity of small employers, each with its own separate workers' compensation insurance plan, who are present on construction sites for variable and often short periods of time. Construction of Denver International Airport (DIA) provided a unique opportunity to describe the magnitude of injury on a major construction project for which complete data on injury and hours at risk were available for over 32,000 employees working 31 million hours.

For construction project owners and states wishing to reduce the incidence and burden of work-related injury and illness, knowledge about the effects of particular project organizational features, such as OCIPs, and of legal reform of workers' compensation systems upon injury and payment rates is important. These are potentially effective tools within the domains of project ownership and government.

Methods Comprehensive payroll data for all workers, who were paid standard Davis-Bacon wages, allowed calculation of person hours at risk by job classification. Complete reporting, facilitated by a single workers' compensation plan covering all contracts and by an on-site medical clinic and designated provider system, allowed us to determine both total and lost-work-time (LWT) injury rates per 200,000 hours at risk. Workers' compensation payment rates were calculated and compared with expected loss rates, derived by the National Council on Compensation Insurance. All rates were calculated by relevant time periods.

Overall Results An apparent lack of validity of nationally determined injury rates did not allow us to make meaningful comparisons with DIA rates, leaving unanswered the question of the effects of an OCIP on injury rates. Moreover, no similar data for a similar project without an OCIP with which to compare the DIA experience existed; we could therefore draw no conclusion about the effects of an OCIP on worker morbidity. Without information about the workers' compensation experience of similar projects in states without legal reform during the same period, it is not possible to attribute the reduction in DIA payment rates we found for the pre-reform and post-reform periods to workers' compensation reform.

Background for the Project

The Denver International Airport (DIA) was built between September 1989 and August 1994; 2,843 contracts were awarded to 769 contractors. With over 32,000 individual employees and 31 million person hours of work, the building of DIA was the largest construction project in the world at the time. Beginning in December 1990, the City and County of Denver implemented an Owner-Controlled Insurance Program (OCIP) which provided all workers' compensation and general liability insurance for the project; established an on-site medical clinic and physician referral system as designated provider for the entire project; and created a project-wide safety infrastructure. Demographic data for all on-site employees were entered in a project-wide database. Contractors reported monthly regular and overtime payroll by job classification. These data were stored in the project-wide database, as were workers' compensation claims. This administrative database provided an unprecedented opportunity to study risk of injury for construction workers.

Specific Aims

The first two specific aims of the study, "Risk Factors for Injury in Denver Airport Construction," were successfully attained and are documented in four publications, listed in the final section of this report. These two aims were:

1. To describe the magnitude of work-related injury and illness by trade and project; and
2. To assess modifiable risk factors for construction-related health problems.

The third specific aim of the study addressed the effects of both workers' compensation legal reform and an owner-controlled insurance program on worker morbidity. That specific aim read as follows:

Specific Aim 3: To estimate the morbidity impacts of both an owner-controlled insurance program and workers' compensation reform in Colorado which occurred midstream in the airport construction

This report addresses only the third specific aim.

Methods

We examined work-related injury and illness in 32,081 individual employees building the DIA between December 1990 and August 1994. We identified 4,634 workers' compensation claims with payment. We obtained information on the 963 claims with lost work time (LWT), defined as missing more than three scheduled work shifts, from the Colorado Division of Workers' Compensation. From payroll data adjusted for overtime pay, we estimated person hours by dividing payroll for each trade by the prevailing Davis-Bacon wage (adopted by the City for paying workers at DIA) for that trade. From claims and person hours, we calculated injury rates per 200,000 hours (equal to 100 full-time employees) at risk. With claims as the numerator and hours at risk as the denominator, the injury rates we describe are a measure of incidence. Confidence intervals for injury rates were calculated assuming a Poisson distribution for number of claims (Haenszel et al., 1962).

We calculated workers' compensation payment rates per $100 of payroll. To compare payment rates with statewide expected rates, we used Colorado-specific expected loss rates (ELR) derived by the National Council on Compensation Insurance (NCCI) for 1992 (1995). ELRs represent average workers' compensation claim payments per $100 of payroll among workers with the same job classification across industries. To make payment rates and calculated ELRs comparable, we adjusted payments and payroll to 1992 dollars, capped individual payments at $126,000 (the limit used by NCCI) and included only medical and indemnity payments (the payments included by NCCI).

Results and Discussion

To achieve the third specific aim, two questions were proposed to be answered. We will address each of these questions in turn and describe our findings below.

Question 1. Did this owner-controlled insurance plan result in better health and safety, as reflected in fewer workers' compensation claims and expenses per payroll hour, than the construction industry had in Colorado and the nation during the 1990-94 time period?

The DIA construction project did not result in fewer total claims per payroll hour than did the construction industry in the nation, as reported by the Bureau of Labor Statistics (BLS) for any of the four years of the project (Glazner et al., 1998). In only one year, 1994, was the DIA rate for lost-work-time (LWT) injuries alone lower than that reported by BLS. No injury-rate data based on hours at risk exist for the state of Colorado for any industry, but there is no reason to believe that Colorado-specific data would be different from national data.

For two of the four years of DIA construction (1992 and 1993), the claims payment rate at DIA per $100 payroll was lower than the expected loss rate for Colorado construction; for the other two years, it was higher (Glazner et al., 1998). For a more complete explanation of these injury rate and payment rate findings and the methods used to reach them, see Glazner et al. (1998) (reprint attached to this report).

Question 2. Did the legislative reform of the Colorado Workers' Compensation Act in 1991 result in lowering the medical, indemnity, or disability payments for comparable workers' compensation claims submitted from 7/91 through 8/94 compared to claims submitted from 12/90 through 6/91? Did this reform have any effect on prevention of work-related injury and illness at this project?

While workers' compensation reform legislation was passed in Colorado in 1991, its most important provisions did not take effect until 1993. These consisted of two principal changes: (1) treatment guidelines had to be issued by the Workers' Compensation Division of the state and used by physicians (the first of these, low-back pain guidelines, were issued in 1993); and (2) physicians had to be trained and accredited to perform impairment ratings by July 1993. The division developed a two-day impairment ratings course and test that were used in early 1993 to train and accredit physicians. We therefore examined differences in payment and injury rates for the two periods, 12/90 - 6/93 and 7/93 – 8/94.

Payment Rates. The payment rates for all types of injuries (LWT and non-LWT) declined from the first period to the second. Table 1 shows the workers' compensation payment rates per $100 payroll for the two time periods, adjusted for inflation to 1992 dollars. They are compared with expected loss rates, which are a measure of prevailing risk. We calculated expected loss rates for each construction period shown in the table based on the expected loss rates for the job classifications of workers at DIA during each period. Since expected loss rates are calculated by capping payments at $126,500, we also capped DIA payments at that level in order to make our comparison valid.

Table 1: Payment rates for lost work time (LWT), non-LWT and total injuries for the periods, 12/90-6/93 and 7/93 – 8/94, Denver International Airport construction

Period	**Payment Rates per $100 Payroll***			
	Total Injuries	**LWT Injuries**	**Non-LWT Injuries**	**Expected Loss Rate**
12/90 – 6/93	$7.21	$6.39	$0.68	$6.20
7/93 – 8/94	5.06	4.32	0.63	4.96

* The payment rates shown are adjusted to 1992 dollars and capped at $126,500.

Table 1 provides information on payment rates per $100 payroll, and therefore includes data on non-injured workers. To measure the differences in the two periods with respect to payments for injured workers only, we examined average payments for the two time periods, thereby excluding non-injured workers from the denominator. Table 2 shows the average payment per injury for the two time periods.

Table 2: Average payment for LWT, non-LWT, and total injuries for the periods, 12/90-6/93 and 7/93 – 8/94, Denver International Airport construction

Period	**Payment per injury**			
	All injuries (n)	LWT injuries (n)	Non-LWT injuries (n)	Unknown type* (n)
12/90 – 6/93	$9,368 (3095)	$38,184 (690)	$940 (2370)	$ 11,973 (35)
7/93 – 8/94	6,711 (1539)	32,385 (273)	922 (1257)	$36,466 (9)

* The injuries in this column are those for which information about type (LWT or non-LWT) is missing.

Injury Rates. Injury rates declined between the period 12/90-6/93 and 7/93-8/94, although the change in non-LWT injury rates was not significant. See Table 3.

Table 3. LWT, non-LWT, and total injury rates for the periods, 12/90-6/93 and 7/93 – 8/94, Denver International Airport construction					
Time Period	**Person Hours**	**Total Injury Rate (CI*)**	**LWT Injury Rate (CI*)**	**Non-LWT Injury Rate (CI*)**	**Expected Loss Rate**
12/90-6/93	19,829,194	31.2 (30.1,32.3)	7.0 (6.5,7.5)	23.9 (23.0,24.9)	$6.20
7/93-8/94	11,228,888	27.4 (26.1,28.8)	4.9 (4.3,5.5)	22.4 (21.2,23.7)	4.96

* Confidence intervals are in parentheses.

The decline in total injury rates between the two periods was 12.2 percent (30% for LWT injury rates). The decline in ELRs, the best available measure of prevailing risk, between the two periods was 20 percent. Given that the prevailing risk of the work performed, as measured by ELRs, declined more than the actual total injury rate, it is impossible to conclude that injury rates declined for any reason other than the decline in prevailing risk.

Conclusion

Effects of an Owner-Controlled Insurance Program. Our earlier findings with respect to injury rates and payment rates led us to the conclusion that construction injury is underreported to the BLS, perhaps to a considerable degree (Glazner et al., 1998). Because of this, we felt that there was no adequate standard against which to measure DIA's injury rates. This same objection applies to some extent to ELRs, which are calculated based on workers' compensation claims and would therefore suffer from the same shortcoming as BLS injury rates. We cannot determine conclusively, therefore, whether DIA injury and payment rates were in fact lower or higher than injury and payment rates experienced elsewhere in the state or the nation.

Another approach to determining the relative effectiveness of an Owner-Controlled Insurance Program (OCIP), would be to compare the DIA results with those of another, similar project without an OCIP. No construction projects similar in size and complexity were under way in the world at the time of DIA construction. Had there been such a project, however, it is unlikely that, in the absence of an OCIP, there would have been a centralized database on workers, payroll, and workers' compensation claims. Researchers would have had to collect data on injuries from a multiplicity of private employers, not all of which would have been cooperative about allowing access to such information. Furthermore, even when the information needed is made available, the likelihood that reporting and data ascertainment would differ among employers is high, leading to collection of non-comparable data from employer to employer.

Given the apparent lack of validity of nationally determined rates, and the fact that similar data for a similar project with no OCIP with which to compare the DIA experience are available, we can draw no conclusion about the effects of an OCIP.

Effects of Workers' Compensation Reform. While both injury rates and payment rates declined in the post-reform time period, we were unable to isolate the effects of workers' compensation reform on either injury rates or payment rates from those of several other occurrences. Of particular concern for the usefulness of the injury and payment rate figures in answering this question is the dramatic increase in the project's safety infrastructure (an increase from 5 to 41 employees), which occurred in early 1992, and which may have had an important effect on injury rates and therefore payment rates. Moreover, the work performed in the early years of the project (e.g., site preparation involving heavy machinery) was more dangerous than work performed later, as reflected by the difference in expected loss rates. Furthermore, we found that workers were more likely to be injured during the first quartile of their contract than in any later quartile (Lowery et al., 1998). By the final year of the project, many contracts were in their final phases, and their injury rates would have declined. It is difficult therefore to draw conclusions about the effect of the passage of workers' compensation legal reform on injury and illness rates.

During the early 1990s, changes in the practice of medicine were occurring, because of both medical advances and increasingly rapid movement to managed care as a mode of insuring and caring for patients in both the health insurance and workers' compensation domains. These could have had the effect of reducing the cost of providing care to injured workers or of reducing the amount of time (and therefore indemnity payments) lost from work. The differences in average payment for total and LWT injuries for the two periods are striking, however, (a 28% decline for all injuries and 15% for LWT injuries) between the two time periods), and these changes in the medical environment may not account for all of the differences. Without information about the workers' compensation experience of similar projects in states without legal reform during the same period, however, it is not possible to attribute the reduction in payment to workers' compensation reform.

In earlier progress reports, we documented that we would not be able to conclusively answer the questions posed by Specific Aim 3.

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Present and possible future publications.

There are no existing publications about this specific aim; no future publications are planned.

Publications addressing Specific Aims 1 and 2:

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Construction Injury Rates May Exceed National Estimates: Evidence From the Construction of Denver International Airport

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Background *Construction of Denver International Airport (DIA) provided a unique opportunity to describe the magnitude of injury on a major construction project for which complete data on injury and hours at risk were available for over 32,000 employees working 31 million hours.*

Methods *Comprehensive payroll data for all workers, who were paid standard Davis-Bacon wages, allowed calculation of person-hours at risk by job classification. Complete reporting, facilitated by a single workers' compensation plan covering all contracts and by an on-site medical clinic and designated provider system, allowed us to determine both total and lost-work-time (LWT) injury rates per 200,000 hours at risk by industrial sector, company size, and year of construction. Workers' compensation payment rates were calculated and compared with expected loss rates, derived by the National Council on Compensation Insurance, by sector, company size, and year.*

Results *DIA's overall total injury rates were over twice those published by the Bureau of Labor Statistics (BLS) for the construction industry for each year of DIA construction. Differences in LWT injury rates were more modest. Total injury rates were also at least twice BLS's rates for all contractor sizes. The injury rate pattern by company size at DIA differed from BLS's in that small firms had injury rates that were higher than or comparable to most other size categories; BLS's rates for small firms were lower than those for all but the very largest (250 or more employees) contractors. DIA's total workers' compensation (WC) payment rate of $7.06 per $100 payroll was only 11% higher than Colorado-specific expected loss rates reported by the National Council on Compensation Insurance.*

Discussion *Complete reporting, facilitated by the existence of a single WC plan, an on-site medical clinic, and designated medical providers, yielded injury rates significantly higher than previously reported. The relatively small difference between DIA payment rates and expected loss rates suggests that the discrepancy between DIA's injury rates and national estimates is due to underreporting of non-LWT injuries to the BLS. The burden of on-site work-related construction injury may be higher and more costly than has been evident from national data.* Am. J. Ind. Med. 34:105–112, 1998.
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KEY WORDS: occupational injury; construction injury; BLS data; workers' compensation; workers' compensation payments; injury severity

INTRODUCTION

Incidence of work-related injury by industry is difficult to ascertain in the United States. We had a unique opportunity to describe the nature and magnitude of work-related injury and illness among workers who built Denver International Airport (DIA), a public works project for the City and County of Denver, which made its insurance data available to our research team. Despite a multitude of employers at DIA, all workers' compensation claims were recorded in a

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centralized database, along with denominator data in the form of payroll according to job classification, as is typically obtained by insurance companies. The existence of a project-wide workers' compensation insurance plan, coupled with an on-site clinic and designated medical provider system for all contractors, addressed the problems of underreporting work-related injury and illness.

Since 1972, the Annual Survey of Occupational Injuries and Illnesses of the Bureau of Labor Statistics (BLS) has generated rates of occupational injury and illness by Standard Industrial Classification (SIC) Code. The numerators for these rates are taken from Occupational Safety and Health Act (OSHA) logs, which record occupational illnesses and injuries, and from workers' compensation claim reports; denominators are based on employee hours reported to BLS by employers surveyed. Persuasive evidence exists that firms with fewer than 50 employees underreport occupational injuries to this national database [Oleinick et al., 1995]. For the construction industry in particular, BLS rates likely underestimate risk for workers on construction sites by including off-site workers, such as office staff.

Another approach to ascertaining the incidence of work-related injury and illness is to analyze workers' compensation claims. Underreporting is a problem here as well, since many work-related injuries do not result in workers' compensation claims [Klein et al., 1984; Hunting et al., 1994; Waller et al., 1989; Kisner and Fosbroke, 1994; Belville et al., 1993; Silverstein et al., 1997]. When workers' compensation claims and emergency department occupational injury surveillance data for the same population have been compared, neither dataset has been found to fully capture occupational injuries [Fingar et al., 1992]. For some conditions, such as cumulative trauma disorders, medical insurance claims have been useful in surveillance [Park et al., 1992], but a comprehensive picture of incidence would require linking both workers' compensation and medical insurance claims to the working populations at risk. Most studies examining workers' compensation claims either have relatively crude estimates of the numbers of workers at risk [Kisner and Fosbroke, 1994] or have used industry-specific employment figures from state unemployment insurance records [Culver et al., 1993; Waller et al., 1989; Fingar et al., 1992]. The health insurance industry collects employment data that may be linked with claims from their insured firms, but these data are often considered proprietary and, with rare exceptions [Tsai et al., 1989], are not used in published surveillance reports.

Historically, construction has been the most hazardous industry, as measured by total injury rate, and was only recently surpassed by manufacturing [BLS, 1995]. Recent efforts to characterize morbidity and mortality in construction workers have relied on proportionate mortality studies [Robinson et al., 1995], data from BLS's Supplementary Data System [Kisner and Fosbroke, 1994; Culver et al., 1993], workers' compensation claims linked to trade union employment records [Lipscomb et al., 1996], and emergency room surveillance of injuries among construction workers [Hunting et al., 1994; Waller et al., 1989; Zwerling et al., 1996]. The last approach is limited by difficulties in defining the populations at risk, with some studies presenting numerator data only and others attempting a population-based approach using U.S. Department of Labor employment data for the catchment area [Zwerling et al., 1996]. Emergency room data give a valuable picture of more serious injuries to construction workers but are less useful for cumulative trauma disorders, minor conditions and illnesses, and fatalities.

