Comparative Injury and Fatality Risk Analysis of Building Trades

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Abstract: Occupational injury and fatality risk analysis was performed on 16 building trades in the study reported herein. The approach was based on defining risk fundamentally as the product of probability (frequency) and severity, and using the risk plane concept to evaluate and rank the trades in terms of nonfatal injury rates. A parameter named index of relative risk was then used for fatality rate based ranking, and the results separately obtained from these analyses were integrated into a combined risk score for arriving at final rankings. Bureau of Labor Statistics data was used in the study. The risk analysis methodology included both frequency and severity considerations associated with nonfatal injuries. It was observed that simultaneous consideration of frequency and severity gives more comprehensive results than performing risk analysis based exclusively on either frequency or severity. The findings of the study indicated that ironworkers and roofers were the highest risk trades. The information derived from the methodology presented in this paper should be particularly valuable for risk managers, legal and liability experts, and project managers.

DOI: 10.1061/(ASCE)0733-9364(2006)132:5(533)

CE Database subject headings: Risk management; Occupational safety; Injuries; Fatalities; Accidents; Construction industry.

Introduction

The construction industry in the United States has historically suffered a poor record of occupational injuries, illnesses, and fatalities. The Bureau of Labor Statistics (BLS) for 2003 indicate that the highest number of fatalities among all industries occurred in construction, with 1,126 that year. Unfortunately, this number has stayed relatively constant over the past decade. While the incidence rates of total recordable (nonfatal) injuries have shown notable improvement over the same period, there were still 6.8 injury cases per 100 full time workers in 2003, ranking the construction industry as the second highest among all industries in this category.

It is commonly recognized that construction work is inherently dangerous, and construction project sites present a high risk of injury and fatality, especially when the owner and contractor safety programs are not implemented effectively. Construction projects typically engage multiple employers and a variety of trades (e.g., roofers, carpenters, electricians, plumbers, painters, etc.), which carry on a diversity of tasks on project sites. Workers employed in the trades are skilled individuals who are trained in a single, narrowly specialized construction application, which may involve a limited range of materials and systems (Liebing 2001). Construction project work for the trades is scheduled in a way that will make them work alone, or it may place them with other trades in a common work area. There are varying degrees of hazards and risks associated with the different types of work performed by these trades. The question often arises on what types and levels of risks are incurred in the work of these trades.

There is a dearth of information in the literature on the quantification of risks for the construction and building trades. However, efforts have been directed by some researchers (Toscano 1997; Clemens and Simmons 1998; NIOSH 1999) towards quantifying and evaluating work-related risks in various industries and businesses. These studies have mostly focused on injury and fatality risks separately, although an attempt was made (NIOSH 1999) to produce a combined index of risk considering both of them together. Data published by the Bureau of Labor Statistics (BLS) were used in these studies to evaluate the risks primarily in terms of the probability of injury and fatality.

It is important to recognize that a large volume of data is required for risk quantification and risk analysis using injury, illness, and fatality statistics for each trade. However, very few construction firms have the quantity and quality of data needed to perform meaningful risk analysis. Although insurance companies maintain extensive records, this data is confidential and not in the public domain. Consequently, all published risk analysis work on injuries and fatalities has drawn on the BLS data, which is easily accessible ⟨http://bls.gov/iif/home.htm⟩.

There are many definitions of "hazard" and "risk" (Brauer 1994; Cox and Tait 1998; University of Bath 2003; British Standard BS 4778). In the context of occupational safety and health, *hazard* can be defined as the potential for an activity or condition to produce harmful effects such as illness, injury, or fatality. *Risk*, on the other hand, is the measure of both the likelihood and the consequences of the hazards associated with an activity or condition. Based on this understanding, the ISO Standard 8402 has defined *risk* as the combination of the probability (frequency) of a defined hazard and the consequences of its occurrence. System safety engineers (Quality 1984) have quantified

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Note. Discussion open until October 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on May 26, 2005; approved on October 19, 2005. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 5, May 1, 2006. ©ASCE, ISSN 0733-9364/2006/5-533–539/$25.00.

this concept by formulating the risk associated with an event as the product of probability and severity.

