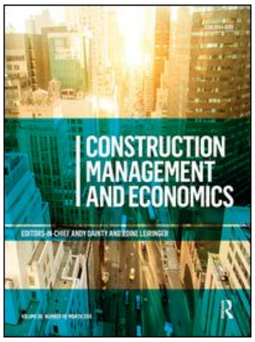

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Safety risk perception in construction companies in the Pacific Northwest of the USA

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Unsafe worker actions contribute greatly to the frequency and severity of construction injuries. Recently, contractors have expressed concern with the high rate of injuries that occur when workers violate company safety policies. To enhance knowledge associated with this topic the following four objectives were targeted: (1) quantifying the current level of safety risk as perceived by construction workers; (2) quantifying the risk tolerance of workers and managers; (3) comparing the risk perceptions and tolerance of workers with managers; and (4) identifying factors that may affect one's risk tolerance. Fifty-one risk perceptions were gathered through interviews with managers and workers of nine different construction firms in the Pacific Northwest region of the United States. The results indicate that the level of current perceived risk is approximately five times higher than the tolerable risk value, workers are most dissatisfied with the frequency of high severity injuries, and there is a statistically significant difference in the risk tolerance between workers and managers. The findings presented can be used by project managers to increase awareness of risk tolerances, current areas where workers feel improvement is most needed, and for goal setting.

Keywords: Safety, risk.

Introduction

Improvement of occupational safety and health is of the utmost importance to the construction industry. Even with recent reductions in incident rates, the US construction industry is responsible for a fatality rate of 11.1 per 100 000 workers and a recordable injury rate of 239.5 per 10 000 full-time workers (Center for Construction Research and Training, 2008). According to US Bureau of Labor Statistics (BLS), the construction industry employs 8% of the American workforce but accounts for 21.7% of all work-related deaths. Disproportionate injury and fatality rates in construction have been recorded in other countries as well. For example, the United Kingdom's Labour Force Survey (LFS) found that the rate of reportable non-fatal injury in construction was an average of 1600 reportable injuries per 100 000 workers between 2004 and 2007, significantly higher than the all-industry average of 950 reportable injuries per 100 000 workers (LFS, 2009). The relatively frequent occurrence of severe construction injuries has been attributed to a multitude of factors including the dynamic and transient nature of construction worksites, exposure to weather, and poor safety culture. Fortunately, strategies developed to improve worker–hazard interactions such as toolbox talks, safety orientations and behaviour-based safety have resulted in measurable improvements (Broderick, 2004).

In recent focus group discussions at a conference in the Pacific Northwest region of the US (NexCon, 2006), large contractors described recent reductions in recordable injury rates but expressed concern with a high rate of low severity injuries that result from violations of predefined safety rules. Bailey (1997) explains that violations may be symptoms of heterogeneity in safety perceptions among varying levels within the organization. Perception surveys are a commonly used tool for studying such phenomena because they can be used to detect differences in attitudes among groups (O'Toole, 2002) and have been used to identify effective safety management practices and characteristics of organizations that contribute to a strong culture of safety (Gill and Shergill, 2004; Choudhry *et al.*, 2007).

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While these studies have confirmed that shared values, attitudes and perceptions are essential to safety success, no study has attempted to quantify safety risk perceptions and tolerances in absolute units of risk. It is expected that a comparison of risk perceptions and tolerances between workers and managers may help explain the high rate of safety violations that occur in hazardous environments. Further, comparisons of perceived current risk and risk tolerance may provide a measure of satisfaction with current safety conditions.

The present study had the following four objectives: (1) to quantify the current level of safety risk as perceived by construction workers and managers in the Pacific Northwest; (2) to quantify the risk tolerance of workers and managers; (3) to compare the risk perceptions and tolerance of workers with managers; and (4) to identify any personal characteristics that may influence one's risk tolerance. It is expected that this information may be beneficial to construction professionals because it can be used to identify specific areas for improvement, to quantify the level of satisfaction that workers have with the safety conditions on their worksite, and to identify whether a difference in risk tolerance exists between workers and managers. For consistency, risk tolerance will be defined as the level of safety risk that workers are willing to accept as a part of their job function. This definition, used to describe one's perception of acceptable risk, is consistent with literature that discusses risk tolerance and the theories associated with acceptable risk (Lowrance, 1976; Fischhoff, 1981; Slovic, 1987; Health and Safety Executive, 2001).