We report here the experience of construction workers building DIA, emphasizing injury rates and workers' compensation payment rates, with particular attention to differences according to company size, company SIC, and year of construction. We also compare the experience of these on-site construction workers at DIA with national average construction injury rates and average payment rates for Colorado.

BACKGROUND

The Denver International Airport was built between September 1989 and August 1994 with a construction budget of over $2.7 billion. In total, 2,843 individual contracts were awarded to 769 contractors (number of contracts and contractors consists of unduplicated counts, not including contracts for nominal amounts) without prequalification on the basis of prior health and safety experience. Of these, 74 contractors held 128 general construction or prime contracts and hired subcontractors when necessary. The project employed firms from all three construction industry sectors (SIC codes 15–17), representing virtually all construction trades, to complete contracts for site development, roadway and parking construction, airfield construction and paving, building of concourses and terminals, utility development, and project management.

Beginning in December 1990, the city implemented an Owner Controlled Insurance Program (OCIP) which 1) provided all workers' compensation and general liability insurance for the entire project; 2) established an on-site medical clinic and physician referral system as designated provider for all work-related injury and illness; and 3) created a project-wide safety infrastructure as part of the project's management team. At the time of identification badging, all on-site employees provided demographic information, which was entered in a project-wide database. Contractors reported monthly regular and overtime payroll by job classification, as defined by the National Council on Compensation Insurance (NCCI); these contract-specific reports were subsequently audited. These data were stored in a centralized database, as were workers' compensation claims, generated for treatment rendered at and coordinated by the on-site clinic. If a first report of injury was not supplied for a claim, the insurance carrier requested one from the injured worker's employer before paying the claim. For some claims, no first report was submitted; therefore, no payment was made. No financial incentive or disincentive existed for medical staff to classify conditions as work-related, and the clinic provided walk-in medical care on-site for nonoccupational conditions for a modest fee.

MATERIALS AND METHODS

Cohort, Claims, and Payments

We retrospectively examined work-related injury and illness in a cohort consisting of 32,081 individual employees badged for on-site work during the construction of DIA between December 1990 and August 1994. For this group, we identified 4,634 workers' compensation claims with payment. We obtained information on the subset of 963 claims with lost-work-time (LWT) from the Colorado Division of Workers' Compensation, which records only those claims for injuries causing an employee to miss more than three scheduled work shifts or resulting in death or permanent disability.

Claims payment data were updated through March 1997, at which time 1.7% of all claims remained open. We estimated total payments for open claims by incorporating the total reserves set aside for these claims by the insurance carrier for the OCIP. We organized claim payments into three categories: medical, indemnity (wage loss, permanent disability, disfigurement, and death), and other (transportation, vocational rehabilitation, and litigation services) and adjusted them for inflation, as appropriate. For the proportion of indemnity payment determined by claimant wage, we used the annual percent change in the Colorado state average weekly wage, since this was the basis for payment for the majority of claimants receiving wage benefits. Scheduled payments for injuries resulting in permanent partial disability remained unchanged over the construction period, as did the fee schedule for medical services. We adjusted medical payments by year to account for changes in intensity of medical services using national estimates from the national health accounts (Office of the Actuary, U.S. Department of Health and Human Services, personal communication, November 9, 1995). For other workers' compensation payments, we adjusted by year using the Urban Consumer Price Index for all items in the Denver-Boulder area [BLS, 1991–1994].

Company Size and Industrial Classification

The insurance database linked contract payroll and employees with their associated companies. By linking company tax identification numbers with state unemployment insurance records, we obtained company SIC codes for 83% of DIA contractors, as well as size (average annual number of employees) for the year prior to starting work at DIA for 65% of contractors. Company size was available only for Colorado companies. The companies that could not be linked with unemployment insurance records (17% of all DIA contractors) were likely to be out-of-state companies and did not differ in terms of contract payroll size at DIA.

TABLE I. Number of Companies Working at DIA, Payroll, and Person-Hour Percentages by Standard Industrial Classification

Standard industrial classification	Number of companies	Payroll (%)	Person-hours (%)
General building (SIC 15)	35	12.9	13.8
Heavy construction (SIC 16)	72	17.3	18.2
Special trades (SIC 17)	326	49.2	45.8
Nonconstruction	207	13.5	14.9
Unknown industry	129	7.1	7.3
Total	769	100.0	100.0

Payroll and Person-Hours at Risk

We used payroll data to estimate person-hours at risk for all contracts, adjusting for overtime pay by dividing the overtime amounts by 1.5. From adjusted payroll, we estimated person-hours by dividing payroll for each trade by the prevailing Davis-Bacon wage of that trade, adopted by the City and County of Denver for paying workers on the DIA project. Using information from the Colorado Building and Construction Trades Council [1994], we defined trades as combinations of similar NCCI job classifications. Our definitions are not strictly synonymous with trade union definitions, however, because we classified laborers by type of work and could not distinguish them from other trades. We assumed that fringe benefits, specified by Davis-Bacon rates, were not included in trade wage rates, since companies with 20 or more employees accounted for 84% of the project's person-hours and were likely to offer a benefit package in lieu of paying benefits in wages (personal communication, Mary Jayne Villalobos, Denver Auditor's Office, January 2, 1997).

Not all workers at DIA were employed by construction contractors. Approximately 27% of all companies were nonconstruction firms, providing services such as engineering, architecture, product supply, and general business services; these firms, along with 129 (17%) companies with unknown SIC codes, accounted for 21% of payroll (Table I). Unless otherwise noted, the results described refer to companies and contracts with construction SIC codes (15–17) only. SIC 15, general construction, refers to general contractors engaged in construction of buildings; SIC 16, heavy construction, refers to general contractors engaged in highway and street construction; and SIC 17, special trades, refers to contractors engaged in construction trades, e.g., electrical contractors, plumbing and heating contractors, and carpenters.

Rates

From claims and person-hours, we calculated injury rates per 200,000 hours at risk. Each claim represented one injury incident or medical condition, not an individual medical visit. One hundred full-time employees is equal to 200,000 person-hours per year. With claims as the numerator and hours at risk as the denominator, the injury rates we describe are a measure of incidence. We calculated both total and LWT injury rates by industrial sector, company size, and year of construction. The term, "injury," refers to both injury and illness, since less than 10% of all workers' compensation claims were for illnesses. Confidence intervals for all injury rates were calculated assuming a Poisson distribution for number of claims [Haenszel et al., 1962]. The denominator we used for calculating rates is comparable to that used by the BLS, which surveys employers, who report the number of hours their employees work. From the reported hours, BLS calculates the number of full-time employees, which becomes the denominator for its published injury rates (personal communication, Robert Walker, statistician, Bureau of Labor Statistics, June, 1996).

We calculated workers' compensation payment rates per $100 of payroll according to three strata: industrial sector, company size, and construction year. To compare actual stratum-specific payment rates with statewide expected rates, we used Colorado-specific expected loss rates (ELR) derived by NCCI for 1992 [1995]. ELRs represent average workers' compensation claim payments per $100 of payroll among workers with the same job classification across industries. We were able to calculate a weighted average of ELRs for each stratum of interest, weighting by the proportion of payroll accounted for by each job classification. To make payment rates and calculated ELRs comparable, we adjusted payments and payroll to 1992 dollars, capped individual payments at $126,000 (the limit used by NCCI) and included only medical and indemnity payments (the payments included by NCCI). Expected loss rates are a useful standard against which to measure payment, since they approximate prevailing risk for each job.

RESULTS

Injury Rates for All Industries

The total injury rate for the DIA project, including both construction and nonconstruction SIC codes, was 29.8 injuries per 200,000 person-hours at risk. Total injury rates declined over the project period, from 36.1 injuries per 200,000 person-hours in 1991 to 22.4 in 1994. We identified 963 LWT claims through the Colorado Division of Workers' Compensation, resulting in an LWT rate of 6.2 injuries per 200,000 person-hours for all DIA workers. The LWT rate declined from 11.4 injuries per 200,000 in 1991 to 3.7 in 1994.

Injury Rates for the Construction Industry

The total injury rate for DIA construction companies (SIC 15–17) *alone* was higher than for all industries combined: 32.7 per 200,000 person-hours, declining from 37.3 in 1991 to 27.7 in 1994. For contracts with construction SIC codes, there were 826 LWT claims, resulting in an LWT injury rate of 6.8 for all years, declining from 11.6 in 1991 to 4.4 in 1994. The following narrative and Tables II and III focus only on these construction contractors.

Total injury rates for DIA workers in the construction industry were significantly higher than those reported by the BLS for the construction industry during the same years. While rates decreased over time in both cases, DIA's total injury rates were at least 2.3 times those published by the BLS throughout the period. There were also significant differences between DIA's LWT rates and BLS's, although these differences were more modest; in the case of 1994 injury rates, no significant difference was found (Table II).

Differences between the DIA and BLS datasets persist when injury rates by SIC code are examined, but the order of rates by industrial classification was the same for the DIA as for the BLS data, with special trades contractors (SIC 17) showing the highest total and LWT injury rates in both databases (Table II).

DIA's injury rates by company size revealed a pattern different from that published by the BLS. While DIA's total injury rates for every company size class were at least double BLS's rates, the greatest rate difference was observed for very small companies (1–19 employees): DIA's rate for this category was over three times BLS's rate. BLS's injury rate for the smallest firms was considerably lower than its rates for larger companies (20–249 employees), while DIA's total injury rate for small firms was higher than its rates for firms with 100 or more employees, about the same as its rate for firms with 50–99 employees and lower than only one other category—firms with 20–49 employees. DIA's LWT injury rates were significantly higher than BLS's, except in the case of companies with 50–99 employees.

Payment Rates

Of the total 4,634 DIA workers' compensation claims, 3,955 were made by workers in companies classified in SIC 15–17. Of these, indemnity payments were made for 974: 826 for lost work time; 420 for permanent disabilities,

TABLE II. Injury Rates per 200,000 Person-Hours for the Construction Industry, DIA, and BLS,[a] According to Year, Standard Industrial Classification, and Company Size

	Number of injuries	DIA total injury rate	95% CI	BLS total injury rate	DIA LWT injury rate	95% CI	BLS LWT injury rate
Year of construction							
1991	575	37.3[b]	34.4, 40.5	13.0	11.6[b]	9.9, 13.4	6.1
1992	1,135	32.9[b]	31.1, 34.9	13.1	7.2[b]	6.4, 8.2	5.3
1993	1,997	32.2[b]	30.8, 33.7	12.2	5.8[b]	5.2, 6.4	4.9
1994	244	27.7[b]	24.4, 31.5	11.8	4.4	3.2, 6.1	4.9
SIC code							
15—General construction	628	29.2[b]	27.0, 31.6	11.3	6.7[b]	5.6, 7.9	4.5
16—Heavy construction	723	25.6[b]	23.8, 27.5	10.9	6.6[b]	5.7, 7.7	4.3
17—Special trades	2,604	36.6[b]	35.2, 38.0	12.6	7.0[b]	6.4, 7.6	5.1
Company size							
1–19 Employees	430	32.7[b]	29.7, 36.0	9.7	5.8[b]	4.6, 7.3	4.4
20–49	727	35.7[b]	33.2, 38.4	14.4	8.0[b]	6.8, 9.4	5.6
50–99	493	33.8[b]	30.9, 36.9	15.0	6.5	5.3, 8.0	5.6
100–249	1,192	30.0[b]	28.3, 31.7	13.6	6.6[b]	5.9, 7.5	5.0
250–499	343	27.1	24.4, 30.2	NA	3.2	2.4, 4.4	NA

[a]Sources for BLS rates: U.S. Department of Labor, Bureau of Labor Statistics, 1992, 1993, 1994, and BLS News, December 15, 1995.
[b]Rate significantly different from BLS rate ($P < 0.05$).

TABLE III. Workers' Compensation Adjusted Payment Rates for Construction Contractors at DIA and Expected Loss Rates by Standard Industrial Classification, Year, and Company Size ($1992)

	Total claims	
	DIA payment rate	**Expected loss rate**
Industry	Per $100 payroll	Per $100 payroll
General building (SIC 15)	$ 8.77	$7.29
Heavy construction (SIC 16)	8.13	6.33
Special trades (SIC 17)	6.22	6.12
All construction (SIC 15–17)	7.06	6.35
Year		
1991	$16.07	$7.90
1992	6.96	7.07
1993	5.26	5.89
1994	5.06	4.99
Total	7.06	6.35
Company size		
1–19 employees	$ 6.14	$7.92
20–49	8.73	6.38
50–99	5.01	6.00
100–249	7.45	6.28
250–499	4.26	4.46
Total	7.06	6.35

including ten for permanent total disabilities; and two for fatalities. (While there were three fatalities on the DIA project, only two were associated with firms with construction SIC codes.) Indemnity payments for both LWT and disabilities could have been made on the same claim. The total number of claims with indemnity payments included 38 that could not be categorized regarding LWT based on information available. The mean payment for all claims made by construction workers (SIC 15–17) was $9,526/claim; the median payment was $317; payments were less than $68 for 10% of all claims. For LWT claims, the mean was $40,359, and the median was $14,127. LWT claims accounted for 88% of all workers' compensation payments for construction workers.

For all construction SIC codes, the payment rates were higher than expected loss rates (Table III). As was the case with injury rates, payment rates declined over time, as did ELRs, reflecting diminished risk of the work being performed. For only two company size categories were payment rates higher than expected loss rates: firms with 20–49 employees and those with 100–249 employees. In the case of 20–49-employee firms, the difference was sizable.

DISCUSSION

The incidence of work-related injury and illness for on-site workers building the DIA far exceeded the BLS's estimates for the construction industry (SIC 15–17). There are several possible explanations for this: 1) the injury rate at the DIA site was much higher than on construction sites nationally; 2) the DIA experience is representative of construction sites nationally, but underreporting of injury rates to the BLS survey results in sizable underestimates of total construction injuries; or 3) the DIA experience is representative of construction sites nationally, but the inclusion of off-site workers in the BLS survey lowers national injury rates substantially.

We think it unlikely that the injury rate at the DIA site was substantially higher than in construction nationally. While DIA was an exceptionally large project, no component was unusual; the work performed was typical of other projects in the various project domains (e.g., site development, roadway construction, building construction). The overall project was unusual only in the number of contracts involved, and therefore engineering complexities associated with connecting structures built by different companies (personal communication, Stacy Pocrass, Construction Risk Manager for DIA, July, 1997). Moreover, the project's safety management team required written safety plans and job hazard analyses of prime contractors, oversaw contractor compliance with safety rules and regulations, collected attendance logs of required weekly "tool box" safety meetings, investigated incidents and accidents, and administered on-site safety programs, such as drug and alcohol testing and incentive awards. Project management's commitment to safety increased substantially in late 1991, resulting in a several-fold increase in safety personnel at the project management level (from 5 to 41 employees) in early 1992. It seems unlikely that this safety infrastructure, often lacking in construction projects, would be accompanied by injury rates more than twice the national average. The decline in both total injury rates and LWT injury rates at DIA after 1991, while payroll more than doubled during 1992 and nearly doubled again in 1993, argues for the effectiveness of this enhanced safety infrastructure.

A likely explanation for the discrepancy between DIA injury rates and BLS rates is that the latter do not reflect the true incidence of construction work-site injury and illness. We found that DIA's LWT injury rates are more comparable to those reported by the BLS from its annual survey than are total injury rates, suggesting that the apparent excess in injury rates at DIA was largely in the category of injuries without LWT compensation. Moreover, both the overall payment rate and the distribution of payments suggest that many DIA claims were likely related to minor injuries, including first-aid injuries. First-aid injuries are specifically excluded from reporting requirements on OSHA 200 logs, which are one basis of reporting to BLS's Annual Survey [BLS, 1995b]. While they were also not reportable at the DIA, the definition of first-aid injuries at DIA may have been narrower than that of OSHA and the BLS. Other instructions in the BLS survey ("we are providing employers the option of either completing the forms we have provided or of submitting copies of documents that typically exist in establishments" [BLS, 1986]) imply that minor injuries, the care for which has been paid for by the employer or employee with no workers' compensation claim filed, need not be reported. This could be a common occurrence among both larger, self-insured firms and smaller firms anxious to avoid a compensation claim that could affect future premiums. In contrast, at the DIA, claims were generated whenever medical treatment was rendered, even for minor injuries.

Oleinick et al. [1995] concluded that the BLS report of substantially lower injury rates in small construction firms (<25 employees) than in mid-sized firms (50–499) was likely attributable to underreporting. They presented BLS data for all injuries in the construction industry nationally, which showed that companies with fewer than 25 workers reported less than half the injury rate of companies with 50 or more workers. DIA injury rate data by company size contrast with BLS data in that the injury rates for the smallest firms are not the lowest and the range of injury rates by company size is modest. Furthermore, Colorado construction companies with employment of fewer than 50 prior to DIA experienced significantly higher total injury rates (34.5 per 200,000 person-hours) than did larger companies (30.2), consonant with the increased risk of their work, as reflected in their expected loss rates. Thus, our data support the contention that small firms underreport injuries to the BLS Annual Survey. Also consistent with the conclusions of Oleinick et al. for the construction industry, we found that LWT injury rates showed only a modest employment size effect, with the smallest firms (1–19 employees) having rates that were not significantly different from those of mid-sized firms (50–249 employees).