Two methods have commonly been used in evaluating risks (Clemens and Simmons 1998): The risk plane, and its extension, risk assessment matrix. In the risk plane method, a two-dimensional plane is constructed with the x axis representing the probability, P, of an event, and the y axis representing the severity, S, as shown in Fig. 1. Any point on this plane denotes the coordinates of a risk value R, which can be calculated by multiplying P and S. The locus of points derived by equal R values on the risk plane is termed the isorisk contour. The isorisk contour lines can be used to divide the risk plane into a desired number of risk regions. Different points and contours on the plane signify different risk levels. The risk increases as either probability or severity increases, or both increase simultaneously (refer to K1, K2, and K3 in Fig. 1).

The risk assessment matrix method is based on the risk plane concept, and in essence, it transforms this concept to an application tool (Brauer 1994). The risk matrix provides detailed classifications for probability and severity where the probability is characterized as frequent, probable, occasional, remote, or improbable, while severity is classified as catastrophic, critical, marginal, or negligible. So, for a given event or occurrence, it is possible to identify the combination of the associated probability and severity values and determine whether the risk is high or low. From this, a decision can be made on whether some risk reduction is needed, or an operation is permissible at a certain risk level. Details and illustrations of this concept and a sample matrix are provided by Brauer. Only the risk plane method was incorporated in the study reported herein.

The study presented in this paper was undertaken to perform risk analysis on the various trades involved in building construction. The intent was to include nonfatal injury and fatality statistics in risk analysis and to extend the currently used probability based methods with also incorporating severity considerations.

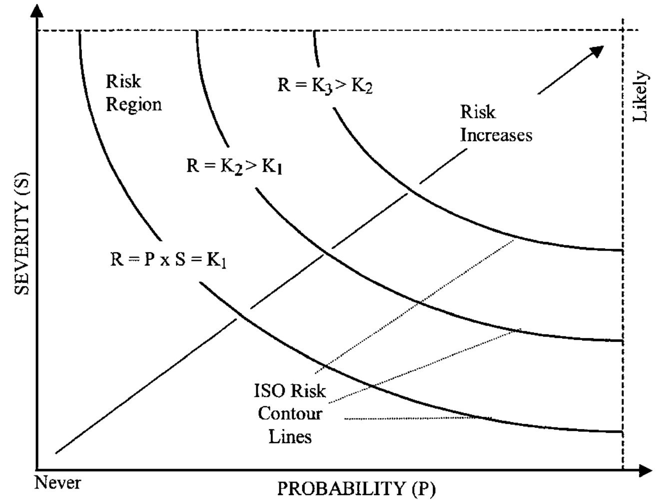

Fig. 1. Risk plane (Clemens and Simmons 1998)

Risk Analysis Methodology

Data Source

The BLS provides several different statistics that can be used to identify and rank dangerous occupations, including annual incidence and fatality rates. Incidence rate is the number of injuries and illnesses per 100 full-time workers and represents their frequency in an industry or an industry sector, identified by the North American Industry Classification System (NAICS) that replaced the Standard Industry Code (SIC) in 2003. It is based on 100 full-time equivalent workers working 40 h per week for 50 weeks in a given year. Fatality rate (also termed rate of fatal occupational injuries) is the number of deaths per 100,000 workers and represents the annual frequency of fatalities.