Literature

Safety risk perceptions can be used to quantify two measures of safety risk: current perceived risk and risk tolerance. Therefore, the factors that influence an individual's risk perception must be understood and appropriate methods of collecting and measuring risk must be identified. Additionally, comparing the risk perceptions and tolerances of workers and managers can be considered a measure of safety climate (Guldenmund, 2000). To provide context for this exploration, literature that discusses acceptable risk, risk perception, and the use of perception surveys to explore safety climate and risk perception will be reviewed.

Acceptable risk

According to Lowrance (1976), 'A thing is safe if its attendant risks are judged to be acceptable' (p. 8). This quote reflects the widely accepted principle that absolute safety is unachievable and that the goal of a safety system should be to reduce safety risk to an acceptable level. If the postulate that safety risk cannot be completely removed from construction processes holds true, so must the corollary that every process has some level of residual risk.

Risk acceptability is at the core of all safety decision making (Rae, 2007). Every safety decision is made with a subjective assessment of risk acceptability and a selection of one of the following alternatives: proceed as planned, invest resources to mitigate a portion of safety risk, or do not proceed. An individual's decision may be affected by personal characteristics or characteristics of the risk itself. For example, Slovic (1987) found that individuals find risks of equal magnitude to be more acceptable if the risk is voluntary, under the individual's control, and has clear benefits.

Risk perception

In order to quantify and compare among risk tolerances (i.e. an individual's subjective assessment of acceptable risk), risk perceptions must be carefully solicited in a standardized fashion. Risk perception is defined as the subjective judgment that one makes about the frequency and severity of particular risks. Typically, these values are obtained by questioning individuals about specific risk scenarios and aggregating the data. According to Starr (1969), some individuals may rate the same environment differently but the statistical aggregation of risk perceptions represents actual conditions when the major sources of bias have been minimized.

In the last 30 years, two major families of theory, the *psychometric paradigm* and *cultural theory*, have been developed by social scientists to explain why people make different estimates of risks in the same environment. Daniel Kahneman and Amos Tversky conducted psychometric research to determine whether risk perceptions reflect actual conditions (Tversky and Kahneman, 1973; Kahneman *et al.*, 1982). These researchers found that people use a number of cognitive shortcuts to evaluate risks and these shortcuts are highly influenced by recent events. Alternatively, the cultural theory states that risk perceptions are influenced by attitudes (Thompson *et al.*, 1990). Under this assumption, individuals are classified by one of the following attitudinal orientations: individualist, egalitarian, hierarchist, fatalist and autonomous.

Both theories support the assumption that, when biases are controlled and the impacts of cognitive shortcuts are minimized, risk perceptions can be an accurate measure of actual risk. Zohar (2000) found that the measure of employees' perceptions about the relative importance of safe conduct in their occupational behaviour reflects the safety climate in a given company and serves as a proxy for site safety in general. Additionally, Hallowell (2008) found that construction workers are capable of identifying and rating occupational safety and health risks with a reasonable level of accuracy.

Safety risk quantification

In order to quantify risk perceptions, a standard and accurate method of quantifying safety risk must be identified. Traditionally, safety risk has been defined in terms of subjective ratings of probability and severity. For example, Brauer (1994) classifies probability as frequent, probable, occasional, remote and improbable. Alternatively, Baradan and Usmen (2006) used archival fatality and lost work time data published by the Bureau of Labor Statistics (BLS) to compare risk among construction trades and Lee and Halpin (2003) created a risk analysis tool that utilizes fuzzy inputs from the user. Recently, Hallowell (2008) developed an objective method of quantifying safety risk using frequency estimates defined in terms of incidents per 200 000 worker-hours (w-h) and severity defined in terms of impact to the worker.

In order to create a severity scale that allows outcomes of various severity levels to be compared and summed, Hallowell and Gambatese (2008) created a relative severity scale. On this scale, various outcomes are assigned a severity score based upon the impact of the outcome to the worker. When quantifying risk objectively, it is important to have consistent measures of frequency and severity. Here, the measure of an individual's risk perception will be made in terms of unit risk defined in Equation 1.

$$\text{Unit Risk (S/w-h)} = \text{Frequency (incidents/w-h)} \times \text{Severity (S/incident)} \quad (1)$$

When performing a comprehensive risk evaluation it is essential to consider all types of risk. Most construction safety risk studies define risk levels using archival data compiled by the Bureau of Labor Statistics (BLS), the Labour Force Survey (LFS), the National Safety Council (NSC), and the Occupational Safety and Health Administration (OSHA). These data sources typically report annual statistics for fatal and lost work-time injuries (i.e. non-fatal injuries that involve time away from work). Using such data to comprehensively define current risk levels presents an incomplete picture because these data are limited only to high severity injuries. Thus, risk perceptions were used to define current safety risk and include the spectrum of possible risks from negligible to fatality.