If the difference between DIA's injury rates and BLS's is largely attributable to underreporting to the BLS survey, as we believe, it is likely that construction firms make fewer workers' compensation claims than are justified. Companies may simply pay for medical treatment and file no claim. Furthermore, medical claims for work-related injuries, which should be paid by workers' compensation insurance, may be made to and paid by health insurance carriers. This could happen for any number of reasons, including physician or worker unfamiliarity with workers' compensation or a wish on the part of the worker or the firm to avoid workers' compensation claims. Workers' compensation premiums are usually calculated individually for each firm, while health insurance premiums, for all but the largest firms, are calculated by pooling the experience of many like-sized firms. Thus, if costs were shifted from workers' compensation to health insurance, a firm's workers' compensation premium could be kept artificially low without an offsetting rise in health insurance premiums, because those premiums would be subsidized by companies sharing the firm's health insurance pool. It may not be feasible to correct underreporting to BLS occurring as a result of cost shifting to health insurance from workers' compensation.

When a company underreports work-related injury, its workers' compensation experience will not reflect its actual injury experience. In such cases, construction project managers and prime contractors that base subcontracting decisions on experience modification ratings, which in turn are based on workers' compensation claims data, will make decisions using erroneous information. Furthermore, if firms do not identify all work-related injuries, they will not correctly assess the magnitude and cost of work-related injury and may not target internal safety resources appropriately. The payment rates described here include only direct costs of injury. If indirect costs, which include lost productivity, disrupted work schedules, administrative time for investigations and reports, training replacement personnel, cleanup and repair or replacement of equipment or property, adverse publicity, and third-party liability claims against the contractor, were included, total costs would increase dramatically. Ratios of indirect to direct costs in construction range from 1.6:1 [Levitt et al., 1981] for all claims to 4.2:1 for medical-only claims and 20.3:1 for LWT claims [Hinze and Applegate, 1991]. National resources, too, might be misdirected if true construction industry injury rates are closer to DIA's rates than BLS's rates, since construction could once again replace manufacturing as the riskiest industry, assuming that underreporting does not occur equally across industries. This assumption is likely to be correct for several reasons: 1) the construction industry includes many small firms relative to other industries, and most evidence points to small firms as those most likely to underreport [Oleinick et al., 1995]; 2) the construction industry, made up almost entirely of firms that must compete with others to work on projects, has a strong incentive to underreport because of the use of experience modification ratings (based on workers' compensation claims) in the bidding process [Levitt and Samelson, 1993]; and 3) construction is one of the riskiest industries, with concomitantly high workers' compensation premiums and, therefore, an economic disincentive to make claims.

Apart from reporting, we would expect DIA's injury rates to be slightly higher than BLS-reported rates because only on-site workers were enrolled in its OCIP. In contrast, BLS staff survey companies and calculate company-wide rates by SIC codes. Even with identical injury experience of on-site construction workers, DIA rates would be higher than BLS rates on the basis of BLS's inclusion of lower-risk off-site workers in the denominator. For instance, in Colorado in 1993, clerical workers accounted for 9.7% of the construction work force. At DIA, clerical workers accounted for only 5% of the work force, suggesting that about half of the clerks employed by construction firms worked off-site [CDLE, 1994]. The small excess of LWT injury rates at DIA, in comparison with BLS rates, might be expected to be largely attributable to this difference in at-risk populations. Counterbalancing this effect, however, is the BLS survey's definition of LWT time as greater than one day, in contrast to Colorado's workers' compensation definition of four or more lost work shifts. The proportion of LWT injuries reported to BLS with fewer than three lost days in both 1992 and 1993 was 27% [BLS, 1995b,c]. This suggests that the DIA's rates should have been substantially lower than the BLS's.

For DIA construction, the overall workers' compensation adjusted payment rate per $100 of payroll was 11% higher than would have been expected based on the overall ELR, calculated using Colorado-specific ELRs by job classification. Because NCCI's rates (the basis for our calculated ELRs) are based on workers' compensation claims, they are limited by any tendency of companies or employees to not file workers' compensation claims for work-related conditions. We believe that higher overall workers' compensation payment rates per $100 of payroll for DIA construction are largely explained by the more complete reporting of work-related injury and illness among DIA construction workers that resulted from the medical, safety, and reporting infrastructures at this project. The increase in payment rate is roughly comparable to the cost of the excess incidence (over BLS rates) in non-work-loss claims, based on average payments for such claims recorded in the DIA database. It is worth noting, however, that the only year in which the adjusted payment rate exceeded the ELR by more than 1.5% was 1991, when DIA's expanded safety infrastructure was not yet fully in operation. These two pieces of evidence suggest that, in addition to more complete reporting of minor injuries, other factors, such as superior claims management and perhaps less severe than average LWT injuries, may be reflected in the overall payment rate. While the large discrepancy between DIA's total injury rates and BLS's appears to have had a relatively small effect on payment rates, the reader should not underestimate the need for reporting minor injuries, since we found that minor injuries are associated with major injuries on the same contract [Lowery et al., 1998]. We are unaware of publicly available sources of payment data for workers' compensation claims in the construction industry with which to compare the DIA payment experience. Such data would be of interest in substantiating our surmise that DIA medical and indemnity payments were not higher than usual payments for work-loss claims for the construction industry.

In summary, the DIA experience gives the best estimate available to date of the burden of on-site work-related injury and illness in construction workers. This burden is substantially higher and more costly than has been evident from data published by the BLS, from the NCCI data, or from the more limited estimates generated by emergency room surveillance studies [Waller et al., 1989; Fingar et al., 1992; Hunting et al., 1994; Zwerling et al., 1996]. Construction worker morbidity has been difficult to study because of the multiplicity of small employers who are present on construction sites for variable and often short periods of time. Denver's OCIP enabled us to aggregate workers' compensation experience over hundreds of contractors on-site with a centralized database, to obtain payroll denominator data and to control for comparable medical care delivery for the largest construction project in the world at that time. Other OCIPs or "wrap-ups" for large construction projects could likewise support such analyses, as long as three crucial elements were in place: 1) a centralized workers' compensation administrative database, 2) on-site designated providers of medical care, and 3) diligent follow-up by the workers' compensation broker to generate claims whenever treatment was rendered. Replication of the current study at a different site would advance understanding of the burden of construction site injury.

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Risk Factors for Injury Among Construction Workers at Denver International Airport

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Background *The Denver International Airport construction project provided a rare opportunity to identify risk factors for injury on a large construction project for which 769 contractors were hired to complete 2,843 construction contracts. Workers' compensation claims and payroll data for individual contracts were recorded in an administrative database developed by the project's Owner-Controlled Insurance Program.*

Methods *From claims and payroll data linked with employee demographic information, we calculated injury rates per 200,000 person-hours by contract and over contract characteristics of interest. We used Poisson regression models to examine contract-specific risk factors in relation to total injuries, lost-work-time (LWT), and non-LWT injuries. We included contract-specific expected loss rates (ELRs) in the model to control for prevailing risk of work and used logistic regression methods to determine the association between LWT and non-LWT injuries on contracts.*

Results *Injury rates were highest during the first year of construction, at the beginning of contracts, and among older workers. Risk for total and non-LWT injuries was elevated for building construction contracts, contracts for special trades companies (SIC 17), contracts with payrolls over $1 million, and those with overtime payrolls greater than 20%. Risk for LWT injuries only was increased for site development contracts and contracts starting in the first year of construction. Contracts experiencing one or more minor injuries were four times as likely to have at least one major injury (OR = 4.0, 95% CI (2.9, 5.5)).*

Conclusions *Enhancement of DIA's safety infrastructure during the second year of construction appears to have been effective in reducing serious (LWT) injuries. The absence of correlation between injury rates among contracts belonging to the same company suggests that targeting of safety resources at the level of the contract may be an effective approach to injury prevention. Interventions focused on high-risk contracts, including those with considerable overtime work, contracts held by special trades contractors (SIC 17), and contracts belonging to small and mid-sized companies, and on high-risk workers, such as those new to a construction site or new to a contract may reduce injury burden on large construction sites. The joint occurrence of minor and major injuries on a contract level suggests that surveillance of minor injuries may be useful in identifying opportunities for prevention of major injuries.* Am. J. Ind. Med. 34:113–120, 1998.

KEY WORDS: occupational injury; construction injury; workers' compensation; occupational epidemiology; injury risk factors

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INTRODUCTION

Little information exists on risk factors for injury in construction workers, although they suffer a disproportionate number of injuries relative to workers in other industries. A major obstacle in research has been a lack of complete incidence and denominator data for calculating injury rates that are also linked with descriptive data with which to characterize risk. In addition, the short-term, episodic nature of construction work, the existence of multiple employers on construction sites, and constantly changing physical work environments have made construction workers difficult to study.

Access to the administrative claims database established for the Denver International Airport (DIA) construction project enabled us to examine risk factors for injury among a large cohort of workers at a single construction site. The DIA administrative database contained information on all workers' compensation claims submitted under the Owner Controlled Insurance Program as well as worker demographic data, information on individual companies and contracts, and payroll by contract and job classification. With these data we were able to calculate injury rates over contract variables of interest and to model injury rates while controlling for prevailing risk of work. We report here our analysis of risk factors for injury among construction workers at DIA and make suggestions for future use of such administrative databases for surveillance and research.

MATERIALS AND METHODS

Study Cohort and Claims

We estimated worker age for the 32,081 individual workers (95% male) badged for on-site work at DIA from December 1990 through August 1994 by subtracting birth date from January 1992, the approximate midpoint of DIA construction. Payroll data and dates of termination were not available for individual employees, so we were unable to calculate duration of work for individuals.

From the administrative database, we identified 4,634 claims with payment, including 963 claims (21%) for lost-work-time (LWT). Three fatalities on the project were counted as lost-time claims. We included claims arising from work-related illnesses (less than 10% of claims) as injuries in this report. All claims were linked with the claimant's company and the specific contract on which the employee was working at the time of injury.

Contract Characteristics

We categorized the 2,843 contracts completed by 769 contractors at DIA by contract status, i.e., prime contract, subcontract, and sub-subcontract, and assigned them to one of seven construction domains: site development, airfield construction and paving, roadway construction, terminal/concourse building construction, site utilities, construction management, and "other." We further classified contracts by size of total payroll (adjusted for overtime and to 1994 dollars), which ranged from less than $100 to over $16 million, by percent overtime payroll, by contract start year, and by length of contract payroll. We linked individual contracts with their corresponding company's Standard Industrial Classification (SIC) code, size (average number of employees in the year prior to DIA work), and Colorado business residence status.

We created a measure of prevailing risk for DIA contracts using Colorado-specific expected loss rates (ELRs) derived by the National Council on Compensation Insurance [NCCI, 1995] according to job classification. We calculated DIA-specific ELRs over contracts as the weighted average of ELRs across job classifications [Glazner et al., 1998].

Injury Rates

We estimated person-hours from contract payroll [Glazner et al., 1998] and calculated injury rates as the number of workers' compensation claims per 200,000 person-hours for the following contract strata: contract status, construction domain, payroll size, percent overtime payroll, start year, contract length, company SIC code, company size, and company Colorado residence status. We determined rates for total injuries, LWT injuries, and non-LWT injuries. To investigate whether injury incidence varied over contract duration, we divided contracts into quartiles of time, and calculated LWT and non-LWT aggregate injury rates for each quartile. Since contract payroll, and thus person-hours at risk, were not evenly distributed over contract length, we also calculated injury rates over quartiles of contract payroll. Ninety-five percent confidence intervals around quartile rates were calculated assuming a Poisson distribution for the number of injuries [Haenszel et al., 1962].

Statistical Analysis

To determine whether an association existed between the occurrence of minor (non-LWT) and major (LWT) injuries on the same contracts, we performed a logistic regression. The binary response, whether or not a contract had at least one major injury, was modeled as a function of covariates. Specifically, the independent variables were 1) the occurrence of one or more minor injuries on a contract, 2) risk, represented by the log of the contract's ELR, and 3) contract person-hours, which, in order to meet the assumption of linearity on the logit scale, was included in the model as a categorical variable, indicating the quartile of contract person-hours to which a contract belonged.

Using generalized linear model techniques [McCullagh and Nelder, 1989], we examined contract-specific risk factors for all injuries, LWT injuries, and non-LWT injuries while controlling for covariates. We assumed that the total number of injuries per contract, ranging from 0–146 injuries, followed a Poisson distribution. We included the logarithm of contract person-hours in the log-linear model for injury count as an offset variable in order to model the rate of injuries. We included a dispersion parameter to adjust standard errors of the parameter estimates, since the scaled deviance was less than one. We limited our analysis to those contracts belonging to the subset of Colorado companies for which we had size information (n = 2,140).

For all significant variables (entered at $P < 0.10$), we calculated adjusted rate ratios, which signify the relative risk of injury for each level of the variable as compared with the reference group (denoted by rate ratio = 1.00) while controlling for all other variables in the model. Confidence intervals excluding 1.00 indicate significant differences in risk ($P < 0.05$) between the specific level and the reference level for that variable.

Since many companies held multiple contracts at DIA, we investigated the possible correlation of injury rates among contracts held by the same company. For each injury type (total, LWT, and non-LWT), we developed two Poisson regression models: 1) specifying an independent error structure which assumes independence of injury rates across all contracts, and 2) specifying a compound symmetric error structure which assumes correlation of injury rates within companies. Generalized estimating equations [Liang and Zeger, 1986] were employed in the case involving correlated errors. We compared the 95% confidence intervals around the respective adjusted rate ratios for the two model types (independent vs. correlated) for each injury type model. We found that for all injury type models, the identification of statistically significant risk factors was identical regardless of the type of error structure assumed, suggesting that the more complex models (assuming correlation within companies) offered no meaningful improvement over the simpler models (independence across contracts). We concluded, therefore, that injury rates among contracts belonging to the same company were not correlated. All regression models were fit using the GENMOD procedure in SAS [1985].

RESULTS

Univariate Analysis

The total injury rate at DIA was 29.8 injuries per 200,000 person-hours, reflecting LWT and non-LWT injury rates of 6.2 and 23.4 injuries per 200,000 person-hours, respectively. Over 12% (3,869) of the workers at DIA suffered injuries resulting in claims, 16% of whom (603) sustained more than one injury. The majority of claimants were male (95%), and though the largest proportion of injuries was sustained by younger workers, the rate of both LWT and non-LWT injury increased with age (Table I).

At least one injury occurred on 695 (25%) of the 2,843 contracts completed at DIA. Contracts starting before 1992, contracts for site development, and short-term contracts lasting 1 month or less experienced considerably higher LWT injury rates than did other contracts in the corresponding strata (Table II). Sub-subcontracts, contracts with no overtime payroll, nonconstruction contracts (SIC Other) and contracts for large companies (≥250 employees) experienced lower LWT injury rates than others within these strata. The rate of non-LWT injuries increased with contract payroll size and contract percent overtime payroll, and was higher among contracts for building construction, special trades (SIC 17) contracts, and sub-subcontracts.

TABLE I. Distribution of DIA Workers and Injury Rates (Total, Lost-Work-Time and Non-Lost-Work-Time Injuries per 100 Workers) by Age Group

Age group[a]	Number of workers[b]	(%)	Number of injuries	Total injury rate[c]	LWT rate	Non-LWT rate
16–19	1,384	(4%)	92	6.6	0.9	5.7
20–29	8,975	(29%)	1,159	12.9	2.5	10.3
30–39	10,936	(35%)	1,528	14.0	2.8	11.0
40–49	6,429	(21%)	1,002	15.6	3.3	12.2
50–59	3,100	(10%)	580	18.7	3.9	14.7
60+	474	(2%)	97	20.5	3.8	16.7

[a]Age information was missing for 783 (2%) workers and 176 injuries.
[b]The denominator for the injury rates in this table is number of employees working any amount of time on this project in each age group, not full-time-equivalents (FTE). The rates shown here are therefore lower than those calculated using FTE.
[c]Differences between total injury rate and (LWT rate + non-LWT rate) reflect either rounding or omission of 44 claims with unknown lost-time status from either the LWT or the non-LWT rate category.

Consistent with the finding of higher risk for short-term contracts, we found that LWT injury rates were significantly higher in the first quartile of contract duration compared with all other quartiles (Table III). LWT injury rates fell by over 50% from the first quartile to the last, with the largest reduction (25%) occurring between the first and second quartiles. Non-LWT injury rates remained unchanged over contract duration until the last quartile. The prevailing risk of work performed, as defined by the expected loss rate, decreased by 22% over contract duration (Table III). Examination of injury rates over quartiles of contract payroll revealed that LWT and non-LWT rates were significantly lower in the last quartile compared with the first quartile (data not shown).

Minor and Major Injuries

We found a positive association between the occurrence of minor (non-LWT) and major (LWT) injuries on contracts. Contracts experiencing one or more minor injuries were four times as likely as those without minor injuries to have at least one major injury (OR = 4.0, 95% CI: (2.9, 5.5)), after controlling for contract person-hours and prevailing risk of work.