While incidence and fatality rates enable comparisons between industries and industry sectors, they do not provide information for specific trades. Since the building trades are categorized by occupational classification systems, it is logical to use injury and fatality statistics attributed to occupational codes for their analysis. For this purpose, the BLS has developed the Occupational Injury and Illness Classification System (OIICS) that provides injury, illness, or fatality data for specific occupations. However, only the numbers of nonfatal injuries and fatalities for various occupations are available in this system, and there are no injury and fatality rate data. Consequently, it became necessary to develop new formulas for nonfatal injury and fatality rates for the trades and to use this data with the formulas to meet the study objectives. Illness data was not included in the scope of the study.

BLS data pertaining to a 4-year period from 1998 to 2001 was incorporated in the study (Bureau 2001). Specifically, the number of nonfatal injuries involving days away from work and median days away from work values were drawn from the work-related injuries database by occupation type ⟨http://www.bls.gov/iif/oshcdnew.htm⟩. In addition, the number of fatalities was acquired from census of occupational injuries database ⟨http://www.bls.gov/iif/oshcfoil.htm⟩. Finally, the number of employment and wage information were obtained from the annual occupational employment statistics database ⟨http://www.bls.gov/oes/home.htm⟩.

The building trades selected for risk analysis consisted of the following: Brickmasons, blockmasons, and stonemasons; tilesetters and marble setters; carpet, floor, and tile installers and finishers; carpenters; cement masons, concrete finishers, segmental pavers and terrazzo workers; construction equipment operators; drywall installers, ceiling tile installers and tapers; electricians; insulation workers; glaziers; painters and paperhangers; pipelayers, plumbers, pipefitters, and steamfitters; plasterers and stucco masons; roofers; sheet metal workers; and ironworkers. BLS groupings of the trades were followed, except for combining the painters and paperhangers, as found in the BLS Occupational Outlook Handbook ⟨http://bls.gov/oco/oco1009.htm⟩. Although construction laborers are known to have high fatalities (more than 300 fatalities every year over the last decade as observed from BLS statistics), this category was excluded from the scope of this research because there is no distinction between the laborers involved in building construction and the laborers engaged in highway and other infrastructure construction.

Further, it should be noted that BLS had been using an occupational classification system based on the occupational codes established in 1990, and it adopted a new system in 2003 referred to as "The 2000 Standard Occupational Classification (SOC) system." The demographic information used in this research was drawn from the data that came from the former system.

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Formulations for Risk Analysis

In the context of this study, nonfatal injury rate was calculated by

$$\mathrm{NFR} = (\mathrm{NF}/E) \tag{1}$$

where NFR=nonfatal injury rate for a given trade; NF=number of nonfatal injuries for a given trade; and E=number of workers employed for a given trade. This statistic represents the frequency (probability) of the occurrence of injury for a given trade in any given year.

Fatality rate was calculated using

$$\mathrm{FR} = (F/E) \cdot 100{,}000 \tag{2}$$

where FR=fatality rate for a given trade; F=number of fatalities for a given trade; and, E=number of workers employed for a given trade. Similar to the case previously indicated for industries, this statistic is for 100,000 workers and is an annual frequency.

Although injury and fatality rates are indications of occupational risk, they are based on just the frequency of occurrence and do not incorporate severity. In this study, the cost of lost time due to injury was adopted as a measure of severity for nonfatal injuries with days away from work. The cost of lost time was obtained by

$$\mathrm{CLT} = \mathrm{MDAFW} \cdot \mathrm{HW} \cdot 8 \tag{3}$$

where CLT=cost of lost time for a given trade; HW=hourly wage for a given trade; and MDAFW=median number of days away from work. The hourly wage was converted to a daily wage amount by multiplying it by 8, which is the number of hours worked in a day. Data on median days away from work and hourly wages were obtained directly from the BLS database.

It is important to note that severity can be expressed either by lost days, or by the cost associated with lost days. The latter approach was selected for this study but it was considered only for nonfatal injuries. It must be understood that in a strict sense, the cost of lost time due to injury concept is not applicable to the fatality cases, even though some of the fatalities recorded in the BLS database might have been preceded by an injury resulting in lost time. However, the BLS does not place such cases in that category and simply reports them as fatalities.

