Individual safety and health outcomes in the construction industry

Brenda McCabe, Catherine Loughlin, Ramona Munteanu, Sean Tucker, and Andrew Lam

Abstract: Between 2004 and 2006, 911 self-administered questionnaires were collected from 84 nonresidential Ontario construction sites. Each questionnaire contained 105 questions and took approximately 15 min to complete. This paper presents one study from that research project that seeks to understand the relationship among worker demographics, worker safety attitudes, and worker health and safety outcomes (e.g., worker well-being and accidents). The participants had an average age of 38.3 years with 15.1 years experience in the industry. Short job tenure, age, experience, and job position were highly related to safety outcomes. Apprentices experienced more accidents, whereas supervisors reported more work-related psychological symptoms. Among the situational factors, higher work pressure, high interpersonal conflict, and low-quality leadership were most strongly associated with work-related health outcomes and accidents. Regression models were developed with a maximum adjusted coefficient of determination of 0.28. A graphical means of modeling the data was demonstrated in the form of a Bayesian belief network.

Key words: attitudes, safety, construction, Bayesian network, regression.

Résumé : Entre 2004 et 2006, 911 questionnaires à remplir soi-même ont été collectés de 84 sites de construction non résidentielle en Ontario. Chaque questionnaire contenait 105 questions et prenait environ 15 minutes à remplir. Cet article présente une étude basée sur ce projet de recherche qui visait à comprendre la relation entre les données démographiques des travailleurs, les attitudes des travailleurs envers la sécurité et les impacts sur la santé et la sécurité des travailleurs (p.ex. mieux-être des travailleurs et accidents). L'âge moyen des participants était de 38,3 ans et ils possédaient 15,1 années d'expérience dans l'industrie. Une faible ancienneté, l'âge, une faible expérience et le poste était tous grandement reliés aux résultats en sécurité. Les apprentis subissaient plus d'accidents, alors que les superviseurs rapportaient plus de symptômes psychologiques reliés au travail. Une plus grande pression au travail, de forts conflits interpersonnels et un faible leadership constituaient les facteurs circonstanciels les plus fortement associés aux résultats en santé reliés au travail ainsi qu'aux accidents. Des modèles de régression ont été développés en utilisant un coefficient de détermination maximum ajusté de 0,28. Une modélisation graphique des données est présentée sous forme d'un réseau de croyances.

Mots-clés : attitudes, sécurité, construction, réseau bayésien, régression.

[Traduit par la Rédaction]

Introduction

The construction industry in Ontario, Canada, is a world leader in both safety standards and safety results (CSAO 2004*a*). This is largely attributed to the support offered by government boards and employer associations that actively involve themselves in improving safety. Although a downward trend in construction fatalities is evident from 1966–2004 (Fig. 1), a spike in 2003 was a significant concern to the government, employer associations, unions, and frontline workers. There were 30 deaths reported in the Ontario construction sector in 2003, up 58% from 2002 (CSAO 2004*a*). Because it is commonly accepted that deaths represent the tip of the iceberg in terms of workplace safety, concern is justifiable.

Bird (1974) proposed that for each major injury (including both fatalities and critical injuries) there may be as many as 600 near-misses (Fig. 2). Data in the Ontario construction industry would seem to support this proposition; among the 396 000 workers in this industry (CSAO 2005) there were 20 deaths. That same year, the Workplace Safety Insurance Board [WSIB (2005*a*)] of Ontario reported that there were almost 5600 lost-time injuries. This represents a significant cost to workers, organizations, and society and suggests that it may be time to begin paying closer attention to "micro accidents" or "near-misses" that are likely to lead to injury and (or) death in this industry.

This paper presents one study from a major research project that seeks to understand some of the individual (e.g., personality) and situational (e.g., quality of supervision) correlates of three work-related health and safety outcomes in

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B. McCabe,[1] R. Munteanu, and A. Lam. Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON M5S 1A4, Canada.
C. Loughlin. Sobey School of Business, Saint Mary's University, Halifax, NS B3H 3C3, Canada.
S. Tucker. School of Business, Queens University, Kingston, ON K7L 3N6, Canada.

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[1]Corresponding author (e-mail: brenda.mccabe@utoronto.ca).

Fig. 1. Fatalities per 100 000 workers (adapted from CSAO 2004*a*).