TABLE II. DIA Injury Rates (per 200,000 Person-Hours) by Contract Strata

Contract variable	Number of contracts	Total injury rate[a]	LWT injury rate	Non-LWT injury rate
Construction domain				
Management	34	9.6	1.4	8.2
Site development	179	24.8	9.4	15.1
Roadways	218	21.0	4.9	15.9
Airfields	386	29.9	6.6	23.0
Utilities	432	25.3	5.4	19.5
Other	342	25.5	4.2	21.1
Buildings	1,252	34.7	6.7	27.6
Company size (number of employees)				
1–19	1,104	28.1	5.1	22.8
20–49	575	34.5	7.7	26.4
50–99	240	30.9	6.3	24.3
100–249	199	28.1	6.2	21.7
250+	22	25.7	3.0	22.4
Missing	703			
Contract status				
Subcontract	1,664	31.2	6.5	24.0
Sub-subcontract	1,051	32.7	4.8	27.5
Prime	128	26.8	6.1	20.4
Contract start year				
1994	91	17.6	5.9	11.8
1993	1,419	28.7	5.5	23.1
1992	1,005	28.5	5.7	22.6
1990/91[b]	328	32.9	7.6	24.9
Company SIC code				
SIC 15	102	29.2	6.7	22.1
SIC 16	303	25.6	6.6	18.7
SIC 17	1,339	36.6	7.0	29.3
Other	782	18.9	4.2	14.5
Missing	317			
Contract payroll size				
>$1 mi.	117	31.3	6.1	24.9
>$100K–$1M	518	28.4	6.5	21.6
≤$100K	2,208	23.6	5.5	18.1
Percent overtime payroll				
>20%	521	33.2	6.4	26.5
>0–20%	1,621	29.7	6.3	23.2
0%	701	12.7	3.6	9.2
Contract length				
≤1 month	368	36.5	15.7	19.1
>1–6 months	948	26.7	5.1	21.6
>6–12 months	774	28.5	6.0	22.2
>12–24 months	642	31.6	6.8	24.6
>24 months	111	28.6	5.7	22.6

TABLE II. DIA Injury Rates (per 200,000 Person-Hours) by Contract Strata (Continued)

Contract variable	Number of contracts	Total injury rate[a]	LWT injury rate	Non-LWT injury rate
Colorado company status				
Colorado	2,507	29.1	5.9	23.0
Non-Colorado	310	33.3	7.8	25.1
Missing	26			

[a]Differences between total injury rate and (LWT rate + non-LWT rate) reflect either rounding or omission of 44 claims with unknown lost-time status from either the LWT or the non-LWT rate category.

[b]This category includes 12 months of 1991 and only 1 month of 1990 data because DIA's insurance program was implemented December 1, 1990.

TABLE III. DIA Injury Rates (per 200,000 Person-Hours) and Expected Loss Rate Over Quartile of Contract Duration

Quartile	LWT injury rate	95% CI	Non-LWT injury rate	95% CI	ELR
1st	8.3	(7.5, 9.3)	24.6	(23.1, 26.2)	$6.31
2nd	6.2*	(5.6, 7.0)	25.5	(24.2, 26.9)	6.01
3rd	5.1*	(4.4, 5.8)	23.3	(21.9, 24.8)	5.17
4th	4.0*	(3.2, 5.0)	15.3*	(13.6, 17.2)	4.92

*Significantly different from 1st quartile.

Poisson Regression Models

Predictors of both LWT and non-LWT injury rates in the Poisson regression models included expected loss rate, construction domain, company size, contract status, start year, and SIC code (Table IV). The risk for each injury type (LWT and non-LWT) differed among levels of these variables, however. For example, in the case of construction domain, site-development contracts were at highest risk for LWT injuries, whereas building contracts had higher risk for non-LWT injuries. For contract status, sub-subcontracts experienced significantly lower risk for LWT injury than did prime contracts. While sub-subcontractors' crude rate of non-LWT injury was considerably higher than that of prime contractors, their risk of non-LWT injury did not differ from that of prime contractors after adjusting for prevailing risk and the other factors in the regression model. Special trades contracts (SIC 17) suffered higher non-LWT injury rates compared with nonconstruction contracts (SIC Other), and heavy construction contracts (SIC 16) experienced significantly lower risk of LWT injury.

With respect to company size, contracts belonging to companies with fewer than 100 employees had elevated risk for both LWT and non-LWT injuries relative to large

TABLE IV. Rate Ratios for Risk Factors for LWT and Non-LWT Injuries in the Construction of DIA (n = 2,140 Contracts)

Contract variable	Number of contracts	LWT rate ratio	95% CI	Non-LWT rate ratio	95% CI
Expected loss rate (log)		1.65	(1.48, 1.83)	1.10	(1.02, 1.19)
Construction domain					
Management	21	0.72	(0.46, 1.12)	0.56	(0.42, 0.74)
Site development	152	1.46	(1.18, 1.81)	0.59	(0.48, 0.73)
Roadways	170	0.67	(0.52, 0.86)	0.66	(0.54, 0.81)
Airfields	241	1.09	(0.88, 1.35)	0.87	(0.73, 1.04)
Utilities	347	0.87	(0.71, 1.07)	0.75	(0.64, 0.88)
Other	265	0.37	(0.23, 0.60)	0.84	(0.66, 1.08)
Buildings	944	1.00	—	1.00	—
Company size (number of employees)					
1–19	1,104	1.73	(1.36, 2.20)	1.28	(1.10, 1.49)
20–49	575	2.51	(2.01, 3.15)	1.25	(1.08, 1.44)
50–99	240	2.07	(1.64, 2.62)	1.17	(1.01, 1.36)
100–249	199	1.70	(1.38, 2.11)	1.11	(0.98, 1.26)
250+	2	1.00	—	1.00	—
Contract status					
Subcontract	1,220	0.88	(0.73, 1.06)	0.86	(0.74, 0.99)
Sub-subcontract	827	0.53	(0.41, 0.69)	0.93	(0.77, 1.12)
Prime contract	93	1.00	—	1.00	—
Contract start year					
1994	77	1.37	(0.57, 3.30)	0.44	(0.15, 1.25)
1993	1,065	0.78	(0.67, 0.90)	0.90	(0.81, 1.01)
1992	726	0.84	(0.76, 0.94)	0.93	(0.86, 1.01)
1990/91	272	1.00	—	1.00	—
Company SIC code					
SIC 15	83	0.80	(0.61, 1.05)	0.99	(0.80, 1.24)
SIC 16	234	0.67	(0.51, 0.87)	0.94	(0.75, 1.18)
SIC 17	1,150	0.88	(0.73, 1.07)	1.48	(1.26, 1.74)
Other	673	1.00	—	1.00	—
Contract payroll size		*	*		
>$1 mi	91			1.30	(1.09, 1.54)
>$100K–$1M	349			1.09	(0.92, 1.28)
≤$100K	1,700			1.00	—
Percent overtime payroll		*	*		
>20%	358			1.57	(1.13, 2.17)
>0–20%	1,248			1.20	(0.88, 1.64)
0%	534			1.00	

*Variable nonsignificant at $P < 0.10$ level.

companies (≥250 employees). Contract payroll size and overtime proportion of payroll were associated only with non-LWT injury rates when controlled for other variables in the model, with contracts of over $1 million and contracts with greater than 20% overtime payroll having increased risk for these injuries. Results of models of risk factors for non-LWT and total injuries were similar (data for total injuries not shown).

DISCUSSION

Risk of worksite injury is heightened for older workers, workers new to a site, workers on contracts for building construction and site development, workers on contracts with sizable overtime payroll, and on contracts belonging to small and mid-sized companies. Furthermore, the occurrence of minor injuries (non-LWT) increases the risk of having major (LWT) injuries on the same contracts. These findings extend what is known about risk factors in an industry plagued with high injury rates.

Older workers at DIA were more likely to suffer work-related injuries, confirming the findings of several reports on construction-worker mortality [Buskin and Paulozzi, 1987; Kisner and Fosbroke, 1994] and morbidity [Fredin et al., 1974]. Other reports, however, have suggested that younger workers are at increased risk for all injuries [Lipscomb et al., 1996; Vézina et al., 1996] and that older construction workers (over 44 years) are underrepresented among LWT injuries [OSHA, 1992]. Older workers have been found to employ better safety practices in the construction industry [Dedobbeleer and German, 1987], but such practices may not predict injury avoidance. We found that the rates of both LWT injuries and non-LWT injuries at DIA increased with age, with no evidence that young, presumably less experienced, workers were at higher risk. Further study of the specific types of injuries and accidents sustained by older workers would be useful in developing appropriate prevention strategies for these workers.

Our findings of higher injury rates at the beginning of contracts and for short-term contracts are consistent with other reports indicating that injuries are more likely to occur during the first month of employment [OSHA, 1992; Culver et al., 1993; Vézina et al., 1996] and with an influx of new workers to a site [Hubbard and Neil, 1985]. There are a number of factors that likely contribute to these early injuries, including worker unfamiliarity with the site and/or unfamiliarity with job tasks specific to the project [Hubbard and Neil, 1985]. Exposure to safety training and safety instruction at initial employment has been shown to positively affect worker safety performance [Dedobbeleer and German, 1987]. At DIA, all new workers, regardless of prior work experience, attended an orientation covering general on-site safety procedures (personal communication, Skip Guarini, Field Safety Manager DIA, January 1997). Job-specific safety training, however, was subject to the policies of individual employers. Our findings suggest that studies to evaluate the efficacy of site-specific and job-specific safety training in reducing injury in workers new to a site would be valuable.

The excess risk of non-LWT injuries for building construction contracts may be attributable to the work environment created by having multiple trades, numerous employers, and diverse operations existing in close proximity to one another. With nearly five times the recorded person-hours of any other domain, building construction was the largest, most concentrated, and most diverse work effort on the DIA site. Inasmuch as these factors affect the safety of the work environment, enhancement of safety efforts in concentrated work areas may prove beneficial. The increased risk of LWT injury among workers in site development suggests that injuries sustained when operating heavy equipment tend to be more severe. On the other hand, the specialized nature of the work may limit opportunities for modified or light duty work following injury, resulting in more lost work time than would otherwise occur.

Our finding of increased risk for non-LWT injuries on contracts with sizable overtime payrolls (>20% of total payroll) confirms that time constraints and work pressure have adverse effects on safety and work-related morbidity [Salminen et al., 1993; Levitt and Samelson, 1993; Fredin et al., 1974]. We were not able to link overtime payroll to individuals to determine whether injuries were more common among workers paid for overtime. Overtime work, however (which occurred on the vast majority of contracts at DIA), is likely a marker for schedule pressure on contracts and the construction workforce as a whole. We did not find, as others have [Vézina et al., 1996], that risk of LWT injury increases with increasing overtime work. One possible explanation for the lack of association between overtime and LWT injury in the multivariate analysis is that workers earning high overtime wages are reluctant to miss work when injured. The federal wage base adopted at DIA was considerably higher than average wages paid in Colorado for similar occupations [CDLE, 1996]. It is also possible that contracts with and without overtime differed relative to specific tasks performed which may have been only partially controlled for in the models by ELRs.

With respect to company size, our findings confirm several others showing that fatal and nonfatal injuries among construction workers are more likely among employees of small or mid-sized firms [Suruda, 1992; Buskin and Paulozzi, 1987; Hinze and Raboud, 1988; Salminen et al., 1993]. These findings conflict with national injury estimates [BLS, 1994], which indicate that employees of very small construction companies (<20 employees) experience injury rates as low as those of employees of large companies (500+ employees). While lower injury rates among large companies may be attributable to more stable workforces and to the availability of safety resources [Salminen et al., 1993], low injury rates among small companies are probably due to underreporting of injury to the Bureau of Labor Statistics [Oleinick et al., 1995; Glazner et al., 1998]. The reporting procedures established under DIA's Owner Controlled Insurance Program coupled with its on-site medical clinic facilitated the complete reporting of injury, thereby virtually eliminating the potential for reporting bias by company size. Our results indicate that employees of smaller companies are at higher risk of injury than those of large companies when controlling for job risk and other predictors of injury.

Multivariate analysis revealed that sub-subcontracts had significantly lower LWT injury rates than did prime contracts, contradicting a report by Salminen et al. [1993], which suggested that subcontracts are 1.5 times more likely to have serious worksite injuries compared with main contractors. Our finding is strengthened by our ability to control for prevailing risk of work, which, at DIA, was considerably higher for sub-subcontracts than for prime contracts, as measured by ELRs ($7.60 vs. $5.72 per $100 payroll). Sub-subcontractors generally perform a much narrower scope of work as compared with prime contractors, which may in part explain the lower injury rates for these contracts. The specialized and potentially hazardous nature of the work performed on these contracts likely requires that these workers be well trained.

Expected loss rates, which are typically used within the insurance industry to set workers' compensation insurance premiums, proved to be a significant predictor for all injuries. We validated the use of ELRs as a measure of risk by demonstrating the strong relationship between log ELR and injury occurrence on a contract level. When independent variables were examined univariately in the Poisson regression model, only construction domain accounted for more of the variability in contract total injury rates (as measured by Akaike's [1974] information criteria). Tables of state-specific ELRs are available for those states using the National Council on Compensation Insurance (NCCI) as their rating bureau. These data, linked with numerator and denominator data reported by job classification code, enable a fine distinction in the measurement of expected job risk that can be used in epidemiologic research and by project safety personnel to identify contracts at particularly high risk of injury.

Our findings have several implications for public health resource allocation and safety management. The absence of correlation between injury rates among contracts held by the same company suggests that targeting safety resources at the level of the contract, as opposed to the company, may be an effective approach to injury prevention. The association between minor (non-LWT) and major (LWT) injuries on contracts underlines the importance of monitoring both types of injury. Although major injuries often get the attention of management, minor injuries account for the vast majority of injuries at most construction sites (75% at DIA) and are associated with sizable direct and indirect costs to the employer [Hinze and Applegate, 1991; Levitt and Samelson, 1993]. Occurrence of minor injuries may be a useful trigger for assessment of safety practices and intervention to avert major injuries. Limited safety resources can also be targeted to older workers, workers new to a site, contracts for building construction and site development, contracts with sizable overtime payroll, and contracts belonging to small and mid-sized companies. Project management may consider requiring that employers provide job- and site-specific training to new workers, with consideration given to the fact that some new workers may be inexperienced in construction work. On contracts with substantial overtime or other risk factors (including having had a minor injury), interventions might include increasing requirements for safety infrastructure, job hazard analyses, and safety training of management and workers.

This retrospective analysis is a model for analyses that could be performed during large construction projects having centralized claims databases, so that surveillance can lead to intervention during the life of the project. We recommend creating administrative databases that can link individual workers to contracts and to payroll, enabling calculation of rates by demographic, overtime, and job categories. Further, we would suggest that the amount of lost work time be included in indemnity claim files, obviating the need to link claims data with state labor department data files [Glazner et al., 1998]. Finally, information about companies, such as employment size and prior experience modification rating (EMR), would be invaluable for such a database. Without EMR data, the question of whether prior company experience predicts injury experience on a large project with owner-managed safety infrastructure will be difficult to answer. The answer to this question has important implications for bid prequalification on projects for which owners hope to minimize preventable work-related injury and its costs.

In summary, ongoing surveillance with administrative databases established for Owner Controlled Insurance Programs could make them an important resource for project prevention activities, as well as for occupational health and safety research.

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Contractor Safety Practices and Injury Rates in Construction of the Denver International Airport

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We sought to explain the variation in injury rates found for categories of companies and contracts involved in the construction of the Denver International Airport (DIA) by surveying contractors about company and contract-level safety practices. We conducted 213 telephone interviews (83% response) with representatives of contracts with payrolls of more than $250,000. We investigated the bivariate relationship between safety actions reported in the survey and injury occurrence by calculating the aggregate injury rates (lost work-time (LWT) rates and non-LWT rates) for the group of respondent contracts reporting always taking the action and for the group not always taking the action. Using Poisson regression, we examined the association between contract injury rates and contract safety practices while controlling for variables previously shown to affect contract-level injury rates. In Poisson regression, two actions, 1) disciplinary action always resulting when safety rules were violated and 2) always considering experience modification ratings when selecting subcontractors, were associated with lower LWT injury rates. Three actions or contract characteristics resulted in lower non-LWT rates: management always establishing goals for safety for supervisors, conducting drug testing at times other than badging or after an accident, and completing the DIA contract on budget, rather than over budget. Reportedly consistent use of a number of accepted safety practices was associated with significantly higher injury rates in bivariate and multivariate analyses. The pattern of counterintuitive results found in this study suggests that questions reflecting agreed-upon safety practices, when asked of the person responsible for all on-site construction activities, are likely to elicit normative responses. Objective validation of reported safety practices is critical to evaluating their efficacy in reducing injury rates, along with measures of both time at risk and outcome and control for prevailing risk of the work performed. Am. J. Ind. Med. xx:000–000, 1999. *© 1999 Wiley-Liss, Inc.*

***KEY WORDS:** occupational injury; construction injury; safety surveys; workers' compensation; company safety practices*

INTRODUCTION

An analysis of workers' compensation data from the construction of the Denver International Airport (DIA), the largest construction project in the world from 1991 through 1993, revealed higher contract-specific work-related injury rates for small companies, building construction (relative to other construction domains), special trades contractors, large payroll contracts, and contracts with more than 20% overtime payroll, when controlled for a measure of prevailing risk of work performed [Lowery et al., 1998]. These conclusions provide little insight, however, into the reasons

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for the risks. To assist in interpretation of contract risk, we present here data obtained from interviews of representatives of contracts completed in the construction of the airport. Because we had previously shown independence of injury rates for contracts operated by the same company [Lowery et al., 1998], we sought to explain differences in contract-specific risk by conducting and analyzing the survey at the contract, rather than company, level. Nonetheless, we included numerous questions directed at explicating the influence of company characteristics on contract safety performance.

The construction of DIA involved 2,843 individual contracts completed by 769 contractors in six major construction domains: site development, roadway and parking construction, airfield construction and paving, building construction, utility development, and management. Contractors working at DIA represented all of the major (2-digit) construction Standard Industrial Classifications (SIC) — 15 (general contracting), 16 (heavy construction), and 17 (special trades) — as well as several nonconstruction classifications. Contract payrolls ranged from under $100 to over $16 million, with a median of approximately $13,000. All workers' compensation claims were recorded in a centralized administrative database, which also included denominator data in the form of payroll according to job classification. The presence of a project-wide workers' compensation insurance plan, coupled with an on-site clinic and designated medical provider system for all contractors working at the project, addressed the common problem of underreporting work-related injury [Glazner et al., 1998].