Steps for Analysis

A two-step approach was taken to perform the risk analysis (Baradan 2004). As a first step, nonfatal injuries and fatalities were analyzed separately. The second step was based on the first, where the results for nonfatal injuries and fatalities were integrated into a combined risk analysis.

Nonfatal injuries were analyzed employing the risk plane, with NFR values (representing probability or frequency) on the x axis, and CLT values (indicating severity) placed on the y axis. The calculated values of NFR and CLT were used to plot points on the risk plane for each trade, which allowed comparisons between the trades in terms of the combinations of frequency and severity values relative to the isorisk contours. In addition, the trades were ranked from 1 (highest) to 16 (lowest) based on risk values. The risk value R is obtained as the product of NFR and CLT.

Fatalities were analyzed using the index of relative risk, which is calculated by

Table 1. Risk Score Criteria for Nonfatal Injuries and Fatalities

Nonfatal injuries		Fatalities	
Risk region	Risk score	Index of relative risk	Risk score
1	7	>1.50	7
2	6	1.25–1.49	6
3	5	1.00–1.24	5
4	4	0.75–0.99	4
5	3	0.50–0.74	3
6	2	0.25–0.49	2
7	1	0.01–0.24	1

$$\mathrm{IRR} = \mathrm{FR} \Bigg/ \left[\left(\sum F \Big/ \sum E\right) \cdot 100{,}000\right] \tag{4}$$

where IRR=index of relative risk for a given trade; FR=fatality rate for a given trade; ΣF=summation of the number of fatalities for all building trades; and ΣE=summation of the number of employed workers for all building trades. As before, this statistic is for 100,000 workers. The trades were ranked from 1 to 16 based on IRR. The IRR concept is attributed to the previous work done by Toscano (1997).

The second step of the risk analysis consisted of assigning individual risk scores to each trade for nonfatal injuries and for fatalities, and calculating a combined risk score as

$$\mathrm{RS}_C = \mathrm{RS}_{\mathrm{NF}} + i \cdot \mathrm{RS}_F \tag{5}$$

where RS_C=combined risk score for a given trade; $\mathrm{RS}_{\mathrm{NF}}$=nonfatal injury risk score for a given trade; i=index of harm; and RS_F=fatality risk score for a given trade. Nonfatal injury risk scores ($\mathrm{RS}_{\mathrm{NF}}$) were assigned to the trades based on where they fell in the risk regions. Fatality risk scores (RS_F) were determined according to the magnitude of the IRR values of the trades. In all cases, the risk scores were established on a scale from 1 to 7. The assigned risk scores are presented in Table 1. Although not shown in the table, zero fatality risk scores were assigned to those trades for which no fatalities were reported.

The index of harm term, i, in Eq. (5) implies that the effects of nonfatal injures and fatalities on the combined (additive) risk score term can be uneven. Previous researchers (Solomon and Abraham 1980; NIOSH 1999) selected a value of 2 for this coefficient, which indicates that the weight of fatalities is twice that of nonfatal injuries. It was decided to use the same i value to compute RS_C in this study, although it was recognized that there may be a range of values for this coefficient. Index of harm may vary from trade to trade, and in cases where there are high-cost disabling injuries, it can be lower than 2.

Results and Discussion

Risk analysis results for nonfatal injuries and fatalities are presented in this section in Tables 2 and 3 and in Figs. 2 and 3. Table 2 shows the mean values of nonfatal injury rates, median days away from work, hourly wages, cost of lost time, and fatality rates for the 4-year period from 1998 to 2001. According to this data, ironworkers have the highest nonfatal injury rate, followed by roofers, glaziers, carpenters, insulation workers, and carpet floor and tile installers and finishers. The lowest nonfatal injury rate is observed for construction equipment operators, succeeded by the trade group of cement masons, and concrete and terrazzo