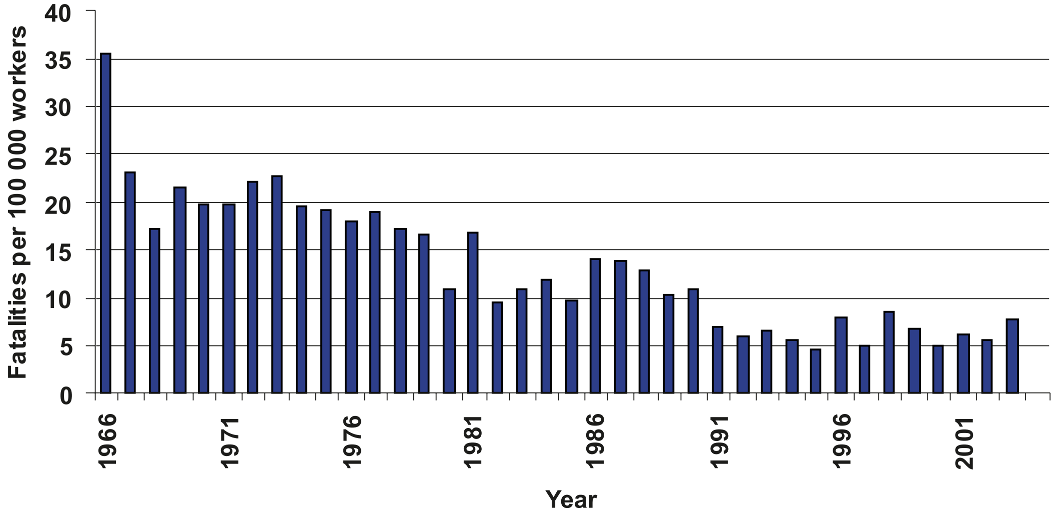
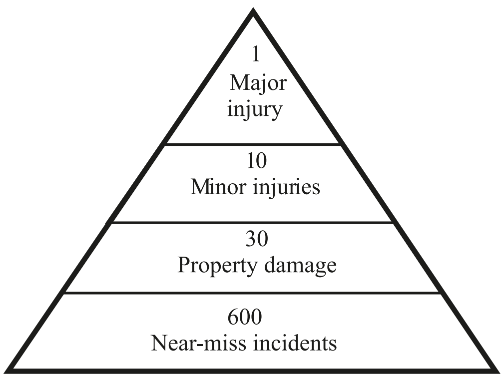


Fig. 2. Incident pyramid (Bird 1974).



the construction industry. These outcomes include the prevalence of work-related accidents as well as psychological and physical symptoms. A unique contribution of this study is that we use two distinct approaches — multiple linear regression models and a Bayesian belief network — to analyze our data and explore these relationships. We also contribute to the literature by adding a data point to safety research in the construction industry, by investigating incidents likely to lead to injury in addition to accident outcomes.

Literature review

Research has shown that occupational health and safety outcomes are related to both individual and situational factors (Barling and Frone 2004). We discuss each category separately beginning with individual factors. Table 1 summarizes the relationships between the individual and situational factors and the three safety outcomes (i.e., prevalence of work-related accidents, psychological symptoms, and physical symptoms). Because so few of these relationships have been studied in the construction industry, we make no prediction about the relative strength of each of these factors; instead, we treat strength as an empirical question.

Individual factors

The current study analyzes four individual predictors of accidents and well-being: age, conscientiousness, safety consciousness, and fatalism. Several studies have shown that younger workers are more likely to be injured on the job than older workers (Loughlin and Frone 2004; Salminen 2004), and nationally representative studies suggest that psychological health generally improves with age (Korten and Henderson 2000). Research has shown that two personality variables, conscientiousness — defined as the degree that someone is careful and mindful when doing tasks — and safety-specific conscientiousness, are negatively correlated with both workplace injuries (Clarke and Robertson 2005; Kelloway et al. 2006) and physical health (Grant and Langan-Fox 2007), but not related to psychological health (Miller et al. 1999). The relationship between fatalism (defined as the feeling that external forces have more influence over one's own safety) and accidents remains unclear (Harrell 1995); however, studies suggest that fatalism is negatively related to psychological well-being Daniels and Guppy (1997); Danna and Griffin (1999).

Situational factors

Safety research has moved from a focus on individual workers toward workplace factors, with a growing emphasis on systems approaches (considering the influence of work groups on individual safety). Cooper (1998) defined work attitudes as psychological constructs that describe how people consistently think, feel, and behave toward a particular object. Attitudes are socially constructed because people tend to internalize the views and opinions of persons close to them, such as their co-workers or supervisors.

Numerous scales measure safety climate (Zohar 1980; Shannon et al. 1997; Williamson et al. 1997; Glendon and Stanton 2000). No single measure of safety climate is consistent across industries (Coyle et al. 1995), although several underlying themes have been identified, including management and supervision, safety system, risk perception, work pressure, attitudes regarding skill level, qualifications, and job knowledge (Flin et al. 2000; Vredenburgh 2002).

Only two papers pertaining to safety climate in the construction industry are widely recognized (Dedobbeleer and Beland 1991; Glendon and Litherland 2001). Factors influencing safety climate are thought to be dependent on loca-

Table 1. Summary of literature review.

	No. of physical symptoms	No. of psychological symptoms	No. of incidents–accidents
Individual factors			
Age	+	–	–
Conscientiousness	–	0	–
Safety consciousness	–	0	–
Fatalism	0	+	?
Situational factors			
Factors affecting safety climate:			
Coworker safety perception	0	–	?
Supervisor safety perception	0	–	?
Management safety perception	0	–	?
Safety program perception	0	–	?
Job safety (low risk perception)	–	–	–
Unionization	0	?	?
Leadership	–	–	–
Job involvement	0	-	0
Interpersonal conflict at work	+	+	0
Work pressure	+	?	+
Role overload	+	+	+

Note: +, positive relationship; –, negative relationship; ? conflicting findings; 0 no relationship or unknown. Definitions of "incidents–accidents" vary in the literature and this will influence findings.

tion (Gadd and Collins 2002). This may be one reason why there are so few studies pertaining to the safety climate in the construction industry, as the "workplace" is continuously changing. Perhaps most importantly, the temporary nature of the physical workplace may not allow a safety climate to be established. This study attempts to examine safety climate in this unique, sometimes dangerous, work environment.