Safety perception studies

A safety perception survey was used to quantify risk perception and risk tolerance. Use of perception surveys to measure attributes of safety climate is prominent in the existing body of literature. The most frequently studied factors of safety climate are management, risk and safety systems (Guldenmund, 2000). Typically, perceptions are obtained through subjective surveys that utilize ratings on Likert-type scales to compare employee views among organizational levels, geographic regions and firm types. Most commonly, these tools are used to assess safety climate by investigating attitudes toward organizational commitment, roles of supervisors and managers, personal roles, risk-taking behaviour and employee satisfaction (Dedobbeleer and Beland, 1991; O'Toole, 2002; Findley *et al.*, 2007). Perception surveys have also been used to strategically investigate attitudes towards new regulations, management strategies (Gill and Shergill, 2004), impact safety improvement strategies (Carder and Ragan, 2003), and relative importance of safety factors (Zohar, 1980).

A common finding in these studies is the existence of subcultures within organizations that do not share perceptions of safety climate (Lee, 1998; Collinson, 1999; Harvey *et al.*, 1999; McDonald *et al.*, 2000). Specifically, studies have identified differences in attitudes and perceptions among workers with differing job titles (Lee, 1998; Findley *et al.*, 2007), compensation levels (Collinson, 1999), and shift times (Health and Safety Laboratory, 2002). Such dissimilarities in safety attitudes and perceptions among different groups were attributed to divergent management styles and levels of concern for safety issues (Health and Safety Laboratory, 2002).

Group differences in perceived safety climate lead to misunderstandings and conflicts and suggest an absence of a cohesive safety culture (Health and Safety Laboratory, 2002). These differences also undermine the effectiveness of safety programmes (Pidgeon, 1998; McDonald *et al.*, 2000). Bailey (1997) also suggests that consistency perceptions and attitudes influence the likelihood that workers will comply with safety and health policies as there is a connection between management's approach to safety, the employees' perception of management, and accident/injury rates. Hill (2004) describes safety violations that may result from these inconsistencies such as: operating equipment without proper clearance, operating at an unsafe speed, making safety devices inoperative, using equipment inappropriately, unsafe positions or postures, and failure to use safe attire or personal protective devices. While these actions typically do not result in very severe injuries, they contribute significantly to workers' compensation claims and, therefore, to safety risk in general. Violations are frustrating and perplexing for employers because workers may become injured as a result of breaking the predefined safety rules and ignoring safe behaviour techniques that were taught in orientation and training sessions.

Point of departure

To build upon safety perception research surveys were conducted in the Pacific Northwest region of the USA that investigated the perceived level of safety risk on construction sites, quantified the level of risk that workers find acceptable (i.e. risk tolerance), and evaluated the potential impacts of personal characteristics on risk tolerance. Such knowledge is needed to understand risk tolerance, assess the level of satisfaction workers have with the safety in the construction environment, and to provide a potential explanation for the number of violations of established safety-related processes and procedures. The departure from the current body of knowledge was established by quantifying risk tolerance in absolute units of risk and implementing an innovative risk perception survey tool.

It should be noted that a standard for acceptable risk cannot be created as acceptable risk values are dependent on many personal and situational factors (Fischhoff, 1994). Rather, the aim was to aggregate risk tolerance values for a group of construction labourers, tradesmen and professionals in an effort to better understand perceptions and the driving factors behind safety decisions (Rae, 2007). Comparisons among these values may also help to explain why safety rules set by management are not always followed.

Research methods

As indicated, the chief objectives were to quantify the level of perceived construction safety risk, to identify the risk tolerances of active construction employees, and to compare the risk perceptions of workers with managers. To maintain external validity, the research team collected data from 51 individuals employed by nine different firms representing several trades. Owing to geographical and monetary constraints, only individuals currently employed in the Pacific Northwest of the United States were included.

Contacts held by the research team were used to create a preliminary database of firms in the Pacific Northwest. This database was then sorted by trade and one firm from each trade was randomly selected using the random number generator in Microsoft Excel. Only firms with annual revenue greater than $10 million were included. In this method, a stratified random sample within the convenience sample was created. Subsequently, the selected contractors were contacted and informed of the research objectives, the expected time commitment, and the need to collect confidential data from the workers. Fifty-nine per cent of the firms agreed to participate.