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Table 2. Mean Values of Nonfatal Injury and Fatality Related Data

Building trade	Abbreviation	1998–2001 mean values: Nonfatal injury rate	Median days away from work	Hourly wage ($)	Cost of lost time ($)	Fatality rate
Brickmasons, blockmasons, and stonemasons	Br	0.031	8.25	19.15	1,264	14.18
Carpenters	Cp	0.043	7.25	16.50	957	12.23
Carpet, floor, and tile installers and finishers	Cr	0.042	10.50	15.61	1,311	0
Cement masons, concrete and terrazzo finishers	Cn	0.015	9.25	14.63	1,083	0
Construction equipment operators	Op	0.003	23.50	14.22	2,673	7.55
Drywall installers	Dr	0.038	9.00	16.82	1,211	8.38
Electricians	El	0.025	8.25	19.84	1,310	17.28
Glaziers	Gl	0.046	5.00	15.09	604	0
Insulation workers	In	0.043	8.25	14.44	953	10.70
Ironworkers	Ir	0.056	8.50	18.41	1,252	52.70
Painters and paperhangers	Pa	0.026	8.00	14.19	908	14.93
Plasterers and stucco masons	Pl	0.026	9.75	16.23	1,266	0
Plumbers, pipelayers, pipefitters, steamfitters	Pm	0.030	7.50	18.93	1,136	9.26
Roofers	Rf	0.052	10.25	14.69	1,205	55.30
Sheet metal workers	Sh	0.033	6.25	16.47	824	8.19
Tilesetters and marble setters	Ti	0.028	7.50	17.63	1,058	0

finishers. On the other hand, construction equipment operators show the highest median days away from work and cost of lost time among all trades, although their injury and fatality rates are quite low. Carpet floor and tile installers and finishers, electricians, plasterers and stucco masons, brickmasons, blockmasons and stonemasons, ironworkers, and drywall installers also show relatively high costs of lost time, mainly because of the relatively higher hourly wages associated with these trades.

Similar to the case of nonfatal injuries, roofers and ironworkers lead all other trades again in fatality rates. Electricians also show a relatively high fatality rate, although their rate is significantly lower than those of the previous two trades. Five trades show zero fatality rates; namely, carpet, floor, and tile installers and finishers, cement masons, concrete and terrazzo finishers, glaziers, plasterers and stucco masons, and tilesetters and marble setters.

Fig. 2 illustrates the risk plane formed by plotting the nonfatal injury rates (NFR) against cost of lost time (CLT). Each trade is represented on this plane by a point whose coordinates are the NFR and CLT values calculated for the given trade (e.g., for glaziers, NFR=0.046, CLT=604). Six isorisk contours have been drawn on this plane indicating risk (R) values of 10, 20, 30, 40, 50, and 60, obtained by multiplying nonfatal injury rate and cost of lost time (e.g., $R=0.02\cdot 1{,}000=50$). Note that the selection of R values of 10–60 with increments of 10 was driven by the specific ranges of values pertaining to the data derived in this research. It

Table 3. Trade Risk Ranking Results

Building trade	Nonfatal injuries: R	Rank	Risk region	Risk score	Fatalities: Index of relative risk	Rank	Risk score	Combined results: Risk score	Rank
Iron workers (Ir)	65.9	1	1	7	3.78	2	7	21	1
Roofers (Rf)	63.0	2	1	7	3.97	1	7	21	1
Carpet, floor, tile installers (Cr)	55.8	3	2	6	0	12	0	6	12
Drywall installers (Dr)	45.5	4	3	5	0.6	9	3	11	8
Insulation workers (In)	41.2	5	3	5	0.88	6	4	13	5
Carpenters (Cp)	41.0	6	3	5	0.77	7	4	13	5
Brickmasons (Br)	39.2	7	4	4	1.02	5	5	14	3
Plumbers (Pm)	33.8	8	4	4	0.66	8	3	10	9
Electricians (El)	33.2	9	4	4	1.24	3	5	14	3
Plasterers and stucco masons (Pl)	32.0	10	5	3	0	12	0	3	13
Tilesetters and marble setters (Ti)	28.2	11	5	3	0	12	0	3	13
Glaziers (Gl)	27.3	12	5	3	0	12	0	3	13
Painters and paperhangers (Pa)	23.9	13	5	3	1.07	4	5	13	5
Sheet metal workers (Sh)	17.2	14	5	3	0.59	10	3	9	10
Cement masons, concrete finishers (Cn)	15.5	15	6	2	0	12	0	2	16
Construction equipment operators (Op)	7.2	16	4	1	0.54	11	3	7	11