METHODS

Study Sample

We selected for the survey contracts having total payroll, adjusted for overtime [Glazner et al., 1998], of more than $250,000 in any of four of the principal airport construction domains: site development, roadway construction and paving, airfield construction, and terminal/concourse building construction. This payroll size was chosen to avoid instability of workers' compensation claim rates resulting from insufficient person-hours at risk of injury. The use of these selection criteria resulted in the inclusion of 257 DIA contracts performed by 119 companies. Although the selected contracts represented only 9% of all DIA contracts, the payroll accounted for by these contracts constituted the majority of DIA work, with 68% of total project person-hours.

Questionnaire and Survey Execution

Safety research has shown the following company characteristics to be associated with successful safety programs: strong management commitment to safety, including personal involvement of management in safety activities [Shafai-Sahrai, 1973; Levitt, 1975; Cohen, 1977; Smith et al., 1978; Cleveland et al., 1979; Zohar, 1980; Hinze and Raboud, 1988; Habeck et al., 1991; Shannon et al., 1997]; safety training having high company priority [Levitt, 1975; Cohen, 1977; Zohar, 1980]; open communication between workers and management [Hinze, 1976; Cohen, 1977; Smith et al., 1978; Cleveland et al., 1979; Habeck et al., 1991]; good housekeeping and high levels of use of safety devices [Cohen, 1977; Smith et al., 1978; Hinze and Figone, 1988; Shannon et al., 1997]; minimization of job pressure (i.e., use of cost and schedule to put pressure on workers) [Hinze, 1976; Hinze and Figone, 1988]; high degree of worker participation and autonomy [Smith et al., 1978; Habeck et al., 1991; Shannon et al., 1992, 1997]; and use of management guidance and counseling about safety, including individual praise or recognition for safe performance [Levitt, 1975; Cleveland et al., 1979; Habeck et al., 1991]. We therefore sought to use a survey instrument that included questions about these characteristics.

For our survey, we adapted a mail survey questionnaire that had been developed to investigate disability management factors and organizational practices as they related to workers' compensation claims experiences in several nonconstruction sectors in Michigan [Habeck et al., 1991; Hunt et al., 1993]. We asked respondents to the DIA contractor survey to characterize, using a 5-point Likert scale, the frequency of practices on a contract with respect to: A) safety accountability and intervention, B) work and company environment, C) company commitment to safety, and D) relations among prime contractors and subcontractors. Questionnaire sections A–C represented the contract's safety practices, while section D and subsequent questions collected other contract-specific information. Several of these subsequent questions sought numerical estimates or categorical answers regarding other topics: workforce characteristics, workers' compensation experience, and contract-related factors. (Tables II through IV list many of the questions asked in sections A–C.) We field-tested the adapted version of the instrument for its suitability as a telephone interview using DIA contractors with contracts having payrolls between $100,000 and $250,000. The field test resulted in wording modifications and elimination of several ambiguous questions. It also revealed, by virtue of interviewing supervisory personnel at several different levels, that the person most knowledgeable about contract-specific practices was the highest level on-site supervisor.

Trained and monitored interviewers from the Survey Research Unit of the Colorado Department of Public Health and Environment conducted computer-assisted telephone interviews (CI3 CATI, Sawtooth Software, Evanston, IL) from May through August 1995, about a year after construction had ended for nearly all contractors. We sought to interview the on-site company representative with the highest level of supervisory authority for the specific contract. In cases in which this person was unavailable (usually for reasons of being out of state or no longer being employed by the company), we conducted an interview with the second highest level supervisor on-site. If that person was unavailable, we conducted the interview with the on-site supervisor's immediate superior. For some companies with multiple contracts, the same person was responsible for several contracts. In this situation, the respondent was asked to complete each survey individually. Of the 42 respondents who supervised multiple contracts in the survey, only 9 (21%) chose to provide simultaneous answers for more than one contract.

Representation of Survey Data

Early examination of the full range of responses captured by the Likert scale revealed that answers to nearly all of the questions clustered in the "always" and "usually" categories (for over 63% (26) of the questions, more than 85% of respondents answered "always" or "usually"; for only 3 of the 41 questions did less than 70% of respondents answer "always" or "usually"). This response distribution did not allow for comparisons among respondent contracts using the full Likert scale. Accordingly, we dichotomized the five-point Likert scale responses in questionnaire sections A–C by identifying whether respondents indicated that the stated action always occurred or that it did not always occur (answers of "usually," "sometimes," "occasionally," "never," and "don't know," as well as refusals). A rationale for this was that "always" answers may indicate articulated company policy.

In addition to exploring the effects on injury rates of safety practices as captured by individual survey questions, we examined the effects of summary measures of safety culture. To accomplish this, we aggregated survey items by calculating the number of "always" responses to the questions about safety practices for each of the questionnaire sections, A–C.

DIA's Administrative Database

We linked survey responses with contract data contained in DIA's administrative database, available from the City and County of Denver. This database contained all workers' compensation claims (classified as lost work-time (LWT) or non-lost work-time (non-LWT) injuries), claim payments by contract, payroll by job classification and contract, and classification of contract by construction domain, among other variables [Glazner et al., 1998; Lowery et al., 1998], thereby making possible the calculation of LWT and non-LWT injury rates. LWT was defined using Colorado workers' compensation's definition: missing four or more work shifts. We calculated injury rates per 200,000 hours at risk from claims and person-hours, estimated from payroll data contained in the administrative database. The method we used to calculate injury rates is described in detail elsewhere [Glazner et al., 1998]. We obtained Standard Industrial Classification and company size information for Colorado contractors for the year prior to their first DIA contract from the Colorado Department of Labor and Employment's Unemployment Insurance files. For each contract, we used payroll reported by job classification to calculate expected loss rates (ELR) — weighted averages of the National Council on Compensation Insurance's (NCCI) Colorado-specific expected workers' compensation payments reported by job classification [Glazner et al., 1998; NCCI, 1995]; these ELRs served as indicators of prevailing risk of work performed on contracts.

Statistical Analysis: Respondents vs. Nonrespondents

To examine differences in the distributions of contract-specific variables between survey respondents and nonrespondents, we used data contained in the DIA administrative database. We performed Chi-square tests on categorical variables (contract status as prime, subcontract or higher level subcontract; contract domain; start year; company size; SIC code; and state of company residence) and Wilcoxon rank sum tests for continuous variables (workers' compensation payment rate, ELR, adjusted payroll, percent overtime payroll, and contract length in days). We calculated, according to respondent status, LWT and non-LWT aggregate injury rates, in which the numerator of the aggregate rate was the number of injuries for that group of contracts, and the denominator was the total person-hours for that group of contracts. We tested for differences in aggregate injury rates by constructing 95% confidence intervals around injury rates, assuming a Poisson distribution for the number of injuries [Haenszel et al., 1962].

Bivariate analysis

We investigated the relationship between each reported safety action and injury occurrence by calculating an aggregate injury rate for the group of contracts whose respondents reported that the action always occurred on the contract and an aggregate rate for those indicating that the action did not always occur. Differences between injury rates for the two categories of contracts were then determined by calculating 95% Poisson confidence intervals around the rates. To determine the degree of association between the summary measures of safety practices and contract injury rates, we calculated Spearman rank correlation coefficients.

Poisson regression

To examine the association between contract injury rates and contract safety practices while controlling for variables shown to affect contract-level injury rates [Lowery et al., 1998], we used Poisson regression. We assumed that the number of injuries per contract, ranging from 0–26 for LWT injuries and 0–140 for non-LWT injuries, followed a Poisson distribution. In order to model the rate of injuries, we included the logarithm of contract person-hours as an offset variable in the log-linear model for injury count. We included a dispersion parameter to adjust standard errors of the parameter estimates, since the scaled deviance was unequal to one. Generalized linear model techniques [McCullagh and Nelder, 1989] were used to develop the models using the GENMOD procedure in SAS [1996].

We developed separate Poisson regression models for each survey item to examine relationships between distinct safety practices and risk of injury. Having found that risk factors for LWT and non-LWT injuries at DIA differed [Lowery et al., 1998], we fit separate models for these two types of injury outcome. In each model, we included previously identified contract risk factors as covariates, regardless of their statistical significance in the newly developed model. Therefore, each resulting model was defined by the outcome (LWT or non-LWT contract injury rate), a set of covariates, and the individual safety practice. Using these techniques, we also created separate regression models to examine the relationships between our calculated summary measures of safety practices and injury rates.

RESULTS

Respondents

We located contact persons for 244 (95%) of the 257 contracts in our sample and completed interviews with representatives of 213 (83% of the total sample). The 102 companies responding to the survey included 62 with single contracts and 40 with multiple contracts. There were several significant differences between respondents and nonrespondents. The 13 nonrespondent contracts for which we could not locate a contact person were more likely to have been with non-Colorado companies, to have higher proportions of payroll accounted for by overtime pay, and to have a higher aggregate LWT injury rate (10.9 per 200,000 person-hours vs. 6.6 for respondents). Because the *aggregate* rate was higher for this group of nonrespondents, we investigated the range of *individual* contract injury rates. The range of contract-specific LWT injury rates per 200,000 person-hours was only 0–25 for this group, contrasted with 0–57 for respondents. The median contract-specific LWT injury rates were 10.3 for those we were unable to locate and 4.8 for respondents.

Nonrespondents who refused to take part in the survey (31 contracts) more often began their DIA contracts in 1993, had shorter contract lengths, and had a higher *aggregate* non-LWT injury rate (31.2 per 200,000 person-hours vs. 26.4 for respondents). The range of *contract-specific* non-LWT injury rates for refusers was smaller than for respondents — 0–75 contrasted with 0–117 for respondents. The median non-LWT contract-specific injury rate for refusers was 21.3, while for respondents it was 22.4. No significant differences existed between respondents and nonrespondents in workers' compensation payment rate, expected loss rate, adjusted payroll, contract status as prime, subcontractor, or higher level subcontractor, SIC, company size, or construction domain.

Survey respondents held the positions of highest supervisory authority on the construction site in 87.3% of cases, with titles of company owner/president (8%), project engineer (52%), on-site manager/superintendent (27%), or foreman (0.5%); dedicated safety professionals were respondents in 4 cases (2%). The remaining 11% had a variety of other titles. Nearly half of the respondents were assigned full-time to the DIA construction site; another quarter spent at least half-time at the site.

About half (112 or 53%) of contracts for which interviews were completed employed subcontractors, with a median of 3 and a range of 1 to 70 subcontracts. Usual number of employees on-site, exclusive of subcontractor employees, ranged from 3 to 425, with a median of 25 employees for respondents. Maximum employment, exclusive of subcontractor employees, ranged from 5 to 500, with a median of 40. Employment in the year prior to the first DIA contract for the respondent company is shown in Table I as are other characteristics for the respondent contracts. All but three of the 213 contracts surveyed had overtime payroll, with 36 contracts (16.9%) having adjusted payrolls in which overtime pay accounted for over 20%. Another 31% of contracts had between 10 and 20% overtime payroll, and the remaining 51% had overtime payrolls of less than 10%.

Results of Bivariate Analyses

Prevalence of contract safety practices: Sections A–C

A large majority of survey respondents reported that activities reflecting positive A) safety accountability of company managers, supervisors, and workers; B) characteristics of work and company environment; and C) practices of company management with respect to supporting safety, occurred usually or always in their DIA contracts. Despite this apparent tendency to answer positively, the proportions of contracts for which actions representing high safety standards were reported as *always* occurring varied considerably.

TABLE I. Distribution of Survey Respondents by Company Size (Number of Employees) in the Year Prior to Denver International Airport Construction, Construction Domain, Standard Industrial Classification, and Contract Status

Number of company employees*	Number of contracts	Percentage of contracts
1–19	24	14.1
20–49	41	24.1
50–99	30	17.6
100–249	59	34.7
250 or more	16	9.4
Construction domain		
Site development	12	5.6
Roadways and parking	17	8.0
Airfields and paving	27	12.7
Building construction	157	73.7
SIC**		
General construction (SIC 15)	24	11.3
Heavy construction (16)	34	16.0
Special trades (17)	122	57.3
Nonconstruction	25	11.7
Contract status		
Prime contract	50	23.5
Subcontract	139	65.3
Higher-order subcontract (sub-subcontract)	24	11.3

*Company size missing for 43 contracts.
**SIC missing for 8 contracts.

With respect to safety accountability and intervention (Section A of the questionnaire), only about half of contract respondents reported primary preventive actions as *always* occurring. These actions included: management recognizing and reinforcing safe behavior through personal contact and written praise (only 53% reported that this always occurred); management establishing goals for safety for supervisors and providing them regular feedback on performance (49%); supervisors documenting even minor accidents and safety violations for review and consideration (49%); management and labor jointly conducting safety audits (55%); conducting job hazard analyses (57%); ongoing environmental monitoring (47%); and correction of identified hazards on a timely basis (57%).

Critical review of respondents' answers to questions in sections A–C of the questionnaire (results available upon request) reveals that they did not appear to differ according to characteristics such as SIC and construction domain, but differences in reports of actions by company size were often apparent. For questions on safety accountability and intervention, the largest companies (250 or more employees) were notably less likely than others to answer that most of these actions always occurred, although two statements on these topics elicited "always" responses from the respondents for *all* large companies: 1) safety performance was part of the on-site manager's job evaluation, and 2) supervisors completed accident reports promptly. (The largest companies (250 or more employees) we interviewed were the safest with respect to more serious (LWT) injuries and second safest with respect to minor (non-LWT) injuries, while smaller companies (fewer than 50) were the least safe.)

Reports of always achieving optimal work practice and interpersonal environments on DIA contracts appeared to vary more than did reports of optimal safety accountability and intervention. Small firms (1–19 employees) were most likely among all company size groups to answer "always" to positive statements regarding work practice and interpersonal environments, contrasting with the largest companies, which were most likely not to answer "always." In particular, statements connoting collaborative working relationships among workers and managers were most likely to be mentioned as always occurring by respondents for the smallest firms; these same statements were least likely to elicit an "always" response from the largest firms. Also, statements about consistent use of safety equipment, good equipment maintenance, and good site housekeeping most often received "always" responses from the smallest firms, while they least often elicited "always" responses from the largest firms. More than a third of respondents (35.2%) reported that an OSHA inspector coming onto the contract's project site would have found significant violations at least some of the time; respondents from the largest firms were more likely than those from all other firms to say that OSHA inspectors would have found violations.

When asked questions directed at company commitment to safety, more than a third of respondents (38%) indicated inconsistent leadership and participation in safety management by top company management. Similarly, 37% reported that top management did not always attend safety meetings and training sessions. In 46% of contracts, top management was not thought by the respondent to always have direct knowledge of the potential hazards in the workplace. *All* respondents from the largest companies (250 or more employees), however, answered "always" to four of the eight statements concerning company commitment to safety. These were: 1) top company managers wore protective gear as appropriate and followed safety rules; 2) top company managers regularly reviewed the company's accident and workers' compensation claim performance; 3) [the] company spent money to address unsafe conditions and equipment; and 4) top company management considered safety equally with schedule and budget goals. Respondents from smaller companies (fewer than 250 employees) were less likely to answer "always" to statements about company commitment to safety. While the largest firms were least likely to give "always" responses to statements about safety accountability and intervention and company and work

TABLE II. Denver International Airport: Safety Accountability and Intervention (Section A): Significant Differences in Aggregate Injury Rates (LWT and non-LWT) Between Contracts Answering "Always" and Those Giving Other Responses to Statements

Questionnaire statement	LWT injury rate	Non-LWT injury rate
A3: Your company used a system for workers to report hazardous conditions without fear of getting into trouble	—	A > NA
A4: Management established goals for safety for supervisors and provided regular feedback on their performance	A > NA	***NA > A***
A5: Safety performance was part of the on-site manager's job evaluation	—	***NA > A***
A7: Supervisors documented even minor accidents and safety violations for review and consideration	—	A > NA
A9: Your company identified specific tasks and projects with potential hazards	A > NA	—
A10: Your company used environmental measurements to identify situations of risk on an ongoing basis	—	***NA > A***
A13: Your company provided training to new and transferred workers regarding specific hazards for their particular job before being placed on the job	A > NA	A > NA
A14: Supervisors were trained about possible hazards and safe work practices for jobs they supervised	—	A > NA
A17: Identified hazards were corrected on a timely basis	A > NA	—
A18: Accident reports identified causes and recommended corrective action	—	***NA > A***

A = respondent indicated that the action in the statement always occurred. NA = not always; respondent indicated that the action in the statement usually, sometimes, occasionally, or never occurred or that he did not know how often it occurred or that he refused to answer. A > NA indicates that the contracts answering "always" had a significantly ($P < 0.05$) higher aggregate injury rate than did contracts giving other (not "always") answers. NA > A indicates that the contracts giving other (not "always") answers had a significantly higher aggregate injury rate than did those saying "always." Expected results are in bold italics. A dash (—) indicates no significant difference in injury rates between those answering "always" and those giving other answers. Questionnaire statements not shown involved no significant differences with respect to either LWT or non-LWT injury rates. The complete questionnaire is available from the first author on request.