Safety climate, defined as the shared perceptions of safety practices and policies among co-workers, supervisors, and management, has been the focus of much research in the past decade (Clarke 2006). Whereas some studies find that safety climate is associated with lower injury rates, a recent meta-analytic study suggested that safety climate in general has no effect on accidents and injuries (Clarke 2006). In this study, we consider the components contributing to workplace safety climate separately (e.g., safety programs, co-workers, supervisors, management). In terms of psychological health, meta-analytic evidence suggests that workers in supportive work climates report higher psychological health (Carr et al. 2003). Relatedly, studies show that a high level of social support is related to higher psychological well-being (Lee and Ashforth 1996).

The relationship between the quality of supervision and accidents is fairly consistent, with most studies showing a negative relationship between high-quality supervisory leadership and accidents and injuries (Hinze and Gordon 1979; Hinze 1987; Barling et al. 2002; Hofmann and Morgeson 2004; Kelloway et al. 2006). Also, evidence shows that supportive and encouraging supervision (i.e., high-quality leadership) is associated with higher levels of employee wellbeing (Hinze 1981; Sosik and Godshalk 2000; Barling et al. 2005).

In terms of unionization, studies have shown that when workers experience unsafe work they are more likely to join a trade union (Barling et al. 2003). With respect to psychological well-being, the evidence is inconclusive; one study found that unionized workers experienced more worry and stress on the job than nonunion workers (Baugher and Roberts 1999). The literature suggests that union members tend to have a more realistic view of their job and consequently show less satisfaction than their nonunion counterparts (Bender and Sloane 1998). This does not necessarily mean that union members are less satisfied with their supervision, leadership or the job itself, but that they tend to be more aware of and have a means to address important issues. Baugher (2004) found that unions help workers cope with workplace hazards and give them a strong voice for their concerns, including safety issues. However, research is mixed as to whether this leads to lower injury rates (Kelloway 2004).

The evidence regarding the relationship between job involvement, defined as the extent to which one identifies with their job, and injuries is also mixed (Frone et al. 1995; Probst 2000), although high job involvement is generally associated with better psychological health (Lee and Ashforth 1996).

Researchers have not yet studied how interpersonal conflict in work groups relates to accidents. However, lower interpersonal conflict is related to lower exposure to workplace aggression (Hershcovis et al. 2007), and perhaps not surprisingly, higher levels of interpersonal conflict at work are positively related to reports of strain and physical symptoms (Spector and Jex 1998). One longitudinal study found interpersonal conflict to predict later psychological and physical health as well as work performance (Lubbers et al. 2005).

Most studies have found that work pressure, defined as the time pressure to complete tasks, is positively related to accidents, physical symptoms (Hinze and Roboud 1988; Goldenhar et al. 2003), and injury severity (Gillen et al.

Table 2. Attitudes.

Factor	Criteria	Mean	Median	Summary
F1	Conscientiousness (Goldberg 1992)	4.12	4.10	Participants generally felt they were careful and mindful when doing tasks.
F2	Fatalism (Williamson et al. 1997)	2.47	2.50	Participants disagreed slightly that they had no control over their own safety.
F3	Safety consciousness (Barling et al. 2002)	4.12	4.00	Participants believed that they are aware of relevant safety issues.
F4	Leadership (Barling et al. 2002)	3.81	3.85	There is general satisfaction with leadership's ability to influence and motivate workers.
F5	Role overload (Beehr et al. 1976)	2.32	2.00	Participants generally disagreed that excessive amounts of work are given to them.
F6	Work pressure (Glendon and Litherland 2001)	2.37	2.00	There is general disagreement that workers feel they are pressured to work overly fast.
F7	Job safety perception (Hayes et al. 1998)	2.30	2.00	There is disagreement that their job is safe.
F8	Coworker safety perception (Hayes et al. 1998)	3.46	3.50	There is a slight agreement that co-workers' behaviour is generally safe.
F9	Supervisor safety perception (Hayes et al. 1998)	3.84	4.00	There is agreement that supervisors have good attitudes and behave in a safe manner.
F10	Management safety perception (Hayes et al. 1998)	3.77	3.86	There is agreement that management has a good attitude and behaves in a safe manner.
F11	Safety program perception (Hayes et al. 1998)	3.95	4.00	There is a general agreement that safety programs and policies are useful and clear.
F12	Interpersonal conflict at work (Spector and Jex 1998)	1.84	1.71	Participants did not report many conflicts at work with co-workers and supervisors.
F13	Job involvement (1–6) (Kanungo 1982)	3.92	4.00	There is some agreement that the participant's job plays an important role in their life.

2002). In contrast, findings regarding the relationship between work pressure and psychological health are mixed (Frone et al. 1995; Lee and Ashforth 1996). In jobs where workers have more control, psychological distress is less likely (Spector 1986; Van Der Doef and Maes 1999).

Role overload, the degree to which one has too many tasks to do, has been positively associated with work-related accidents and injuries (Barling et al. 2002), and negatively related to psychological well-being (i.e., positively related to experiencing psychological symptoms) (Lee and Ashforth 1996).

Table 1 summarizes the relationships between the health and safety outcomes and the individual and situational factors discussed above. Again, we make no prediction about the relative strength of each predictor.