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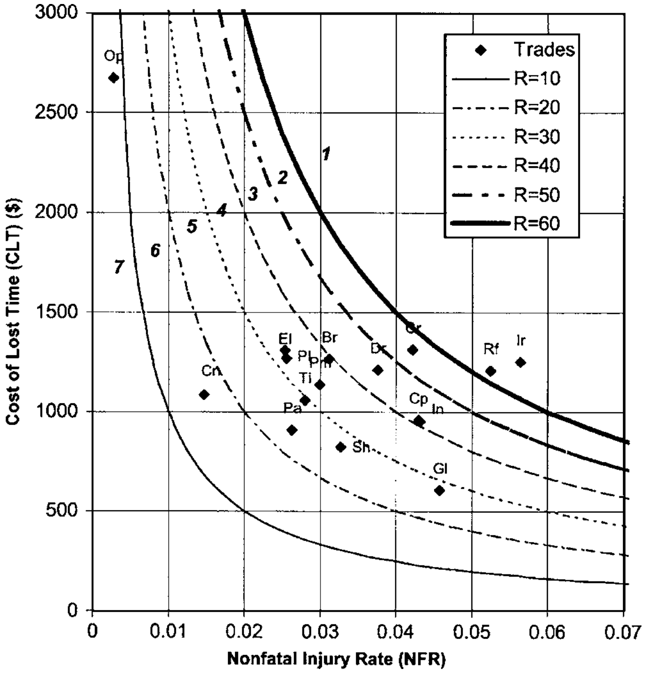

Fig. 2. Risk plane for years 1998–2001

would be possible to increase or decrease the number of contour lines according to the desired sensitivity levels of observations. Seven regions (1–7) separated by these isocontours have also been established on the risk plane. Higher R values represent higher risk levels, whereas higher numbers for the risk regions represent lower risk levels. Although there may be multiple trades that fall into a given risk region, it is possible to distinguish between these trades by observing their R values. For instance, there are two trades in risk region 1: ironworkers and roofers. As shown in Table 3, the respective R values for these trades are 65.9 and 63.0, which are used to rank them from high to low.

The rankings for all of the 16 trades analyzed in terms of nonfatal injuries, fatalities, as well as the combination of nonfatal injuries and fatalities, are summarized in Table 3. Also shown in this table are R values, risk region number designations, indices of relative risk, and risk scores. The risk scores for nonfatal

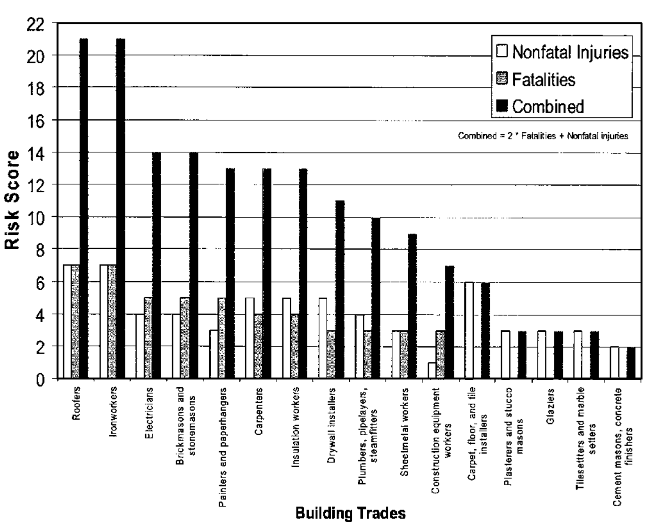

Fig. 3. Risk scores of building trades

injuries, fatalities, and combination of nonfatal injuries and fatalities are graphically displayed in Fig. 3, from which comparisons can be drawn between the trades for each case.