TABLE III. Denver International Airport: Work and Company Environment (Section B): Significant Differences in Aggregate Injury Rates (LWT and non-LWT) Between Contracts Answering "Always" and Those Giving Other Responses to Statements

Questionnaire statement	LWT injury rate	Non-LWT injury rate
B1: Excellent housekeeping was achieved at your work area	—	***NA > A***
B2: Equipment was well maintained	A > NA	—
B6: Jobs were modified to keep heavy and repetitive lifting to a minimum	A > NA	—
B7: Strategies were used to reduce repetitive movements	A > NA	A > NA
B8: Job satisfaction among workers on this contract was high	A > NA	—
B11: Skills in working with people and communication were considered in selecting supervisors and managers on this contract	A > NA	—
B12: On this contract, workers felt free to raise issues and concerns, or make suggestions	—	A > NA
B13: Management sought and considered worker input in project decisions	—	A > NA
B14: Your workers had some control over work process and productivity demands	—	A > NA
B15: Workers felt rushed in completing their jobs on this contract	—	Never > Not Never*
B16: An OSHA inspector coming onto this project site at DIA would have found significant violations for citing your company	Never > Not Never*	—

For key to abbreviations, see Table II.
*Because "always" answers to these statements reflected an undesirable safety environment, they were analyzed differently, with "never" and not "never" (i.e., "always," "usually," "sometimes," or "occasionally" answers) constituting the dichotomous pair.

environment, they were most likely to give "always" answers to statements about company commitment to safety.

Associations of safety practices with injury rates

T2 Table II shows the association between "always" answers to individual statements in Questionnaire Section A (Safety Accountability and Intervention) and aggregate injury rates. We found no significant associations with LWT injury rates in the expected direction (i.e., the aggregate LWT rate for contracts for which the respondent indicated always performing the safety action was significantly lower than that for those not answering "always"). Answers to four statements, however, were significantly associated with LWT injury rates in the direction contrary to the expected one; that is, contracts for which questionnaire answers indicated that the safety action always occurred had significantly higher aggregate LWT injury rates than did other contracts. For non-LWT injury rates, "always" responses to four statements were associated with a lower rate (expected), and four were associated with a higher rate (nonexpected).

Answers to questionnaire statements in Section B (Work and Company Environment) were even less likely than those for Section A to be significantly associated with injury rates in the expected direction (Table III). For six T3

TABLE IV. Denver International Airport: Company Commitment to Safety (Section C): Significant Differences in Aggregate Injury Rates (LWT and non-LWT) Between Contracts Answering "Always" and Those Giving Other Responses to Statements

Questionnaire statement	LWT injury rate	Non-LWT injury rate
C1: Top company management provided leadership and actively participated in managing safety	—	A > NA
C2: On-site top company management supported the safety program by attending safety meetings and training sessions	—	A > NA
C5: Top company management had direct knowledge of the potential hazards in the workplace	A > NA	—

For key to abbreviations, see Table II.

statements, contracts with "always" answers had a significantly higher aggregate LWT injury rate, but none of the "always" answers were associated with a significantly lower LWT injury rate. "Always" answers to one statement regarding achievement of excellent work-site housekeeping were associated in the expected direction with non-LWT rates.

None of the answers to questions in Section C (Company Commitment to Safety) was associated in the expected direction with either LWT or non-LWT injury rates, although "always" answers to three questions were associated with a significantly *higher* aggregate LWT or non-LWT
T4 injury rate (Table IV).

When we correlated contracts' summary measures (the number of "always" responses) for each section (A, B, and C) with their injury rates (LWT and non-LWT), we found nonsignificant correlations for sections A and B. A higher number of "always" responses to questions regarding company commitment to safety (Section C) was weakly correlated with higher LWT injury rates ($r = 0.17$, $P < 0.02$).

Relationships between contractors and subcontractors

Nearly half (48%) of respondents reported always having cooperative working relationships with their prime contractors or subcontractors. Of the 112 respondent contracts with subcontractors, only half always received information from subcontractors regarding accidents and safety risks for their work at DIA. Only 16% of contractors reported always considering insurance industry experience modification ratings (EMRs), a measure of workers' compensation claims experience over the three preceding years, in selecting subcontractors. A minority of contracts (47%) indicated that they always emphasized safety equal to schedule and budget goals in dealing with subcontractors.

Among the 164 respondents (77%) for subcontracts, similar percentages reported that their contract safety policies were never (15%) and always (18%) improved because of policies of the contractor to whom they reported. Regardless of subcontractor status, 75% of respondents reported some increased actions to improve safety at DIA compared with pre-DIA jobs. Contracts that always increased their safety actions tended to rate their DIA accident experience as lower than average for their company more often than those indicating any other level of increased safety action.

"Always" answers to questionnaire statements with respect to optimal contractor-subcontractor relations were not associated with lower injury rates. Contracts whose representatives indicated that the company always had cooperative working relationships with prime contractors and/or subcontractors, however, had a significantly higher aggregate LWT injury rate, and those indicating that the respondent company's subcontractors always gave them information about their accidents and safety risks at DIA had a significantly higher aggregate non-LWT rate.

Workforce characteristics

The median proportion of employees who had worked for the respondent companies prior to the DIA contract was 50%, ranging from 0 to 100%. Using a Spearman rank correlation, we found that having higher proportions of previous employees was associated with lower non-LWT injury rates ($r = -0.29$, $P < 0.01$).

For the majority (57%) of contracts, at least a portion of the workforce was represented by a union, and 84% of these contracts employed only unionized workers. Among contracts with union workers, 48% of respondents reported always having a cooperative working relationship between union and management, with an additional 39% reporting usually having a cooperative relationship. For contracts with union workers, reporting always having cooperative relationships was associated with a higher aggregate LWT injury rate. Among contracts with union workers, 75% had no grievances filed; of those with grievances, the number ranged from 1 to 15. Contracts with grievances filed had a significantly lower aggregate non-LWT injury rate than did those with no grievances.

Contract self-assessments

Several questions were asked to assess how well contract supervisors monitored their work-related injuries. At the DIA construction site, contractors were provided weekly reports about injury experience in the preceding week. The injury experience of subcontractors was reported under the name of the prime contractors they worked for. Approximately one-quarter (27%) of respondents could not classify their own contract's accident experience at DIA at all (i.e., as higher than average, average, or lower than average) relative to all companies at DIA. Those unable to classify their experience had a significantly higher aggregate LWT injury rate than did those classifying their accident experience as lower than that of other companies; they also had a significantly higher aggregate non-LWT injury rate than those classifying their accident experience as average or lower than average. Among those that did classify their experience, a majority were reasonably accurate in their self-categorization: those indicating higher than average injuries had significantly higher aggregate LWT and non-LWT injury rates than did the contracts whose respondents indicated lower than average accident experience.

Company safety-related provisions

Nearly 80% of respondents reported having alternative placement options for injured workers, and having this capability was significantly associated with lower aggregate LWT and non-LWT injury rates. DIA project management always conducted substance abuse tests after accidents, but beginning in January 1992, the project's safety program required substance abuse testing at the time of employment as well. Over 40% of respondents, however, reported that their companies conducted substance abuse testing in addition to these requirements. In bivariate analysis, this policy was not associated with aggregate LWT injury rates, but it was associated with a lower aggregate non-LWT injury rate. The majority of contracts (62%) provided safety incentive programs, but having such programs was not associated with injury rates.

Schedule and budget characteristics

About 18% of respondents indicated that their contractual work was completed ahead of schedule, and 10% reported having been behind schedule. Contracts completed ahead of schedule more often reported that top company management always considered safety equal to schedule and budget goals; they were also more likely to report that the company always emphasized safety as equal to schedule and budget goals in dealing with subcontractors. Contracts that were on schedule had a significantly higher aggregate non-LWT injury rate than did those that were ahead of schedule, but responses to this question were not associated with LWT injury rates. About one-quarter (27%) of respondents reported that their contracts were completed over budget. Those whose contracts were completed over budget less often reported that the company emphasized safety equally with schedule and budget goals. In bivariate analysis, contracts reporting being over budget had a significantly higher aggregate LWT injury rate than did those reporting being on budget and a higher non-LWT injury rate than did those reporting being on or under budget. Being over budget was not correlated with percentage of overtime work at the contract level.

Multivariate Analyses of Injury Rates

Many of the significant associations that appeared in bivariate analysis disappeared when contract risk factors [Lowery et al., 1998] were controlled for, but several new associations became apparent. The risk factors controlled for included: prevailing risk (expected loss rate); construction domain; company size; contract status as prime, subcontract, or higher order subcontract; contract start year; and SIC, for both LWT and non-LWT injury rate models, as well as contract payroll size and percent overtime payroll for the LWT rate model.

With respect to individual safety practices (questionnaire sections A–C), separate Poisson regression analyses were conducted. Only two safety practices, when they were reported as always occurring, were associated with lower injury rates (Table V). The only safety practice for which "always" answers predicted a lower LWT injury rate was violation of safety rules always resulting in disciplinary action (question A2). The only safety practice for which "always" answers predicted a lower non-LWT injury rate was management establishing safety goals for supervisors and providing regular feedback on performance (question A4). On the other hand, contracts whose respondents answered "always" to a number of other positive statements about safety practices had significantly *higher* risk of injury in the Poisson models than did those not answering "always." (Only one summary index among the questionnaire sections addressing safety practices, that for "Company Commitment to Safety" (Section C), was significant in the model, but it was predictive of higher LWT injury rates.)

In addition to answers about safety practices, answers to several other questions asking for more objective or categorical information (questionnaire sections D–G) were associated with lower injury rates. In particular, conducting substance abuse testing at times other than at badging and after accidents (question F4) was associated with lower non-LWT rates; always considering EMRs in selecting subcontractors (question D6b) was associated with lower LWT rates, and completing the contract on budget rather than over budget (question G2) was associated with both lower LWT and non-LWT injury rates. Having any contract employees represented by unions (question E4a) was associated with higher non-LWT injury rates.

TABLE V. Denver International Airport: Significant* Differences in Aggregate Injury Rates (LWT and non-LWT) Between Contracts Answering "Always" and Those Giving Other Responses to Statements and Questions Regarding Safety Practices, While Controlling for Contract Risk Factors Previously Shown to Affect Injury Rates**

Questionnaire statement	LWT Injury rate	Non-LWT injury rate
A2: Violating safety rules resulted in disciplinary action	***NA > A***	—
A4: Management established goals for safety for supervisors and provided regular feedback on their performance	—	***NA > A***
A9: Your company identified specific tasks and projects with potential hazards	A > NA	—
B6: Jobs were modified to keep heavy and repetitive lifting to a minimum	A > NA	—
B7: Strategies were used to reduce repetitive movements	A > NA	—
B12: On this contract, workers felt free to raise issues and concerns, or make suggestions	—	A > NA
C1: Top company management provided leadership and actively participated in managing safety	—	A > NA
C5: Your company spent money to address unsafe conditions and equipment	A > NA	—
C8: Top company management considered safety equally with schedule and budget goals	A > NA	—
D5: Your company had cooperative working relationships with its prime and/or subcontractors	A > NA	—
D6b: In selecting subcontractors, your company considered EMRs	***NA > A***	—
E4a: Was any of your work force on this contract at DIA represented by a union?	—	Yes > No
F4: Did your company conduct substance abuse testing at DIA at times other than badging or after an accident had occurred?	—	***No>Yes***
G2: Did you complete this DIA contract work under budget (U), on budget (On), or over budget (Ov)?	***Ov>On***	***Ov>On***

For key to abbreviations, see Table II.
*Significance defined as $P < 0.05$.
**The risk factors controlled for were: prevailing risk (expected loss rate), construction domain, company size, contract status as prime, subcontract, or higher order subcontract, contract start year, and SIC.

DISCUSSION

In contrast to earlier research, this study found few instances in which reports of consistent use of accepted safety practices were associated with lower injury rates. In fact, consistent use of a number of safety practices was most often associated with significantly *higher* injury rates in bivariate as well as multivariate analysis. Many of these findings are contrary to those found in earlier studies [Smith et al., 1978; Cohen, 1977; Shannon et al., 1992, 1997; Habeck et al., 1991; Cleveland et al., 1979]. This study's use of objective injury rates as the outcome variable, made possible by the ability to link data collected in a survey of contractors with an administrative claims database, was unusual compared with most construction safety research. Most studies of construction company characteristics and their effects on safety have relied for their outcome measures on self-reported injury rates [Dedobbeleer and German, 1987; Hinze and Raboud, 1988; Levitt et al., 1981; Bentil and Rivara, 1996] or safety ranking of projects, companies, or supervisors by safety inspectors or other contractors [Zohar, 1980; Hinze and Figone, 1988]. We found only one study of safety in the construction industry [Hinze, 1976] in which OSHA-reportable injury data were used.

Answers to questions in the sections of the questionnaire asking for numerical estimates or categorical (i.e., factual, rather than opinion) answers were more often associated in the expected direction with injury rates in bivariate and multivariate analysis than were questions in the earlier sections. These questions asked, for example, whether alternative placement options existed for injured workers, whether drug testing was conducted at times other than badging or after an accident, and whether the contract was completed over, under, or on budget. Many of the answers were not associated with injury rates, but among those that were, the majority were associated in the expected direction in both bivariate and multivariate analysis.

Respondents able to classify their contract's accident experience as higher than, lower than, or the same as that of other companies or of their own experience prior to DIA construction were found to be accurate in bivariate analysis. Those unable to classify their experience relative to other companies had higher LWT injury rates, suggesting either that they may have simply been unwilling to classify their experience because they knew it was high (respondents did not know that the research team had actual contract-specific injury rates) or that an on-site supervisor who does not have a good sense of the contract's relative accident experience may manage projects less safely.

The role of unions in injury occurrence was complex: in bivariate analysis, having cooperative union/management relations was associated with higher LWT injury rates, and having filed one or more grievances was associated with lower non-LWT injury rates. Neither of these associations held up in multivariate analysis, but the presence of union workers on a contract was positively associated with higher non-LWT injuries, once risk factors were controlled for. These findings corroborate one finding of Shannon et al. [1992], who found that unionization was associated with higher lost-time injury rates, but do not support another from the same study, i.e., that the number of grievances is positively associated with lost-time injury rates.

Aside from union representation, only two bivariate findings from the questionnaire sections asking for numerical estimates or categorical answers remained significant in multivariate analysis: 1) substance abuse testing conducted at times other than badging and after an accident was associated with lower non-LWT injury rates, and 2) completing the contract over budget was associated with both higher LWT and non-LWT injury rates. The substance abuse testing result suggests that substance abuse is implicated in minor injuries and that testing is an effective deterrent. The budget overrun results corroborate the negative effects of job pressure (defined by Hinze [1976] as use of schedules or budgets to apply pressure to workers) on safety found by other researchers [Levitt, 1975; Hinze, 1976; Hinze and Figone, 1988]. Our specific finding that projects that were over budget were less safe may confirm a suggestion by Hinze and Raboud [1988] that safety activities are reduced under these circumstances.

Contractors of different sizes reported very different frequencies for certain safety practices. Respondents for large companies rarely reported that most safety practices occurred all of the time, but *all* of them reported that several safety practices *always* occurred. These latter actions may have had more to do with company rules and actions than attitudes, including items such as supervisors completing accident reports promptly and top managers regularly reviewing the company's accident and workers' compensation claim performance. Small companies were less likely to indicate that these actions always occurred, but they were much more likely than respondents from the largest firms to respond that actions and attitudes suggesting collaborative working relationships always occurred. This is consistent with the notion that smaller firms place a high value on good workplace relationships. This has been observed in earlier research into the safety practices and values of small companies, which also found that, in small firms, there was little recognition of health and safety as legitimate functions of management [Eakin, 1992]. Our findings do not suggest that the value placed on good workplace relationships is misplaced; in fact, the safety literature emphasizes it as a characteristic of low-injury companies. Rather, our findings suggest that it may be useful for smaller companies to integrate clear concern for safety into their management practices.

The pattern of results for this survey suggests that statements that reflect agreed-upon safety practices, but that ask for opinions about the frequency of their occurrence from the person responsible for all on-site activities, are likely to elicit normative responses. Research into safety practices and culture at the company and site level in construction is now more than two decades old, and its findings have become accepted principles. It is unlikely that the respondents to this survey were ignorant of practices widely believed to promote safety. It is conceivable that several characteristics of respondent firms, i.e., being part of a high-risk industry working on a high-profile project and being large (44.2% of respondents were with firms with 100 or more employees), would contribute to heightened knowledge and sensitivity to safety. While it is also possible that the position held by the respondent could affect responses, we found little support for this idea. The respondent group with highest level titles (owner, president, vice-president) were somewhat more likely to answer "always" to questions in section A of the questionnaire, but were no more likely to answer "always" to questions in sections B and C than were other respondents.

We doubt that the practices we found to be associated with higher injury rates, for instance, top management considering safety equally with schedule and budget (associated here with higher LWT injury rates), if always performed lead systematically to higher injury rates, in part because safety research that depends on direct observation, rather than self-report, has found many of them to be effective in reducing injury rates [Smith et al., 1978; Cleveland et al., 1979; Shafai-Sahrai, 1973].

The pattern of counterintuitive findings, particularly with respect to questions asking about safety practices, might be explained to some extent by methodological weaknesses. The survey took place after DIA construction was virtually complete, about a year after most of the contracts were complete, and in some cases, more than a year later. As a result, answers may have been influenced by contracts' workers' compensation experience, with respondents providing answers reflecting good safety practice as a result of heightened awareness of injury costs. Also, while most of the questions we asked had been used in prior research that found expected associations with injury outcomes, the answers we obtained consisted of unvalidated self-reports on the part of managers. To minimize the effects of this, our analysis dichotomized responses into "always" and "not always" in an attempt to isolate enforced company policy from practices about which on-site managers had some choice.

The study's strengths, however, were notable. We obtained an extremely high response rate for such a population and interviewed the person most knowledgeable about the contract in nearly every case. The sample was diverse with respect to company size, domain of work, and SIC. The ability to link responses to an administrative database with complete numerator (injuries) and denominator (hours at risk) data is almost unique in construction safety research. Related to this is the ability to control for other predictors of risk in Poisson regression models. While the counterintuitive results found in this study could be partly explained by incomplete control for inherent risk, we were able to control for *prevailing* risk using ELR by job classification.