In order to collect the risk perception data, a sample of workers from each firm was asked to participate in two, 15-minute structured interviews that targeted both workers and managers. Interviews were selected over traditional surveys as the method of data collection because of the complexity of the instructions and the sensitivity of the data. Face-to-face interaction also ensured that the respondents fully understood the questions being asked and provided the interviewer with the opportunity to clarify questions. One should also note that interviews were selected as they provide richer data than simple written surveys.

Before individuals were interviewed, they were asked a series of demographic questions that addressed trade, age, marriage status, number of children, number of years of work experience, number of years with current employer, injuries personally experienced and injuries viewed. Once this demographic information was obtained, workers were then asked to participate in two structured interviews, one focusing on the quantification of perceived actual risk and the other focusing on the quantification of risk tolerance.

When workers and managers were interviewed to determine their perception of the current conditions, they were asked to estimate the current frequency of accidents of various injury severity levels. For example, interviewees were asked to rate the average frequency of minor first aid injuries for a worker in their trade. Interviewees were provided with a definition of the injury severity level (e.g. minor first aid injury) and were asked to rate frequency in units of time such as number of days, weeks, months or years. To ensure complete data and accurate estimates, they were asked to rate the frequency of multiple severity levels ranging from negligible to fatality. Once the risk perception values were defined, workers were asked to rate the frequency that would be *acceptable* for each of the severity levels using similar units of time. These values are taken to represent the workers' risk tolerance. A copy of the interview form used to quantify risk tolerance is provided in Figure 1. It should be noted that the definition of 'medical case' used in this study differed slightly from traditional use of the term and was changed based upon feedback provided by the interviewees.

In total, 83 workers and managers representing nine firms were interviewed in half-hour sessions. Owing to the complex nature of the questions and the sensitivity of the data, some individuals preferred not to respond or felt as if their responses would be inaccurate as their response would be no more than a guess. Of the 83 original participants, 51 provided complete information and were confident with their responses. Only the

SAFETY PERCEPTION SURVEY - WHAT IS ACCEPTABLE?

Interviewer ID: ____________	
Project ID: ____________	
Interviewee ID: ____________	
Contact information for Project Manager: ____________	

From the severity level below, please indicate the ACCEPTABLE time between incidents FOR YOUR TRADE. For example, how long SHOULD it take, on average, for an injury to happen where someone had to seek minor first aid? These responses should indicate the level of safety risk that you are willing to take as part of your work.

Severity	Description	Acceptable duration between incidents (i.e. 1 incident per every _____)
Near miss	Incident that does not result in harm to a worker	
Negligible	Incident that results in extremely minor (mostly unnoticeable) injury	
Temporary discomfort	Incident that resulted in temporary discomfort (one workday or less) but does not prevent the worker from functioning normally	
Persistent discomfort	Incident that resulted in persistent discomfort (more that one workday) but does not prevent the worker from functioning normally	
Temporary pain	Incident that resulted in temporary pain (one workday or less) but does not prevent the worker from functioning normally	
Persistent pain	Incident that resulted in persistent pain (more than one workday) but does not prevent the worker from functioning normally	
Minor first aid	Incident that required minor first aid treatment. The worker may not finish the workday after the incident but returns to work within one day	
Major first aid	Incident that required major medical treatment (worker returned to regular work within one day)	
Lost work-time	Incident that resulted in lost time (worker could not return to regular work within one day)	
Medical case	Incident that resulted in significant medical treatment and resulted in lost work time (worker could not return to regular work within one day)	
Permanent disablement	Incident that results in an injury that causes permanent disablement	
Fatality	Incident that results in the death of a worker	

Figure 1 Sample interview form

complete data obtained from the 51 individuals were analysed to determine the statistical significance of comparisons as it was believed that it represented the highest quality sample. Partial responses from the remaining 32 respondents were not included in any analyses. While all 51 participants worked and resided in the Pacific Northwest region of the US, over 40% of the interviewees indicated that they have worked outside the region and that the work conditions were similar regardless of geographical location. Therefore, it is expected that the scope of inference may extend beyond the convenience sample. During the sampling and subsequent statistical analyses of data, Ramsey and Schafer (2002) were used for guidance.

In addition to interviewing workers and lower-level managers (e.g. labourers, crew leaders and foremen), at least one upper-level manager and/or safety managers were interviewed using the same structured surveys. These managers were supervisors and policy-setters in each of the nine firms. In addition to providing their risk perceptions, these managers confirmed their management role with respect to construction safety and health (i.e. directing the safety programme and setting company safety and health policies). Alternatively, workers were defined as employees of the construction firm who have no managerial responsibility for other workers on site.