As observed from Table 3, for the case of nonfatal injuries, ironworkers and roofers are ranked as the two highest-risk trades, followed by carpet, floor, and tile installers as the third ranked trade. Drywall installers, insulation workers, carpenters, and brickmasons are ranked between 4th and 8th with R values ranging from 45.5 to 39.2. While plumbers, plasterers and stucco masons, tilesetters and marble setters, glaziers, painters, and paperhangers are ranked 9–13 with R values between 33.8 and 23.9, sheetmetal workers and cement masons, concrete finishers are ranked 14th and 15th, respectively. It is noted that construction equipment operators have a very high severity rating compared to all other trades, which could be due to the high energies involved with moving equipment and their moving parts. Despite this high statistic, equipment operators still exhibit the lowest ranking (16th) of all in the nonfatal injury category because of the infrequency of nonfatal injuries encountered in this trade. The reason for this is that the frequency of nonfatal injuries for this trade is very low compared to all other trades. This implies that having only a high severity (or frequency) rate does not necessarily indicate high risk, because the risk value is affected equally by frequency and severity.

Table 3 also shows that roofers and ironworkers are the highest ranked trades in the case of fatalities, as well. However, their positions (1 and 2) are transposed. The third ranking trade is the electricians, while painters and paperhangers and brickmasons, blockmasons, and stonemasons are ranked 4th and 5th, respectively. Insulation workers, carpenters, plumbers, drywall installers, sheetmetal workers, and construction equipment workers have intermediate rankings. With no reported deaths, carpet, floor, and tile installers and finishers, cement masons, concrete and terrazzo finishers, glaziers, plasterers, and stucco masons, and tilesetters and marble setters come last in the fatality-based risk ranking.

The IRR values used for ranking the trades based on fatalities show a linear form based on assigning risk scores to IRR intervals of 0.25. It is observed that above the cutoff value of 1.50, which is between the risk scores of 6 and 7, the IRR values for roofers (3.97) and ironworkers (3.78) increase considerably. Therefore assigning a risk score of 7 to these two trades would be somewhat deceiving because it obscures the much higher risks associated with them. If we were to continue with assigning the intervals linearly, the risk scores for these two trades would have come out to be 16. This way, exceedingly high risks associated with these two trades would be better highlighted. Although this observation does not change the ranking results, it is observed that these two trades are well above the others in terms of the magnitude of risk.

The joint effects of nonfatal injuries and fatalities are integrated into combined risk scores that are presented in Table 3 and Fig. 3, Again, ironworkers and roofers are distinctively the two trades that are exposed to higher risk than the rest of the trades, with equal combined risk scores of 18. Similarly with the linear intervals, this number would be 39. Following these two trades, five others line up with risk scores of 14 and 13; namely, brickmasons, electricians, insulation workers, carpenters, painters, and paperhangers. With risk scores ranging from 6 to 11, drywall installers, plumbers, sheetmetal workers, construction equipment workers, and carpet, floor, and tile installers form the next group. Finally, plasterers and stucco masons, tilesetters and marble setters, and glaziers appear last in the combined ranking with risk scores of 3.

