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

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Background *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.*

Methods *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.*

Results *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.*

Conclusions *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. 35:175–185, 1999.

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

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conclusions provide little insight, however, into the reasons 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 contracts	Percentage of contracts
Number of company employees*		
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

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.

accountability and intervention and company and work environment, they were most likely to give ''always'' answers to statements about company commitment to safety.

Associations of safety practices with injury rates

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

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 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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