The reader should note several limitations of these research methods. The original database of contacts was selected in the Pacific Northwest in a non-random fashion. Therefore, the scope of inference cannot be statistically extended to a greater population. However, as indicated previously, the majority of workers interviewed were previously employed in other regions in the United States. Additionally, there is no evidence that indicates that the Pacific Northwest represents a special population. Therefore, there is a theoretical, but not statistical, justification for extending the inferences beyond the firms interviewed. Second, only firms agreeing to participate were included, perhaps biasing the results. Finally, these research methods operate under two fundamental assumptions: (1) workers are capable of identifying the risk level in their work environment; and (2) workers are capable of identifying their own risk tolerance. If either of these assumptions were to be false, the quality of the data presented would be compromised. Discussion of limitations is continued in the conclusions section.

Results

Firms representing the following nine trades were represented: plumbing subcontractors; electrical subcontractors; formwork carpenters; suppliers; roofers; excavators; framers; excavation support system specialists; and cast-in-place concrete specialists. Multiple crafts were included in an attempt to include a diverse sample that represents the major crafts in the American construction industry.

In total, 51 individuals were interviewed. Forty-two of the interviewees were classified as labourers and lower-level managers and nine were classified as upper-level managers. One upper-level manager was interviewed from each firm (nine total). Employees responsible for managing multiple crews with a title of superintendent, project manager, safety manager, vice president of operations, etc. were classified as upper-level managers. Alternatively, employees responsible for managing small crews or with no management function such as foremen, crew leaders, tradesmen, journeymen, labourer, etc. were classified as labourers and lower-level managers. While there is a significant range in experience, the interviewees averaged 18 years in construction, 7 years with their current employer, and 14 years in their respective trades. Other demographics include the following:

- 36 (68%) are currently married;
- 47 (89%) have children;
- 10 (19%) have sustained an occupational injury that required more than first aid treatment;
- 12 (23%) have viewed an incident where a co-worker was injured more severely than a first aid injury.

Detailed information about the interviewees' backgrounds was not solicited.

When soliciting frequency values, workers were asked to define the frequency of accidents that they would expect to experience when conducting their regular work tasks. These frequency values were defined by the workers in a variety of units ranging from hours to years. In order to compare responses, each worker's frequency ratings were converted into worker-hours. These adjusted values are summarized, by severity level, in Table 2. This table includes the perceived current risk and risk tolerance defined in terms of worker-hours (w-h). The table also illustrates the subjective severity scale adapted from Hallowell (2008) and the calculated perceived actual risks and acceptable risks (S/w-h). For clarity, unit risk values are multiplied by a factor of 100.

The descriptive statistics resulting from the interviews can be found in Table 3. This table summarizes the vital statistics of the data including the number of respondents, the minimum, median, mean and maximum unit risk values (S/w-h). One will note that this table distinguishes between low severity risks and high severity risks for both the current perceived risk and risk tolerance. Here, low severity risks are defined as injuries that range from negligible to minor first aid injury and high severity risks are defined as major first aid injuries through fatality. These cut-off points were used because these values typically define the boundary between what is OSHA recordable (high severity) and those injuries that are not OSHA recordable (low severity). These values were separated because little is known about the low severity risk levels and the high severity risk values, especially fatalities and lost work time injuries can be compared with archival data.

As seen in Tables 1 and 2, the perceived current risk is greater for high severity risks than for low severity risks and workers have a much lower tolerance for high severity risks. Furthermore, the mean perceived current risk is approximately five times higher than the mean risk tolerance. It should be noted that Tables 2 and 3 both represent an aggregation of worker and manager data.

Figure 2 illustrates the residual risk for the various severity levels. *Residual risk* is defined here as the difference between perceived actual risk and risk tolerance in units of S/w-h. The writer uses this term to describe the risk levels that are above and beyond tolerable levels, which is consistent with Rae (2007).

Table 1 Risk perceptions (S/w-h)

Severity level	Relative severity	Perceived current frequency	Acceptable frequency	Perceived actual risk	Acceptable risk
	(S)	(w-h)	(w-h)	(S/w-h × 100)	(S/w-h × 100)
Negligible	1	36	42	2.8	2.4
Temp. discomfort	2	65.8	168.8	3	1.2
Persistent discomfort	4	75.7	284.1	5.3	1.4
Temp. pain	8	37.3	207.7	21.5	3.9
Persistent pain	16	104.1	312.4	15.4	5.1
Minor first aid	32	132.2	340.7	24.2	9.4
Major first aid	64	367.5	748.5	17.4	8.6
Lost work time	128	715.6	828	17.9	15.5
Medical case	256	918	1115.6	27.9	22.9
Permanent disablement	1024	2606.4	NEVER	39.3	0
Fatality	26 214	608 300	NEVER	43.1	0