Research methodology

Between 2004 and 2006, data were collected from construction workers at 84 nonresidential construction sites across Ontario. Sites were identified in many ways, including reviewing construction association membership directories and building permit documents, and visiting active sites. Once permission to access the site was received, a research team went to the site to meet with the workers and collect the data. Typically, this took place during a coffee break or organized meeting (e.g., safety meetings).

The protocol required the researchers to first explain the research objectives to the workers, to emphasize that their participation was voluntary, and that their responses would only be seen by the researchers. They were first provided a consent form, which they signed and dated. As each participant completed the consent form, it was placed in a collection box and the participant was then handed the questionnaire. Once the questionnaire was complete, it too was placed in the box and the participant left the room to return to work (i.e., consent forms and questionnaires were collected separately). When all papers were collected, the research team returned with the collection box.

In all, 911 construction workers completed the self-administered questionnaires. Each survey contained 105 questions and took approximately 15 min to complete. The sampling error was ±2.7% at 90% confidence or ±4.3% at 99% confidence.

Each survey consisted of four sections: demographics, attitudes, health outcomes, and accident reporting. In addition to health outcomes, accidents, and the attitudinal scales previously discussed (Table 2), the demographic portion of the survey collected information on age, trade, years in construction, tenure with employer, number of employers and projects in the previous 3 years, hours worked per week in high and low season, job position, safety committee participation, and union membership.

Characteristics of the sample

Table 3 presents a summary of the demographic data, including the range of responses. Age was reasonably distributed across the skilled trades. Participants had a median of two employers in the previous 3 years, with median time with the current employer being 2.5 years.

Factor scales for situational and individual variables consisted of a series of statements (between four and 10) that focused on each construct (Table 2). These scales were reli-

Table 3. Responses to demographic questions.

	Responses		
Question	Range	Mean or %	Median
Age	18 to 69	38.3	38
Years in construction	0.01 to 50	15.1	14
Years with present employer	0.01 to 44	5.34	2.5
Number of construction employers worked for in the last 3 years	1 to 50	2.91	2
Number of projects worked on in the last 3 years	1 to 120	10.8	5
Average number of hours worked per week in high season	4 – 90	46.1	44
Average number of hours worked per week in low season	8 – 65	37.7	40
Served on a safety committee	Yes or no	37.8% yes	—
Member of a union	Yes or no	77.6% yes	—
Job position	Supervisor; journeyman; apprentice	26.9%; 56.3%; 16.9%	—

Table 4. Health and safety outcomes predicted.

Physical symptoms	Psychological symptoms	Incidents–accidents
Headache–dizziness, persistent fatigue, respiratory injuries, strains–sprains, cut–puncture, temporary loss of hearing, eye injury, electrical shock, dislocated–fractured bone, skin rash–burn, hernia	Lost sleep due to work-related worries, unable to concentrate on work tasks, unable to enjoy day-to-day activities, felt constantly under strain, losing confidence in self, felt incapable of making decisions	Exposure to chemicals, overexertion while handling–lifting–carrying, trap by something collapsing–caving–overturning, slip–trip–fall on same level, struck against something stationary, struck by moving vehicle, struck by falling–flying objects, contact with moving machinery, fall from height

Table 5. Descriptive statistics for health and safety outcomes.

	No.		Distribution (%)	
Outcome variable	Mean	Median	Yes	No
Physical symptoms	5.83	4	81.3	18.7
Psychological symptoms	3.57	1	54.8	45.2
Accidents	3.38	2	65.9	34.1

able and valid in previous studies, although nearly all of these previous samples did not involve construction workers. Based on published studies, we adapted items to the construction industry where necessary, and confirmatory factor analysis showed that these items related to the underlying constructs [(principal components analysis (PCA)]. Scale reliability was verified using Cronbach's alpha. Responses were scored on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), except for F13, which had a six-point scale in conformance with the original research (the responses were aggregated to determine a score for that factor).

Table 4 shows the items that measured physical symptoms, psychological symptoms, and accidents (Barling et al. 2002). Workers were asked to report the number of times they experienced each occurrence in the past 3 months (based on norms in the psychological literature, it is assumed that workers can accurately recall events in the past 3 months). It is important to note that these measures were based on previous research in other industries and no attempt was made to associate accidents with symptoms. A headache may be due to fumes, a fall or poor posture. Associating the cause with a symptom was not within the scope of this project.

Table 5 shows the health and safety outcomes experienced in the previous 3 months. Only 87 respondents out of 911 reported no symptoms or accidents, resulting in approximately 90% of the respondents experiencing at least one outcome.

To examine relationships with the outcomes experienced, the demographic factors were split into quartiles and the average outcome recalculated for each quartile (Table 6; only correlations significant at the 0.05 level are shown).

Age was negatively related to all three outcomes predicted. In particular, this data confirms that young workers experience more accidents than older workers (CSAO 2004*b*). The mean number of accidents in the 4th age quartile was approximately half of the first quartile across all outcomes. The trend between accidents and years in construction mirrored age closely. It is interesting to note that no significant relationship existed between construction experience and psychological symptoms. As workers spent more time with an employer, the physical symptoms and accidents they experienced decreased. The visible difference was between the respondents that had been with their employer for more than 7 years. Interestingly, hours per week during the high season had no relationship with physical symptoms or accidents. This may be due to the timing of

Table 6. Prevalence by demographic factors.