The findings set forth here suggest a number of approaches for future research. Unless external validation, perhaps involving site inspections, can also be performed, there may be limited usefulness in conducting surveys to collect data about company safety practice, since knowledge about good safety practice is apparently widespread, and normative answers may be given. Intervention studies, rather than retrospective cohort studies, may be most useful in assessing the effects of contractors' safety practices on injury rates. Furthermore, conducting a survey and analyzing its findings without outcome measures such as those available for this study and without the ability to control for known risk factors may not provide meaningful results. We showed that a substantial number of contract respondents (about half) indicated that they did not consistently apply widely accepted safety practices. Evaluation of the effectiveness of safety interventions using robust methods could motivate enhancement of safety programs by construction contractors, project owners, and government.

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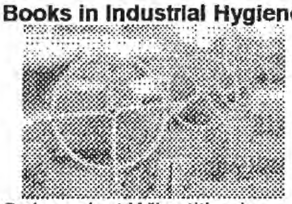

Article

Analysis of construction injury burden by type of work

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Keywords

occupational injury; construction injury; workers' compensation; type of work; trades

Abstract

Background

To lay groundwork for identifying patterns of injury etiology, we sought to describe injury experience associated with types of work performed at construction sites by examining workers' compensation (WC) claims for the 32,081 construction workers who built Denver International Airport (DIA).

Methods

Injury rates and WC payment rates were calculated for 25 types of work based on claims and payroll data reported to DIA's owner-controlled insurance program according to National Council on Compensation Insurance job classifications. By linking DIA claims with corresponding lost-work-time (LWT) claims filed with Colorado's Workers' Compensation Division, we were also able to obtain and examine both total and median lost days for each type of work.

Results

Injury experience varied widely among the types of construction work. Workers building elevators and conduits and installing glass, metal, or steel were at particularly high risk of both LWT and non-LWT injury. Median days lost by injured workers was highest (202 days) for driving/trucking. Median days lost for most types of work was much greater than previously reported for construction: 40 days or more for 18 of the 25 types of work analyzed. WC payment rates reflect both number and severity of injuries and were generally not significantly different from expected losses. They were, however, significantly higher than expected for driving/trucking, metal/steel installation, inspection/analysis, and elevator construction.

Conclusions

Analysis of injury data by type of work allows targeting of safety resources to high risk construction work and would be useful in prospective surveillance at large construction sites with centrally administered workers' compensation plans. Am. J. Ind. Med. 37:390-399, 2000. © 2000 Wiley-Liss, Inc.

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TYPE-OF-WORK ANALYSIS REVEALS WIDE VARIATION IN SEVERAL MEASURES OF INJURY BURDEN IN CONSTRUCTION WORKERS

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ABSTRACT

Construction workers have higher lost-time injury rates than do workers in any other industry in the United States. These workers represent numerous trades and perform diverse tasks. To examine the risk and severity of injury associated with the types of work construction workers perform, we examined 4,490 injuries occurring among 32,000 construction workers building Denver International Airport. Using claims and payroll data contained in a centralized database created for this construction project, we calculated rates of injury and workers' compensation payment rates according to type of work, defined according to job classifications established by the National Council on Compensation Insurance. Injury rates for the majority of work categories exceeded those reported by the Bureau of Labor Statistics (BLS) for contractors performing similar types of work. The median days lost due to injury for nearly all types of work at DIA far exceeded that reported for the construction industry by BLS. Payment rates per $100 payroll, which reflect severity of injuries, were highest for workers involved in roofing, driving/trucking and concrete construction. Several types of work, most notably driving/trucking, metal/steel installation, and elevator construction, were associated with payment rates significantly higher than would have been expected based on average payment rates for similar work in Colorado. Because it includes the experience of non-trade-union workers, who perform much construction work, type-of-work analysis provides a more comprehensive perspective on occupational risk than does trade-specific analysis. Moreover, such analysis provides information about the risk associated with performing certain types of work and is therefore a necessary precursor to developing targeted safety interventions.

INTRODUCTION

Construction workers experience higher lost-time injury rates than do workers in any other industry (BLS, 1995a). Previous analyses have shown that risk of injury is higher for workers in building construction and site development compared with that in other construction domains, such as roadway construction (Lowery et al., 1998). Injury risk is greater for special trades contractors (SIC 17) than for either general building construction (SIC 15) or heavy and highway construction contractors (SIC 16) (BLS, 1995a; Glazner et al., 1998). There is little information, however, on the risk of injury associated with specific types of construction work, such as concrete construction, iron and steel erection, electrical wiring or plumbing. Knowledge about the types of work associated with high injury rates and with particularly severe injuries would be useful for project owners and safety professionals in planning for and developing effective injury prevention strategies.

Carpenter's injury rates have been estimated from workers' compensation claims data linked with union work hours (Lipscomb et al., 1995) and from emergency department records for defined geographical areas (Waller et al., 1989). The proportionate distribution of injuries among various construction trades (Helander, 1991; Hunting et al., in press) and by phase and type of construction (OSHA, 1992b; Construction Safety Association of Ontario, 1995) is available, but these studies were not able to calculate *rates* of injury because they lacked denominator data. Although counts of claims can be used to estimate the magnitude of injury and proportionate distributions, only rates capture the *risk* of injury.

The Bureau of Labor Statistics (BLS) reports injury and illness rates for Standard Industrial Classification (SIC) codes; the rates are based on employer-reported injuries and person hours worked. These rates reflect the injury experience among *companies* that perform similar work, i.e., general building construction (SIC 15), highway construction (SIC 16) and specialty work, e.g., electrical work (SIC 17). Companies report all injuries and hours worked, including those for administrative and clerical staff, under a single SIC code; the rates, therefore, do not accurately reflect the injury risk for individual workers who may perform different types of work within the company. In order to describe the injury experience associated with types of work commonly performed at construction sites and to identify particularly hazardous types of work, we examined workers' compensation claims linked with payroll data for 32,081 construction workers involved in the construction of Denver International Airport (DIA). This database allowed comparison of claim rates and costs of injury among diverse types of construction work with identical claims management and designated medical providers (Glazner et al., 1998; Lowery et al., 1998).

METHODS

Claims and Payroll. Workers' compensation claims and payroll for the Denver International Airport (DIA) construction project were captured in an administrative database developed under the project's Owner-Controlled Insurance Program (OCIP). Insurance claims adjusters stationed on site generated claims for all work-related injuries and illnesses, including both major and minor injuries treated at the on-site medical clinic. Lost-work-time (LWT) claims were identified as those resulting in more than three days absence from work. Three fatalities on the project were also included as LWT claims. For this analysis, we have defined claims for work-related illness (less than 10 percent of all claims) as 'injuries'.

Claims and payroll data were recorded for each of the 2,843 individual contracts completed at DIA and were reported according to job classifications established by the National Council on Compensation Insurance (NCCI). Job classifications define very specific types of work, rather than specific types of workers or trades and are a means of classifying workers into categories of risk for workers' compensation insurance purposes. For example, job classification '5059' is assigned to workers who erect iron and steel frame structures below two stories in height, whereas job classification '5040' applies to iron workers building frame structures *over* two stories (NCCI, 1995b). Insurance companies use these job classifications reported by companies in determining workers' compensation insurance premiums. We adjusted payroll for overtime and to 1992 dollars and, using prevailing Davis-Bacon wages (required for all project workers), estimated person-hours at risk.

Type of Work. We categorized 71 NCCI job classifications contained in DIA's administrative database into 25 'types of work' (Appendix 1). In many cases, a particular type of work, e.g., 'plumbing', was defined by a single job classification, 5183 - plumbing. For other types of work, e.g., 'carpentry', we grouped several job classifications: 5020- acoustical ceiling installation, 5146-furniture/fixture installation, 5437- cabinet installation, 5443- lathing, 5445- wallboard installation and 5403 - carpentry, NOC (not otherwise classified).

We categorized both injuries (claims) and payroll by contract into 'type of work' categories. For most contracts (90%), payroll was reported for the types of work for which any injuries were recorded. For some contracts (N=273), however, we identified injuries categorized under types of work for which there was no reported payroll. For example, we found claims recorded under 'carpentry work' for a contract for which the entire payroll was reported under 'concrete construction'. It is common in construction for contractors to report their payroll under specific job classifications pre-determined at the time of bidding. As was the case at DIA, contractors often combine payroll for workers categorized under different job classifications into a single category describing the majority of their work force (personal communication, Stacy Pocrass, DIA Risk Manager, August 1998). Although the contractor cited above employed carpenters, the type of work performed on the *contract*, and consequently reported on the payroll, was 'concrete construction', the 'prevailing job classification' or 'prevailing type of work'. We reviewed individual injury reports for the claims made by carpenters on this contract and verified that these carpenters were indeed performing tasks associated with concrete construction, such as setting and stripping forms.

For the 273 contracts with discrepancies between reported claims and payroll, we reclassified injuries that did not correspond with payroll by type of work into the 'prevailing type of work' for the contract. For the majority of these contracts (N=208, 76%), identification of the prevailing type of work was straightforward, since all of the payroll was recorded under a single type of work. In order to validate this approach, we examined individual injury reports for all injuries that we reclassified using this method for 20 contracts (7% of contracts with discrepancies). Based on information in these reports about the task the worker was performing at the time of injury and on our determination of the prevailing type of work for the contract, we found that we had correctly reclassified these claims.

For those contracts that reported payroll under multiple types of work (N=65), however, reclassifying injuries was more involved. In some cases, there were two or more predominant types of work for the contract. To reclassify injuries for these contracts, we used the guidance of NCCI's Scopes of Basic Manual Classifications (NCCI, 1995b) and that of Stacy Pocrass, former Risk Manager for the DIA construction project, to identify which of the predominant types of work for the contract best corresponded with the type of work associated with the injury. For example, on a contract with significant payroll reported under both street/road construction and pipefitting, we reclassified injuries reported under 'driving/trucking' into 'street/road construction' which we determined to be the 'most probable' type of work performed by a driver on this contract. There were some cases in which we could not identify a 'most probable' type of work using this method. For these 24 contracts and 61 injuries, we examined written injury reports to aid us in reclassifying these injuries. After this examination, there remained only 15 claims among eight contracts that we could not confidently reclassify into type-of-work categories. All claims (N=131) and person-hours (1,028,147) for these eight contracts were excluded from our analyses.

The type of work categories we developed reflect exposures to particular tasks and work environments that may be more related to risk of injury than are trade categories. Workers in a given trade perform a wide range of tasks, as Lipscomb et al. (1996) found in their study of union carpenters in Washington State and as others have shown in their analyses of the distribution of injuries by trade across industries and types of construction (OSHA, 1992a, 1992b; Construction Safety Association of Ontario, 1995). Likewise, our own evaluation of written injury reports for injuries at DIA showed some discrepancies between the task the worker was performing at the time of injury and his/her self-reported occupation or trade. To the extent that construction workers within a trade are commonly assigned to a range of types of work, analyses of risk that focus on trade will be assessing a heterogeneous set of experiences and may miss real differences in the risk of the work performed.

Lost Work Days. A total of 4,490 claims were included in our analyses, including 933 claims for lost work time (LWT). To determine the number of lost work days for injuries at DIA, we linked DIA claims data with LWT claims data from the Colorado Department of Labor and Employment, Division of Workers' Compensation. We estimated the number of lost work days for claims by summing the number of days a worker received temporary total disability (TTD) and/or temporary partial disability (TPD) benefits. We assumed that the majority of workers at DIA worked a five-day work week and therefore excluded weekend days from our estimates. We converted the number of days a worker was paid TPD (which serves to offset lost wages due to shortened or modified work schedules) into whole days by dividing the total TPD payment by the average daily wage paid for TTD. For those workers who suffered permanent total disabilities or whose injuries resulted in death, we calculated lost work days as the number of work days from the time of injury to his/her 65th birthday. We excluded 40 claims for which LWT status was unknown.

Claims payments. Payments were available for all claims and were categorized into medical, indemnity and "other" payments. Claims payment data reported in this analysis comprise medical and indemnity payments and have been adjusted to 1992 dollars. Payment information was updated in March 1997, at which time approximately 2 percent of claims remained open. We used insurance reserves set aside to pay open claims as a proxy for payments on open claims.

Injury and Payment Rates. From claims and person hours, we calculated injury rates (LWT and non-LWT rates) for 'type of work' as the number of workers' compensation claims per 200,000 person-hours at risk. In addition, we calculated payment rates according to 'type of work' as the total workers' compensation payment per $100 payroll. In order to make DIA payment rates more comparable to expected loss rates (described below), with which we sought to compare payment rates, we capped payments at $126,000 and excluded 'other' payments.

Expected Loss Rates. We compared workers' compensation payment rates for DIA claims with average claims payment rates for similar types of work in Colorado using Colorado-specific expected loss rates (ELR) obtained from the National Council on Compensation Insurance (NCCI, 1995). ELRs are computed by NCCI from claim and payroll data submitted to them by insurance carriers and are used by carriers in setting workers' compensation insurance premiums across all industries. We calculated expected loss rates for DIA work by taking a weighted average of NCCI's ELRs (weighting by the proportion of payroll for each job classification contributing to the type of work).

For each type of work, we tested for a statistical difference between the DIA payment rate and the corresponding ELR using a one sample Chi-square goodness-of-fit test in which the observed value was the DIA rate and the expected value was the ELR. The DIA payment rates and ELRs are reported per $100 of payroll. It is important to note, however, that the statistical significance of the test statistic is dependent on the size of payroll to which the rate is standardized. For example, a statistically non-significant difference in payment rates per *$100 payroll* ($4.72 vs. $3.39) becomes a significant difference in payment rates per *$1000 payroll* ($47.20 vs. $33.90). While the standardization of payment rates to $100 payroll is somewhat arbitrary, the insurance industry, namely NCCI, reports workers' compensation experience in this manner. Therefore, the results of our statistical tests reflect differences at this level of dollar amounts. Two-sided tests were conducted at the 0.05 significance level.

RESULTS

LWT and Non-LWT Injury Rates. Several types of work were associated with LWT injury rates more than 50 percent higher than average for DIA construction and more than twice as high as BLS-reported rates for the construction industry for 1993 (BLS, 1995a) (Table I). We used BLS data from 1993 for comparison because this year was the mid-point of the DIA project. At particularly high risk for LWT injury were workers in elevator construction, metal/steel installation, conduit construction, glass installation, general concrete construction and carpentry. These same types of work were also associated with higher-than-average non-LWT injury rates (Spearman rank correlation coefficient $R=.59$, $p<.01$). A few types of work at high risk for non-LWT injuries, however, did not appear to be at particularly high risk for LWT injuries. Most notable among these were iron/steel erection occurring at heights less than two stories, electrical wiring of buildings, and plumbing, all of which ranked among the ten types of work at highest risk for non-LWT injuries, but exhibited lower-than-average LWT injury rates.

BLS reports injury rates by three-digit Standard Industrial Classification (SIC) codes for construction. Although these categories are not directly comparable to our categories by type of work, we compared rates for categories we thought to be similar. With the exception of LWT injury rates for DIA electrical work and SIC 173, which were equivalent, DIA rates by type of work were higher than BLS rates for contractors performing similar types of work (Table II). LWT rates for carpentry and concrete construction at DIA were nearly twice those for similar contractors reporting to BLS. The most notable difference between DIA's rates and BLS's is in the category of non-LWT injuries; all DIA rates were three- to five-fold those reported by BLS.

Lost Work Days. The days of work lost per injury, including estimated lost days for permanent total (PT) injuries and deaths, ranged from 4 to 10,179 days (approximately 39 years). Because a death or PT injury had the potential to skew the mean number of lost days associated with any one type of work, we eliminated these claims from our analysis of lost-work-days according to type of work (Table III). Excluding these 13 injuries (deaths and PT injuries), the mean and median number of lost work days for the project as a whole were 112 and 52 days, respectively. Owing to instability of the estimates derived from few observations, we also do not report separately types of work having fewer than five LWT injuries (e.g., plastering/finishing, pile driving, bridge/culvert construction, low voltage electrical work, iron steel erection <2 stories and insulation work). The median number of work days lost for driving/trucking, general concrete construction and roofing was considerably higher than for other types of work (Table III). These types of work also accounted for the highest payment rates. The median number of days lost for all types of construction work at DIA combined (52 days) as well as the median for each individual type of work were several times that reported by the BLS for the construction industry (7 days) (BLS, 1995b).

The large discrepancy between BLS and DIA data regarding median days lost is explained in part by different definitions of lost time. BLS estimates include injuries resulting in a minimum of one lost work day, whereas our data, based on the definition of a lost-time claim in Colorado, include only those injuries resulting in more than three lost work days. To make the comparison between DIA's and BLS's medians more equivalent, we re-calculated the BLS median, excluding the percent of cases involving one or two days of lost time. Because the BLS report (1993 data) combines three, four, and five days of lost work into one category, we were unable to isolate and exclude those cases involving three lost days of work. Similarly, the BLS groups injuries with 31 or more lost-days into a single category, so we could only conclude that the recalculated median falls into the category of 31 days or more. The data indicated that the recalculated median falls near the lower end of this category, suggesting that it is still lower than the DIA figure.

Payment Rates and Expected Loss Rates. A somewhat different picture of injury risk emerges when payment rates and ELRs are examined. ELRs represent prevailing risk, since they reflect average workers' compensation payments for particular job classifications across industries. When ELRs are compared with DIA's payment rates, one can readily see which types of work were performed more safely than expected and which were not (Table IV). Payment rates for a number of types of work, including concrete construction (bridges and culverts and plastering and finishing), iron/steel erection (<2 stories) and insulation work were significantly lower than their ELRs, suggesting that these types of work were performed more safely than would have been expected. Particularly notable is that iron/steel erection (<2 stories), which had the highest ELR among all types of work performed at DIA, had one of the lowest payment rates.