Table 2 Descriptive statistics for risk perceptions (S/w-h)

	Perceived current risk			Risk tolerance		
	Low severity risk	High severity risk	Total risk	Low severity risk	High severity risk	Total risk
Number	51	51	51	51	51	51
Minimum	0.004	0.004	0.004	0.000	0.000	0.000
Median	0.044	0.158	0.107	0.024	0.027	0.026
Mean	0.188	0.534	0.344	0.083	0.057	0.067
Maximum	1.975	10.741	4.111	1.703	0.797	0.811

As one can see, these values are not consistent among severity levels. In fact, the residual risk value for fatalities (4.309 S/w-h) was an order of magnitude higher than the other severity levels and had to be omitted from Figure 2 so that the differences among other severity levels remained readable. A comparison of residual risk illustrates the areas where targeted improvement is necessary. Reduction in fatalities and disabling injuries is, of course, the primary target area and has traditionally received much attention. Temporary pain, persistent pain and minor first aid injuries receive far less attention, however, despite the relatively high residual risk.

Analysis

In an effort to evaluate the difference between the worker's risk perceptions of actual conditions and their risk tolerance, the author conducted a statistical comparison. To provide a more complete understanding of the differences between perceived actual risk and

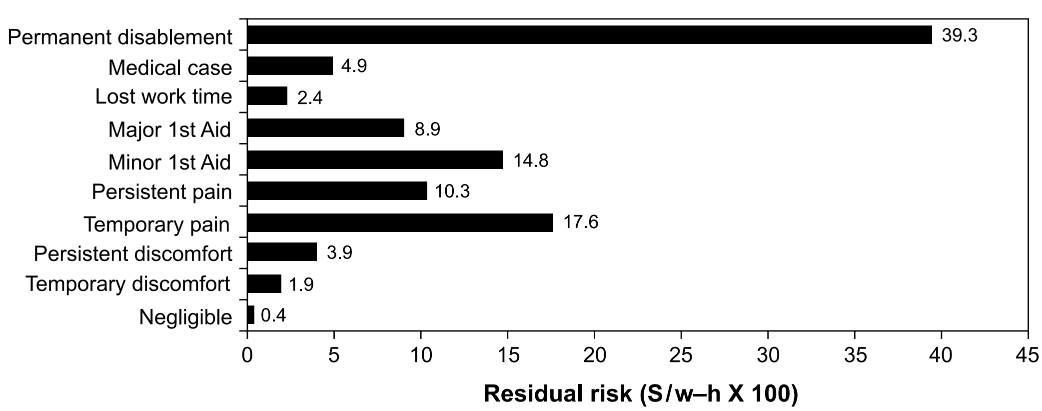

Figure 2 Residual risk (S/w-h × 100)

risk tolerance the low severity, high severity and total risk ratings were individually compared. The Wilcoxon signed rank test was chosen for these comparisons because it is distribution-free (Ramsey and Schafer, 2002). The Wilcoxon signed rank test was selected because the samples were:

- paired;
- approximately normal;
- independent; and
- did *not* have equal sample variances (p-value < 0.05 for the F-test for each comparison).

The downside of this statistical test is that confidence intervals cannot be created with the transformed data in most statistical software packages.

As one can see from the statistical tests summarized in Table 3, there is strong evidence for a difference in the sample means between perceived actual risk and acceptable risk for total risk ($p = 0.0001$), high severity risk ($p < 0.0001$), and low severity risk ($p < 0.0001$). In fact, the actual total risk is, on average, five times (0.289 S/w-h) greater than the tolerable risk level. When evaluating the differences in risk tolerance between managers and workers, a different statistical test was used. Because the samples were unpaired and did not have equal variance, the Wilcoxon rank sum test was utilized. The results of the test indicated that workers, on average, have a risk tolerance that is 0.0044 S/w-h greater than that of managers (p-value = 0.14).

To further understand the factors that may contribute to one's risk tolerance several linear regression analyses and statistical comparisons were made with demographic data. Linear regression analyses were conducted to test for relationships between risk tolerance and age, years with current employer, years in the construction industry, and years with current employer. Surprisingly, the results showed that there were no statistical correlations (r-squared < 0.75) for these personal characteristics. Furthermore, two-sample comparisons of workers with a spouse, offspring, and exposure to high severity injuries all indicated that there is no statistically significant difference in risk tolerance when compared to those workers that are unmarried, have no children, or have not seen a high severity injury ($p > 0.20$). In fact, the only demographic element that resulted in a statistically significant difference was a comparison of those workers that had been injured with those that had not ($p = 0.068$). These workers, however, had a risk tolerance that was, on average, 0.0169 S/w-h (25%) greater than that of workers that had not been injured.