	Health and safety outcomes (average number)		
Factor quartiles	Physical symptoms	Psychological symptoms	Accidents
Age			
≤29	7.94	4.43	4.65
30–38	6.60	3.59	3.87
39–45	5.34	3.48	2.72
≥46	3.82	2.39	2.51
Years in construction			
≤5	7.21	—	3.88
5–14	6.27	—	3.99
15–22	5.85	—	3.32
≥23	4.50	—	2.77
Years with employer			
<1	6.57	—	4.15
1–2.5	6.36	—	4.02
2.5–7	6.46	—	3.27
≥7	4.35	—	2.45
No. of employers in 3 years			
1	5.88	—	3.08
2	4.87	—	3.20
3	6.42	—	3.59
>3	7.59	—	4.77
Hours per week, high season			
<40	—	2.69	—
40–50	—	3.57	—
>50	—	4.65	—
Hours per week, low season			
<40	3.34	—	4.01
40–50	3.21	—	3.68
>50	3.81	—	3.21
Job position			
Supervisor	4.52	5.13	2.48
Journeyman	6.33	2.89	3.69
Apprentice	7.37	4.16	4.53
Union membership			
Yes	—	3.21	—
No	—	4.81	—
Supervisors			
Union	—	4.03	—
Nonunion	—	6.99	—

the data collection. For example, if the data were not collected during the high season, then the worker's responses for the number of experienced injuries and symptoms would not reflect their experience during the high season. Supervisors reported experiencing the most psychological symptoms. Interestingly, the prevalence of psychological symptoms was also greater among the nonunion workers.

Construction workers' health

Outcome data were transformed into binary values indicating whether or not the worker experienced at least one safety or health outcome. Given the cross-sectional nature of this data, it is not possible to determine causality. The questionnaire was set up to gather data on attitudes at a particular moment and the occurrence of incidents for the previous 3 months. Therefore, in the following discussion, consideration will be given that causation could flow in either direction (from attitudes to outcomes or vice versa; workers attitudes could also be formed by their health and safety experiences).

Physical symptoms

The results in Table 7 show that workers reporting at least one physical symptom were younger, less experienced, and had shorter job tenure. Symptom rates decreased with job position, but remained high nonetheless. Those reporting a physical symptom had more negative attitudes toward their perceptions of job safety and job involvement, and reported experiencing more work pressure.

Table 7. Significant factors by physical symptom.

Factors	Physical symptom	
	Yes	No
Age (years)	37.5	41.1
Years in construction	14.4	16.7
Years with current employer	5.1	6.1
No. of employers in last 3 years	3.0	2.4
Job position		
Supervisors (%)	71	29
Journeymen (%)	80	20
Apprentices (%)	93	7
Job involvement (scale)	3.87	4.17
Job risk perception (scale)	2.24	2.64
Work pressure (scale)	2.39	2.14

Psychological symptoms

Workers reporting at least one psychological symptom were somewhat younger and worked more hours per week in the high season (Table 8). More supervisors and apprentices experienced at least one psychological symptom than journeymen. Two-thirds of nonunion workers experienced at least one psychological symptom, whereas only half of union workers did. Those reporting psychological symptoms tended to feel a bit more work overload, pressure, and conflict in their jobs (possibly related to the higher number of hours worked weekly) (Williamson et al. 1997). They also had a more negative perception of their co-workers' safety behaviour. These are not surprising findings; however, they do show the extent to which psychological problems are manifested. The number of years spent with the current employer or the number of employers in the previous 3 years do not have significant relationships with psychological symptoms.

Accidents–incidents

Table 9 illustrates that workers experiencing at least one accident in the previous 3 months were somewhat younger and less experienced, with shorter job tenure. Supervisors were almost twice as likely as apprentices to avoid any accidents. Those experiencing accidents also reported lower job involvement and job safety perceptions (equivalent to a higher perception of risk), and felt more pressure to work fast. They had less confidence in the safety commitment of their supervisors and employers, and in the ability of leadership to influence safety. Although we cannot determine causality, if one assumes accidents are predicting attitudes, it is possible that within a certain amount of time of having an accident, attitudes improve as the worker regains confidence and has a perception of control over safety. If this is the case, the supervision environment could be important in shortening this cycle. If one assumes attitudes are predicting accidents, the potential for intervention is even greater.

First analytical approach: regression

Linear regression prediction models were tested based on previous findings of significant correlations of all factors with the outcome variables. Regression was run using both "Enter" and "Stepwise" methods for introducing the independent variables in the model (normality requirements for the dependent variable were violated for all three variables and therefore, the models could be weak or unreliable).

Table 8. Significant factors by psychological symptoms.

Factors	Psychological symptom	
	Yes	No
Age (years)	36.8	39.6
Hours/week in high season	47.2	44.7
Job position		
Supervisors (%)	57	43
Journeymen (%)	48	52
Apprentices (%)	60	40
Union membership		
Yes (%)	52	48
No (%)	65	35
Coworker safety perception (scale)	3.33	3.64
Interpersonal conflict (scale)	1.98	1.66
Job safety perception (scale)	2.20	2.46
Role overload (scale)	2.47	2.09
Work pressure (scale)	2.52	2.15

Table 9. Significant factors by accident occurrence.