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It is further noted that the fatality rankings dominate the combined ranking results because of the higher weight assigned to fatalities. As a result, trades such as painters and electricians are ranked higher, even though they are ranked, respectively, 11th and 12th in terms of nonfatal injuries. It is obvious that roofers and ironworkers are the two most dangerous building trades overall. These two trades ranked in the top two in every ranking, and no other building trades came close to them in risk scores. On the other hand, it was found that building trades such as cement masons, glaziers, plasterers, and carpet installers and construction equipment workers exhibit relatively lower risk in nonfatal injury, fatality, and combined rankings.

Summary and Conclusions

Sixteen building trades have been analyzed for nonfatal injury and fatality risks in this study using pertinent BLS data. The results showed that ironworkers and roofers rank the highest in terms of both nonfatal injury and fatality risks. The combined risk scores indicated that electricians, brickmasons, stonemasons and blockmasons, painters and paperhangers, carpenters, and insulation workers were also exposed to relatively high risks, while plasterers and stucco masons, glaziers, tilesetters and marble setters, cement masons, and concrete finishers showed the lowest risk scores. Intermediate risk scores were observed for drywall installers, construction equipment workers, and carpet, floor, and tile installers.

The methodology developed and used in this study is based on the risk plane and risk matrix approach, which had been typically used during design and development phases of a variety of system safety applications, including chemical processing, semiconductor manufacturing, and automobile industry for assessing risk associated with different scenarios, events, or activities (Clemens and Simmons 1998). This study extended these concepts and applied them to the field of occupational safety and health for analyzing injury and fatality risks for different building trades by quantifying the risk for each and ranking them.

While previous studies on injury and fatality risks have almost exclusively focused on the probability or frequency component, this study incorporated the severity component as well. The results indicated that relying on either frequency of occurrence or severity of consequences is not a good way of assessing injury and fatality risks; rather, risk analysis incorporating both frequency and severity gave more comprehensive results. For example, if the analysis were performed only by ranking nonfatal injury rates (frequency), glaziers would be ranked as the third high-risk trade, while they were actually ranked 12th in this study. Similarly, if the analysis were to be done only by ranking cost of lost time (severity), equipment operators and electricians would be two of the highest risk trades in the ranking, while they are ranked 16th and 9th, respectively, in this study.

Median days away from work and the resulting cost of lost time were adopted as measures of severity in this study. Median days away from work/lost time can be used as a measure of safety performance. Safety conscious companies strive for reducing lost time to minimal levels, often setting a goal of zero (Garner 2004). This study used hourly worker wages to calculate cost of lost time, which are based on national averages. Similar studies can be performed using hourly wages for a particular state or region, if desired.

While useful results were obtained by using lost time as a measure of severity, researchers should keep in mind that there might be other measures that can be considered. One possibility is to investigate the costs of injuries and fatalities using the Stanford Cost Accounting System (Robinson 1979; Levitt and Samelson 1987; Hinze 1997). In addition, the costs can be adjusted by considering the indirect (hidden) costs of the accidents (Hinze and Applegate 1991). It should be recognized, however, that this can not be accomplished by the BLS data, and other data sources such as workers compensation claims, medical case records, court reports, etc. will have to be utilized for this purpose.

The methodology introduced in this paper is not only applicable to the building trades, but also can be used to analyze the injury and fatality risks for any other trade, occupation group, or industry by using appropriate BLS data, or other relevant data. The information derived from these efforts should be particularly useful for risk managers, legal and liability experts, and project managers. For instance, the question of how dangerous (high-risk) a particular occupation or trade is often comes up in injury litigation; the data generated in this study can shed light into this matter and help answer this question. In addition, equipped with the risk ranking information, construction project managers can plan site activities and safety programs in ways to focus on the higher-risk trades and prioritize hazard mitigation strategies and intervention methods, including training needs, personal protective equipment assignments, etc. to make effective resource allocation decisions.

Performing risk analysis using quantitative techniques must be an integral part of decision making in loss control programs for the construction industry. It is believed that the methodology and tools presented in this paper will be valuable assets for this purpose.

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