Table 3 Statistical comparisons

Comparison/correlation	Statistical test	Statistical strength	Conclusion	Difference in sample means (S/w-h)
Perceived risk: high severity v. low severity	Wilcoxon signed rank	p = 0.0001	Strong statistical evidence	0.372
Perceived v. tolerance (total)	Wilcoxon signed rank	p = 0.0015	Strong statistical evidence	0.298
Perceived v. tolerance (high severity)	Wilcoxon signed rank	p < 0.0001	Strong statistical evidence	0.499
Perceived v. tolerance (low severity)	Wilcoxon signed rank	p < 0.0001	Strong statistical evidence	0.102
Tolerance: comparison non-injured v. injured	Wilcoxon rank sum	p = 0.068	Strong statistical evidence	0.0169
Tolerance: labourers and lower-level mgt. v. upper mgt./safety mgrs	Wilcoxon rank sum	p = 0.14	Moderate evidence	0.0044
Tolerance: correlation with age	Single-variable linear regression	r-squared < 0.75	No correlation	NA
Tolerance: correlation with years with current employer	Single-variable linear regression	r-squared < 0.75	No correlation	NA
Tolerance: correlation with years in industry	Single-variable linear regression	r-squared < 0.75	No correlation	NA
Tolerance: comparison children v. no children	Wilcoxon rank sum	p > 0.20	No significant difference	NA
Tolerance: comparison exposure to high severity injury v. no exposure	Wilcoxon rank sum	p > 0.20	No significant difference	NA
Tolerance: comparison spouse v. no spouse	Two-sample t-test	p > 0.20	No significant difference	NA
Perceived risk: labourers/low-level mgrs v. upper-level mgrs/safety mgrs	Wilcoxon rank sum	p > 0.20	No significant evidence	NA

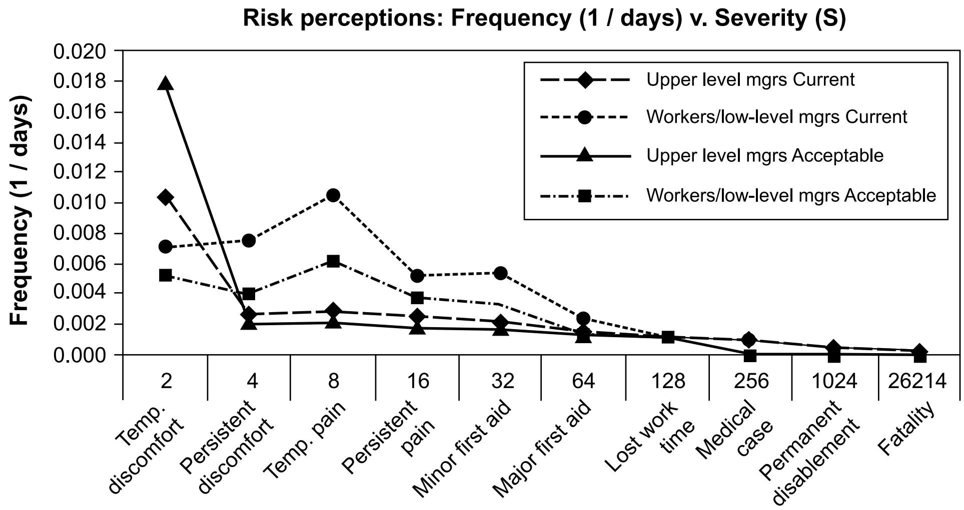

Figure 3 Trends in risk perceptions

In addition to the findings of the statistical tests, several trends can be observed in Figure 3.

Summary and conclusions

The construction industry faces many construction safety problems such as disproportionate injury rates, the lack of complete safety and health risk data, and frequent incidents resulting from safety violations. To study these topics, risk perceptions were gathered from managers and workers of 22 different construction firms and nine different trades in the Pacific Northwest.