Factors	Accident–incident	
	Yes	No
Age (years)	36.8	40.6
Time in construction (years)	14.1	16.3
Time with current employer (years)	4.8	6.2
No. of employers in last 3 years	2.9	3.1
Job position		
Supervisors (%)	63	37
Journeymen (%)	66	34
Apprentices (%)	79	21
Job involvement (scale)	3.78	4.19
Job safety perception (scale)	2.18	2.58
Leadership (scale)	3.7	4.01
Management safety perception (scale)	3.66	3.99
Supervisor safety perception (scale)	3.73	4.05
Work pressure (scale)	2.46	2.13

For all tests, the ANOVA F-statistic was significant, showing that the correlation coefficient, R, and the regression models were statistically significant. As shown in Table 10, the best variance explanation is offered for physical symptoms (28.4% variance explained by the model), then for number of accidents (23.4%), and lastly for psychological symptoms (23%). Although these models do not explain large amounts of variance in the dependant variables, it should be noted that engineering faults typically only explain 10% of the variance in accidents (Vredenburgh 2002). Hence, these numbers could be viewed as noteworthy in comparison.

Only age and interpersonal conflict were significant across all three outcomes. Work pressure predicted both psychological and physical symptoms. Perceptions of management's attitudes toward safety predicted both psychological symptoms and accidents.

Table 10. Linear regression model predictors.

Predictor	Coefficient: No. of physical symptoms*	No. of psychological symptoms†	No. of accidents‡
Constant	17.087	–0.612	9.429
Age	–0.095	–0.043	–0.045
Years w/ employer	–0.051	—	—
Work pressure	–0.856	1.075	
Job safety (risk perception)	1.884	—	–0.618
Coworker safety	–1.254	—	—
Interpersonal conflict	0.780	1.286	1.644
Hours/week, high season	—	0.042	—
Management safety	—	–0.847	–0.649
Role overload	—	1.018	—
Safety program	—	0.947	—
Leadership	—	—	–0.781
Safety consciousness	—	—	0.595

Note: R_a^2, adjusted coefficient of determination.
*$R = 0.545$; $(R_a)^2 = 0.284$.
†$R = 0.490$; $R_a^2 = 0.230$.
‡$R = 0.499$; $R_a^2 = 0.234$.

Second analytical approach: probabilistic modeling

An alternative means of interpreting these data is through a Bayesian belief network (BN). A BN is a graphical representation of conditional dependence among a group of variables. Embedded is a probabilistic approach to determine the likelihood of occurrence of certain variable conditions based upon Bayes' theorem.

A BN consists of nodes, which represent variables, and directional arcs (arrows), which represent conditional dependence relationships between those nodes in such a way that the node at the tail of the arrow (the parent) affects the node to which the arrow points (the child). Although the interpretation of causation is not entirely accurate (causation is unidirectional, but Bayes' theorem is symmetric and bidirectional), the terms cause and effect are often used. A conditional probability is the likelihood of a state of a variable that is dependent on the state of another variable (Jensen 1996; McCabe et al. 1998). Bayes' theorem, $P(A \wedge B) = P(B|A) * P(A) = P(A|B) * P(B)$, is used to revise the probability of the state of a node depending on the evidence introduced for another variable.

Advantages of the belief network as a model are:

- Belief networks are excellent modeling environments for situations where there are conditional or influential relationships. Belief networks can integrate data and expert opinion seamlessly. Where data are missing or are not collectable, a BN may be developed using expert knowledge (Charniak 1991).
- The structure of a network is very intuitive, and domain experts do not need to understand the background theory to be able to participate in knowledge elicitation.
- The models are symmetric in that evidence can be entered at any node, and all remaining nodes are recalculated. You can find the probability of any node. There is no directional constraint on the logic once it has been developed. For example, a belief network developed for the diagnostics (called diagnostic inference) of equipment breakdowns would also provide information about the symptoms of a malfunction, given the cause of the breakdown (called causal inference) without redeveloping the network. In other words, the belief network has the inherent ability to reverse its logic.
- The model represents the processes that occur, rather than an expert's perception of the factors that are at play and their importance. Belief networks have been found to be more effective than rule-based expert systems for capturing knowledge when exceptions to the rules are too important to exclude, but too numerous to express explicitly (Chong and Walley 1996).
- Changes to the model are isolated to the nodes that physically adjoin the changes in the network.