The payment rates for some other types of work were higher than their ELRs. Drivers, for instance, had the second highest payment rate and a relatively low ELR, indicating that safety performance was poor compared both with other types of work at DIA and with similar work performed across all industries in Colorado. Like driving/trucking, other types of work, including metal/steel installation, elevator construction and inspection/analysis, had among the highest payment rates, and had payment rates significantly higher than expected. On the other hand, while roofing was associated with the highest payment rate, it also had the second highest ELR, suggesting that its safety performance at DIA was typical for that type of work.

The injury rates found at DIA were higher than those reported by the BLS (1995a), and this was especially true for non-LWT injuries (Glazner et al., 1998). To determine whether payment rates that were higher than ELRs were explained by more complete reporting of non-LWT injuries, we calculated payment rates for LWT claims only and compared these with ELRs by type of work (Table IV). As expected, the exclusion of non-LWT claims reduced the payment rates, but in no case was the decrease sufficient to bring the payment rates that had been in excess of ELRs down to the level of the ELRs.

Another possible explanation for payment rates that are higher than ELRs is that the types of injury suffered by DIA workers were different from those for the Colorado construction industry at large. Neither BLS nor NCCI reports type of injury by classifications corresponding with our 'type of work' categories, so it was not possible to directly compare the type of injury, body part injured, or injury event for specific types of work at DIA with comparable state or national data.

DISCUSSION

This analysis is an extension of earlier work describing injury rates and workers' compensation payment rates for the construction of Denver International Airport (Glazner et al., 1998). Our previous findings suggested that BLS reports of injury rates underestimate the burden of construction injury. The present analysis was undertaken to determine how the burden of injury is spread across types of work and to identify particularly hazardous types of work on which safety efforts should focus.

Injury rates at DIA by type of work exceeded national rates for construction contractors performing similar types of work. There are several likely explanations for the large differences in rates, including differences in categorization of workers. Our type-of-work categories, defined by similar job classifications, offer a finer categorization of workers than do 3- or 4-digit SIC codes. Construction contractors classified under SIC codes describing the major type of work performed (SIC 150-179) may employ workers in various trades, performing a variety of tasks. Our categorization often combined workers of different trades, but they were performing one central task. Furthermore, BLS rates include in their data relatively low-risk workers such as administrative and office personnel employed by the contractor, whereas our type-of-work rates do not. The large difference in non-LWT rates between similar DIA and BLS work categories is likely to be due, at least in part, to the more complete reporting of "minor" (non-LWT) injuries at the DIA project site (Glazner et al., 1998). Despite the large differences in rates, we found that in some cases, the patterns of injury occurrence among types of work at DIA and construction contractors reporting to BLS were similar. For example, as was the case for DIA, BLS data show higher LWT injury rates among carpentry (SIC 175) and concrete contractors (SIC 177) relative to others and elevated non-LWT injury rates for plumbing contractors (BLS, 1995a).

Among the most striking findings of this analysis was the magnitude of days lost to injury. The median days lost per injury for DIA overall and for every type of work was several-fold the median reported by BLS for construction in 1993. Some part of the disparity between the DIA and BLS lost-days figures undoubtedly stems from the fact that BLS's data included all workers in the construction industry, e.g., administrative workers, but that explanation cannot account for the entire difference. Managerial, sales, and professional workers accounted for only 16 percent of the construction workforce in Colorado in 1993 (Colorado Department of Labor and Employment, 1994). Another likely source of difference is that when companies report lost work days attributable to injuries occurring in the calendar year, they report only through the month of January of the following year and are asked to estimate future lost work days for ongoing injuries. This process of results in the censoring of lost work days for serious injuries and injuries that may have occurred in the later months of the year.

The likely explanation for most of the difference between median lost days reported for DIA and by BLS is the difference in definitions of LWT injuries. BLS data include larger proportions of less severe injuries because they include injuries resulting in one or more lost-work days, compared with the DIA data, which include only injuries resulting in four or more lost-work days. After recalculating BLS's median days lost to remove injuries resulting in one and two days of work absence (Table IV), we found that the median days lost for nearly all of DIA's type-of-work categories remained higher than the BLS median for construction and that the overall DIA median was approximately 73 percent higher. Nevertheless, by presenting only a median that includes the many 1-, 2-, and 3-day lost-time injuries, BLS's reports mask the magnitude of lost time associated with construction injury. The DIA data suggest that the effects of construction injury on worker well-being and company productivity, as well as workers' compensation costs, may be much more substantial than has heretofore been recognized.

The overall payment rate at DIA was higher than its ELR; payment rates for 10 out of 25 types of work were also higher than their ELRs, in some cases, much higher. On the other hand, 15 of 25 types of work had lower (sometimes much lower) payment rates than ELRs. A possible explanation for the high payment rates is complete reporting at DIA, which was facilitated by the on-site medical clinic, at which claims were generated for all treatment rendered, and by a physician referral system, which was the designated provider for all work-related injury and illness. Evidence is accruing to suggest that underreporting of injuries is common (Oleinick et al., 1995; Glazner et al., 1998). ELRs are determined based on workers' compensation claims payments; they are therefore subject to any underreporting that may occur.

Expected loss rates are based on payments for all workers in a job classification, regardless of industry; this likely accounts for some difference from DIA's payment rates. For example, the ELR for drivers applies to drivers in all industries, not only construction. Even ELRs for job classes likely to be working only in construction, e.g., carpenters, include data for workers in types of construction very different from DIA, for instance, residential construction. While ELRs remain the best existing measure of prevailing risk against which to compare a project's experience, they are not industry-specific.

We have identified several types of work that, because of the high risk of injury associated with them, high payment rates and/or severity of injury, as measured by lost work time, warrant further attention by the construction safety community: metal/steel installation, concrete construction, and drivers/trucking. These findings confirm other reports of higher median lost days for drivers (across all industries) and concrete finishers (BLS, 1995b) and of a disproportionate number of injuries among concrete workers (Helander, 1991; Construction Safety Association of Ontario, 1995).

Other types of work exhibited varying combinations of high injury rates, high payment rates, and elevated number of lost days. The variation in injury and payment rates across types of work, as well as the discrepancies between ELRs and payments, is provocative, but we do not have evidence in our administrative database that can adequately explain it. Without such explanations, development of injury prevention strategies for specific types of work may not be well informed. More detailed analysis of specific risks associated with different types of work will be necessary before an understanding thorough enough to design effective injury prevention strategies can be gained. For instance, analyses of the type of injuries incurred, specific tasks workers were performing at the time of injury as well as the environment in which they were working will be needed for this purpose.

One of the consequences of performing type-of-work analysis rather than trade-specific analysis is that comparison of the findings with existing trade-specific studies is not possible. For instance, construction laborers have been found to account for a large proportion of construction worker injuries (OSHA, 1992a, 1992b; Hunting et al., 1994), but because we did not have data identifying trade, we cannot compare these findings with ours. On the other hand, much construction work is performed by non-trade-union workers. Injury prevention is the province of the employer, who must address risk specific to the work performed. Trade-specific analysis can illuminate the risks to which members of certain trades are exposed, but the analysis presented here provides information about the different levels of risk associated with workers performing certain types of work. Such information is a necessary precursor to developing safety interventions specific to tasks or types of work performed and may be more useful than trade-specific analysis for such purposes.

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Table I. Lost-work-time (LWT) and Non-LWT Injury Rates per 200,000 Person-hours By Type of Work, Denver International Airport Construction

Type of Work	Person-hours	Total Number of Injuries	Rank Order LWT Injury Rate	LWT Injury Rate	Non-LWT Injury Rate
Elevator construction	229,875	56	1	12.2	33.9
Metal/Steel installation	439,656	130	2	11.8	46.9
Conduit construction	463,691	117	3	11.2	39.3
Glass installation	436,520	102	4	11.0	35.7
Concrete construction – general	3,258,738	664	5	10.7	29.5
Carpentry	1,227,122	243	6	10.1	29.3
Roofing	120,689	22	7	9.9	24.9
Masonry	702,281	116	8	8.8	23.6
Driving/trucking	181,634	20	9	8.8	13.2
Street/road construction	5,222,795	728	10	8.2	19.3
Iron/steel erection >2 stories	837,219	199	11	7.9	39.4
Inspection/analysis	585,755	84	12	7.5	20.5
Heavy equipment installation	1,669,210	321	13	6.4	32.1
DIA Overall				**6.2**	**23.6**
Painting	341,505	35	14	5.9	14.6
Plumbing	1,785,070	344	15	5.6	32.9
Concrete work - plastering/finishing	37,484	6	16	5.3	26.7
Insulation work	156,642	13	17	5.1	11.5
BLS 1993 – construction industry				**4.9**	**7.3**
Pipefitting	829,460	87	18	4.8	16.2
Electrical wiring – buildings	3,800,022	744	19	4.2	34.4
Sheet metal work	643,827	94	20	4.0	25.2
Iron/steel erection <2 stories	122,297	24	21	3.3	36.0
Pile driving/drilling	74,948	7	22	2.7	16.0
Concrete const. - bridges/culverts	247,998	20	23	2.4	12.9
Electrical - low voltage specialty	337,620	10	24	1.8	4.1
Construction supervision	2,833,998	116	25	0.6	7.6

*Source: Bureau of Labor Statistics, Survey of Occupational Injury and Illness 1993. Washington D.C.: U.S. Department of Labor, 1995.

Table II: Lost-Work-Time(LWT) and Non-LWT Injury Rates for Type of Work at Denver International Airport Compared with Bureau of Labor Statistics (BLS) Injury Rates by Three-digit Standard Industrial Classification (SIC) Code*.

Type of Work / SIC Code	LWT Injury Rates per 200,000 Person Hours		Non-LWT Injury Rates per 200,000 Person Hours	
	DIA	BLS	DIA	BLS
Street/Road construction / SIC 161	8.2	4.6	19.3	6.5
Plumbing / SIC 171	5.6	4.9	32.9	8.5
Painting / SIC 172	5.9	4.2	14.6	4.0
Electrical Work / SIC 173	4.2	4.1	34.4	6.8
Carpentry / SIC 175	10.1	5.9	29.3	7.8
Concrete construction / SIC 177	10.7	5.9	29.5	5.8

*Source: Bureau of Labor Statistics, Annual Survey of Occupational Injury and Illness, 1993. Washington, DC: U.S. Department of Labor, 1995.

Table III. Median and Mean Number of Work Days Lost for Lost-Work-Time Injuries by Type of Work, Denver International Airport Construction

Type of Work	Total LWT Injuries	Deaths/PT Injuries excluded***	Median Number of Days Lost	Mean Number of Days Lost
Driving/trucking	8	-	202	212
Concrete construction – general	174	1	91	150
Roofing	6	-	90	172
Glass installation	24	-	75	81
Metal/Steel installation	26	-	69	76
Electrical wiring – buildings	79	-	66	140
Heavy equipment installation	52	1	61	109
Painting	9	1	60	67
DIA Overall	**920**	**13**	**52**	**112**
Iron/steel erection >2 stories	32	1	50	111
Masonry	31	-	49	109
Carpentry	62	-	48	80
Street/road construction	208	7	47	115
Elevator construction	14	-	46	102
Conduit construction	26	-	40	85
Inspection/analysis	22	-	39	116
Sheet metal work	13	-	35	94
Pipefitting	19	1	30	60
Plumbing	50	-	27	65
Construction supervision	8	-	20	98
BLS Construction 1993*	**204,800**	**NA**	7	**NA**
**BLS Recalculated ** **	**149,709**	**NA**	**31 or more****	**NA**

*Source: Bureau of Labor Statistics, Work Injuries and Illnesses by Selected Characteristics, 1993. Washington, D.C.: U.S. Department of Labor, 1995.
**BLS estimates were recalculated from BLS data after excluding data for one or two days of lost work from the distribution. Because BLS groups days for all injuries resulting in more than 31 days into a single category, our best estimate is that the recalculated BLS median is at least 31 days.
***One injury resulting in either death or permanent total (PT) disability is not shown because the types of work associated with this injury is not shown.
NA = data not available

Table IV. Payment Rate, Expected Loss Rate, and Average and Median Claims Payments by Type of Work, Denver International Airport Construction

Type of Work	Rank Order LWT Rate	Payment Rate[a] (per $100 payroll)	Payment Rate For LWT Injuries Only	Expected Loss Rate (per $100 payroll)	Average Claim Payment[b]	Median Claim Payment[b]
Driving/trucking	9	$19.60*	$19.07	$6.56	$26379	$1691
Roofing	7	18.19	16.80	18.57	16,408	211
Concrete construction – general	5	14.26	12.98	9.58	12,111	368
Metal/Steel installation	2	14.06*	10.51	6.84	8,358	351
Glass installation	4	10.86	10.33	7.77	10,261	243
Elevator construction	1	10.58*	9.67	3.20	7,112	497
Street/road construction	10	9.76	8.94	7.01	15,219	458
Iron/steel erection >2 stories	11	8.99	6.79	18.13	6,907	243
Carpentry	6	7.07	6.28	9.04	5,454	274
Inspection/analysis	12	7.02*	6.49	0.95	7,577	342
Conduit construction	3	6.95	6.59	5.09	8,770	213
Heavy equipment installation	13	6.76	6.02	5.80	7,319	305
DIA Overall		**6.41**	**5.62**	**5.71**	**8,486**	**305**
Painting	14	6.25	5.38	7.61	9,251	454
Masonry	8	6.18	5.84	9.40	6,368	259
Electrical wiring – buildings	19	4.72	3.64	3.39	4,976	246
Pipefitting	18	3.82	3.39	6.72	10,327	311
Plumbing	15	3.35	2.83	5.19	3,338	250
Pile driving/drilling	22	2.86	2.72	8.56	4,556	216
Concrete work -plastering/finishing	16	2.78*	2.63	10.75	2,647	110
Sheet metal work	20	2.75	2.30	7.01	3,513	280
Concrete const. - bridges/culverts	23	2.34*	1.95	10.47	4,416	256
Electrical - low voltage specialty	24	2.32	2.27	2.66	22,529	621
Iron/steel erection <2 stories	21	1.33*	0.96	23.67	1,070	195
Insulation work	17	1.30*	1.11	12.72	2,299	309
Construction supervision	27	1.14	0.62	1.29	4,314	219

[a] Payment rate reflects medical and indemnity payments per $100 payroll. To calculate payment rates, claims payments were capped at $126,000 and adjusted to 1992 dollars in order to make payment rates comparable to expected loss rates.
[b] Average and median claims payments reflect medical and indemnity payments adjusted to 1992 dollars.
* DIA payment rate significantly different from ELR at 0.05 significance level.

Appendix 1. Type of Work classifications as defined by National Council on Compensation Insurance (NCCI) code:

Type of Work	NCCI Job Classification Code(s)
Carpentry	5020: acoustical ceiling installation 5146: furniture and fixture installation 5403: carpentry,not otherwise classified (NOC) 5437: installation of cabinet work or interior trim 5443: interior/exterior lathing 5445: wallboard installation/drywall
Concrete Construction - General	5213: concrete construction (self bearing floors --above ground) 5221: cement work - ground supported (floors, sidewalks, driveways - not for roads, airfields)
Concrete Construction - Bridges/Culverts	5222: bridges and culverts
Concrete Work - Plastering/Finishing	5480: interior plastering (mixing of plaster, troweling)
Conduit Construction	6325: conduit construction (laying coaxial cable underground)
Construction Supervision	5606: construction superintendent (above foremen)
Driving/Trucking	7219: trucking NOC 7380: drivers (distributors, concrete mixers)
Electrical Wiring - Buildings	5190: electrical wiring - within buildings
Electrical Work - Low Voltage Specialty	7600: telephone line maintenance and operation (stringing overhead low voltage wires and laying underground cable) 7601: low voltage cable installation for communications 7605: burglar alarm and sound system installation, computer cable 7610: radio and television production crews
Elevator Construction	5160: elevator erection or repair
Glass Installation	5462: glazier (deliver and install plate glass in buildings)
Heavy Equipment Installation	3724: machinery or equipment erection or repair (electrical power equipment, substation equipment, air conditioning, satellite dish)
Inspection/Analysis	4511-analytical chemist
Insulation Work	5479: insulation work NOC

Iron/Steel Erection - >2 Stories	5040: erecting iron or steel frame structures (>2 stories high)
Iron/Steel Erection - <2 stories	5057: iron/steel erection at ground level (no framing, welding) 5059: iron/steel framing (<2 stories high, welding)
Metal/Steel Installation	5102: installation of metal doors, erection of steel windows, decorative iron work, awnings and tents) 6400: metal fence erection
Masonry	5348: tile, stone mosaic or terrazzo work - inside 5022: masonry NOC
Painting	5474: painting or paperhanging 9501: sign painting and lettering
Pile Driving/Drilling	6003: pile driving 6204: excavation (ditches, filling, backfilling, grading 6252: shaft sinking (pile driving, excavation, concrete work)
Pipefitting	3365: welding or cutting NOC 5188: auto sprinkler installation 6319: gas main or connection construction (utilities companies) 6306: sewer line construction
Plumbing	5183: plumber
Roofing	5551: roofing -all kinds
Sheet Metal Work	5538: sheet metal work, NOC
Street/Road Construction	5506: street or road paving - runways, asphalt surfacing 5507: street or road construction - excavation, grading 6217: excavation for road construction 6229: irrigation or drainage system construction (digging canals, installation of irrigation equip)