The results indicate that there are several safety issues that should be recognized and addressed by management. The first issue that should be recognized is the high level of dissatisfaction represented by the high level of residual risk. Since residual risk is determined by subtracting the level of tolerable risk from current perceived risk, the residual risk value can be used as a measure of satisfaction with current conditions. The data indicate that the workforce in the Pacific Northwest is most dissatisfied with the rate of moderately severe injuries (persistent pain and first aid injuries) and with extremely severe injuries (permanent disablement and fatalities). With the exception of having been injured on the job, personal characteristics of the interviewees had no impact on their risk perception or risk tolerance. This confirms the findings that there is homogeneity of risk perspectives within organizational levels as reported by Zohar (2000).

The results also support the findings of previous research that indicate that managers and workers do not tend to share the same safety perceptions (Lee, 1998; Collinson, 1999; Harvey *et al.*, 1999; McDonald *et al.*, 2000; Smallwood and Haupt, 2005). The statistically significant difference between the risk tolerance of managers and that of the workforce observed indicates that, not only do workers have different attitudes towards safety rules as observed by Bailey (1997), workers and managers also have differing perceptions related to the actual level of acceptable risk (i.e. how often accidents should happen). This difference indicates that the safety and health vision of the management, which is often manifested through safety policies and standards, is not shared by the workers in the sample. This difference provides evidence that the safety culture, defined as shared norms and values among all employees in the firm, is weak in this sample of the construction industry (O'Toole, 2002; Gill and Shergill, 2004). Furthermore, this difference may help to explain the relatively high rate of incidents that result from routine violations of safety rules as observed by industry practitioners. While the data presented here cannot be used to draw causal conclusions, there is a strong theoretic basis that supports the fact that many routine violations of safety rules and safety policies are caused by workers that do not share the safety vision set by management.

There are several limitations that should be noted. First, the sample should be considered a convenience sample. Thus, the scope of the inferences made cannot be statistically generalized to a greater population and the findings may not apply to all firms, especially those with a strong culture of safety or very low incident rates. Second, the research methods operated under the assumption that workers and managers are equally capable of making judgments related to current and acceptable risk levels. If this does not hold true, the statistical difference may represent a difference in ability to perceive risk. Finally, the sample involved trade contractors with an annual revenue greater than US$10 million. Therefore, the scope of inference cannot be extended to very large or very small contractors. Finally, the research team did not collect information related to the injury prevention efforts implemented for each firm. While this is unlikely to affect the results presented, it does limit the scope of inference and direct translation of results.

It should also be noted that data were collected in a time period when the economy was strong in the Pacific Northwest and construction work was plentiful. In this environment, workers generally have less fear of losing their jobs due to violations. That is, in a strong economic climate, workers have less fear of losing their jobs due to a violation (e.g. not wearing required personal protective equipment) than in an economic climate where competition for employment is high. This may have been a factor that contributed to the difference in perception between managers and worker and may also explain why there was a high rate of violations. While the writer cannot validate this phenomenon with the research collected, the effects of economic conditions, potential for job loss, and management's safety priorities should not be ignored as a potential alternative explanation that may impact on the internal validity.

Implications and recommendations

The findings presented here can be used by construction managers and researchers to improve awareness of current conditions, identify areas where improvement is needed, and to better understand the perceptions of the workforce. Despite the fact that the sample size was moderate, the data and analyses summarized provide the construction industry with a better understanding of the current level of risk and the level of acceptable risk as perceived by workers. Also, the data indicate that more attention should be paid to high severity and moderately severe injuries as the current level of perceived risk is over five times as high as the tolerable risk level.

The findings can also be used for goal setting. Despite the pervasive zero injury goal promoted by the Construction Industry Institute (CII) and OSHA, safety risk in construction cannot be reduced to zero. This assumption is supported by a great deal of literature including Lowrance (1976, p. 8), who states,

> Nothing can be absolutely free of risk. One can't think of anything that isn't, under some circumstances, able to cause harm. Because nothing can be absolutely free of risk, nothing can be said to be absolutely safe. There are degrees of risk, and consequently there are degrees of safety.

While achieving zero risk is not possible in the construction industry, it is vitally important to set high goals and maintain continuous improvement. The author suggests that realistic intermediate safety goals can be set that focus on minimizing residual risk. The quantification of residual risk could also be used to guide resource allocation and to focus safety programme elements.

Areas of future studies may build upon and improve the data and analyses provided by further investigating the factors that influence construction safety culture, to incorporate elements of social psychology to reduce the risk tolerance of the workforce and to promote safe behaviour, and to further investigate the potential link between risk tolerance, worker behaviour and culture. Other research areas include investigating the motivators of safe work behaviour and their relationships to risk tolerance and management strategies. Furthermore, the author suggests replication of this study in other regions of the US and across the world to enhance the scope of inference of these conclusions.

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