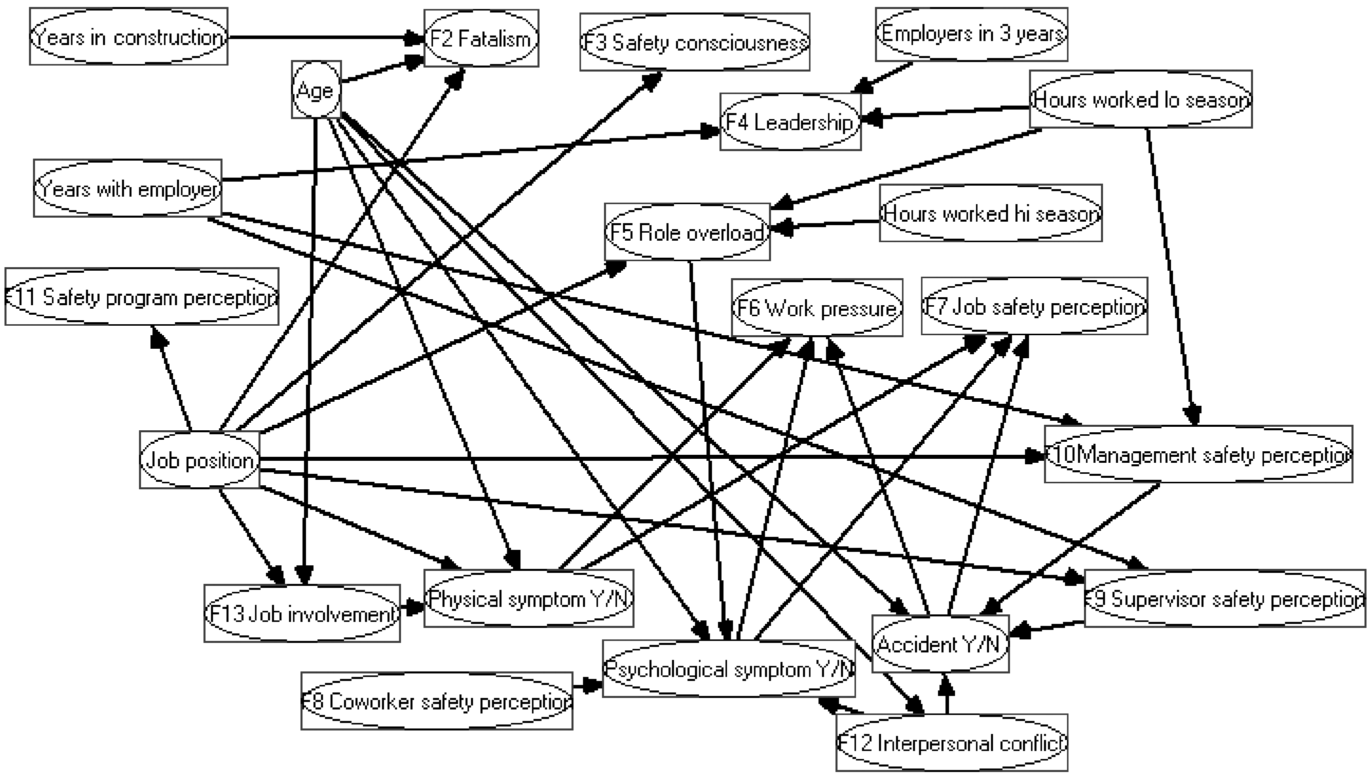
The limitations of belief networks are:

- The difficulty of collecting data and (or) expert knowledge in a consistent and unbiased manner, and translating it to nodes, arrows, and probabilities.
- Networks cannot handle continuous variables under today's technology, but that is slowly changing.

Based on the data collected, a probabilistic model shown in Fig. 3 was developed. Microsoft Belief Network version 1.001 was the modeling environment software. The network has 21 variables and 36 connections. The connections were based on the strength of the correlation and were limited to three parents per variable with the exception of accident and psychological symptom, which have four parents.

Job position and age have the most influence in the network, with connections to eight and six variables, respectively. Several attitudinal factors did not relate to outcomes. Note that work pressure and job safety perception are children (and not parents) of the outcome variables. They were modeled this way for two reasons. First, these attitudinal factors did not have demographic parents, i.e., no demographic variables had sufficient correlation with these two factors to identify them as a parent. Attitudes are often a re-

Fig. 3. Probabilistic model.



sult of experiences and environmental influences, and it may have been odd to model them as orphans (i.e., no parents). Second, turning the arrows around reduced the number of parents on the incident variables. Given the symmetry of Bayes' theorem and the relative simplicity of the model, this should not affect its performance or logic.

Six variables were not included in the model; namely, number of projects in the previous 3 years, union membership, safety training, safety committee, trade, and conscientiousness. Their relationships to the other variables were not strong enough to warrant inclusion, and removing them did not affect model performance. Joint probability tables were extracted from the collected data. The conditional probabilities were checked for accuracy relative to the data, as shown in Table 11. The difference between the data and the model is less than 5% in all cases.

To verify the model, several cases were developed that may represent a common scenario. Each case was tested, and the likelihood of experiencing an incident was evaluated by the network (Table 12). Cases G and H represent opposing attitudes toward interpersonal conflict, the safeness of their job, and their management's safety awareness. Changes in attitude from negative to positive represent a 25% decrease in accidents and 12% decrease in physical symptoms!

Alternatively, we can look at the impact other factors have on attitudes, as shown in Table 13. Here we see that workers have three times the likelihood of feeling work pressure if they experience incidents than if they do not. They are twice as likely to have good job-safety perception if they do not experience an incident, and twice as likely to feel role overload if they have physical and psychological symptoms.

In summary, this model provides a novel way of interpreting the data and allows users to determine the effects of combinations of changes on the sample data. Relationships between variables are shown both qualitatively (by graphical connection) and quantitatively (by probabilities).

Conclusions

The aim of this research was to document relationships between demographics, attitudes toward safety, accidents, psychological, and physical health of Ontario construction workers. In terms of the demographic and individual predictors that related to accidents, psychological, and physical health, what we did not find is perhaps as significant as what we did find.

Six variables on which we collected data were not included in the Bayesian network because their relationships to other variables in the network were not strong enough to warrant inclusion and removing them did not affect model performance (i.e., the number of projects worked on in the previous 3 years, union membership, safety training, participation in safety committees, trade, and (or) conscientiousness). In regard to both conscientiousness and union membership, these findings are not what the literature would predict and leave questions for future research.

The Bayesian network also allowed for an interesting insight into "profiling" who is most likely to be injured at work (Table 12, case G versus H). We see that an individual experiencing low interpersonal conflict at work who also has low perceptions of risk (high job safety) and positive perceptions of management's attitudes toward safety was about 25% less likely to have experienced a workplace accident

Table 11. Prior probability verification.

	Data (%)	BN model (%)	Difference (%)
Attitudinal factors: percentage that disagree <3			
Coworker safety perception	18	18	0
Fatalism	69	70	1
Interpersonal conflict at work	93	96	3
Job involvement	19	21	2
Job safety perception	71	71	0
Leadership	9	10	1
Management safety perception	10	11	1
Role overload	70	72	2
Safety consciousness	3	3	0
Safety program perception	6	5	1
Supervisor safety perception	7	10	3
Work pressure	72	72	0
Outcomes: percentage that experienced at least one			
Physical symptoms	81	79	2
Psychological symptoms	55	59	4
Accident – yes	66	68	2

Note: BN, Bayesian belief network.

Table 12. Verification cases.

		Amount of workers experiencing at least one: (%)		
Case	Worker characteristic	Physical symptom	Psychological symptom	Accident
A	No evidence	79	59	68
B	Age: 18–29 years	80	61	75
C	Age: 18–29 years; years with employer: 0–1; job position: apprentice	**93**	61	75
D	Age: 46–69 years; years with employer: >7; job position: supervisor	**66**	**56**	62
E	Age: 30–38 years; years with employer: 0–1	83	60	71
F	Age : 30–38 years; years with employer: >7	77	61	63
G	Interpersonal conflict: <3 low; job safety perception: >3 safe; management safety perception: >3 high	72	60	**54**
H	Interpersonal conflict: >3 high; job safety perception: <3 unsafe; management safety perception: <3 low	84	**62**	**79**

Note: Numbers in bold typeface indicate lowest and highest probability per incident category.

than someone who is experiencing high interpersonal conflict at work and also has negative perceptions of both job safety and management's attitudes toward safety.

Another way of looking at these relationships using the network is that whereas individual personality variables, such as fatalism and conscientiousness, made little difference in indicating whether or not a construction worker experienced health and safety outcomes, those experiencing at least one of each outcome were three times as likely to feel work pressure and half as likely to perceive their job as safe (Table 13).

These are interesting findings with considerable value to a human resources department trying to reduce workplace accidents. Surveying work groups on a few key variables could be enough to substantially reduce accidents on the job.

In terms of predicting health and safety outcomes using the regression models, it should be noted that engineering faults typically explain about 10% of the variance in accidents (Vredenburgh 2002). In contrast, our regression models explained between approximately 23% (for both accidents and psychological symptoms) and 28% of the variance in the dependent variables (for physical symptoms).

Two predictor variables in the regression models were significant across at least two outcomes. Work pressure predicted both psychological and physical symptoms. Perceptions of management's attitudes toward safety predicted both accidents and physical symptoms. These findings are not particularly surprising; work pressure can lead to frustration, anxiety, and depression, all of which can lead to both psychological and physical symptoms over time (Glendon and Litherland 2001; Spector and Jex 1998). These relationships also confirm previous findings in other contexts (Barling et al. 2002), demonstrating the important relationship between management's attitudes and accidents.

In terms of predicting outcomes, however, the regression models demonstrated that only the age of construction workers and the degree of interpersonal conflict at work were important in predicting all three outcomes. Younger workers

Table 13. Attitudes given incidents.

	Amount of workers (%)			
Attitudes	A: No evidence	B: Age 18–29; 0–1 yearrs with employer; at least one each: accident, physical or psychological symptom	C: Age 39–45; 2.5–7 years with employer; no accident, physical or psychological symptom	D: At least one physical or psychological symptom
Fatalism	30	28	27	31
Safety consciousness	97	97	97	97
Leadership	90	87	93	90
Role overload	28	26	**15**	**34**
Work pressure	28	**37**	**13**	29
Job safety perception	29	**24**	**46**	36
Coworker safety perception	82	78	79	80
Supervisor safety perception	89	**79**	**97**	92
Management safety perception	89	89	97	94
Safety program perception	95	94	95	94
Interpersonal conflict	4	7	7	4
Job involvement	79	78	80	79

Note: Numbers in bold typeface indicate values discussed.

and those experiencing more conflict at work had more psychological and physical symptoms as well as accidents.

Table 6 illustrated that across all three outcomes, means in the youngest quartile of workers (less than 29 years) were approximately double those in the oldest quartile (older than 46 years). This finding supports previous reports about accidents (CSAO 2004*b*) and extends this knowledge to both psychological and physical health. It also suggests where health and safety programs need to be targeted. These findings would direct contractor safety programs to focus on youth, apprentices, and short-term employees in particular.

In terms of interpersonal conflict, these findings are particularly interesting. A recent longitudinal study linked the interpersonal workplace conflict experienced by young workers in other industries to their subsequent psychological and physical health as well as work performance (Lubbers et al. 2005). To the best of our knowledge, researchers have not yet studied how interpersonal conflict in work groups relates to accidents, and our findings would appear to extend this link. Future research will want to consider the mechanism responsible for this relationship (diminished vigilance due to cognitive distraction).

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