Models for Analyzing Logging Safety

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ABSTRACT

Logging safety is a continuing problem. Developing solutions to safety problems requires an effective model of how accidents are produced by the design of logging systems. Such a model for engineering improvements must integrate human, equipment, environmental, and social factors over sufficient time to include antecedent events and management decisions which precede accidents. Various industrial safety models are reviewed and their limitations and applications to logging safety discussed.

Keywords: *Accidents, behaviour, management, models.*

INTRODUCTION

Logging is well-recognized as one of the most hazardous industries in U.S. manufacturing. In 1990, logging (SIC Code 241) reported 17.5 OSHA recordable injuries and illnesses per 100 full-time workers compared to an average of 14.2 for all durable goods manufacturing [3]. In addition to the higher incident rate, logging injuries tend to be more severe, resulting in about 2.5 times more lost workdays per incident than the manufacturing average. The occupational fatality rate for logging has been cited as 161.8 deaths per 100,000 full-time workers, one of the highest for manufacturing [15]. Statistics such as these have been the focus of popular attention in articles with titles such as: *"Is Your Job Killing You?"* [21] and *"In the Logging Woods: Proud Fatalism and Preventable Death"* [10].

While logging safety is certainly a significant problem that must be addressed, there is nothing new in these numbers. Safety problems have always existed in timber extraction. Efforts to control occupational logging accidents have been around almost as long as the industrial safety movement in the United States. In 1924 the Bureau of Standards published the *American Logging and Sawmill Safety Code*, which outlined equipment specifications and safety rules for all phases of logging [4]. Logging safety was instituted as a university course in 1946 at the University of Washington. As the passage of the Occupational Safety and Health Act approached in 1970, Pearce and Stenzel [17] noted, "the logging industry must set its industrial accident house in order or else face the prospect of operating under federal rules and regulations." In 1971, OSHA adopted ANSI Standard 03.1-1971 *Safety Requirements for Pulpwood Logging* as a federal safety standard applying to the pulpwood segment of the industry. Subsequently, the National Institute for Occupational Safety and Health (NIOSH) recommended a comprehensive Federal safety standard that would apply to all logging operations [16]. The forest industry also focused on safety issues with many trade journal articles of the 1960s and 1970s detailing safety management techniques, accident analysis methods, safety motivation, and case studies of successful operations.

Yet, after more than a half century of concern and effort to improve safety in logging, significant problems remain. Rummer [20] reviewed trends in the logging incident and lost workday rates from 1972 to 1988. While the incident rate declined by 40% during that period, the lost workday rate remained about the same (Figure 1). Even though overall safety has improved, logging continues to be one of the most hazardous occupations. This has motivated new efforts to regulate, train, and mechanize. Will these efforts bear fruit? Why does logging persist as one of the most hazardous occupations? What will be the most effective approach to improving logging safety?

Safety engineering offers a rational basis for answering such questions and developing solutions to safety problems. At the heart of engineering is a fundamental understanding of the processes and materials that are brought together in a design. Petroski [18] points out that failure (i.e., injuries) is an integral part of engineering design. Just as engineers design systems to perform an intended function, they must also intentionally design for failure. Engineers design for failure by understanding the system and selecting modes of failure based on rational decision criteria. Thus, a key prerequisite for an engineering approach to safety is an understanding of how the system fails.

Over the years, various models have been advanced to help explain safety failures in logging

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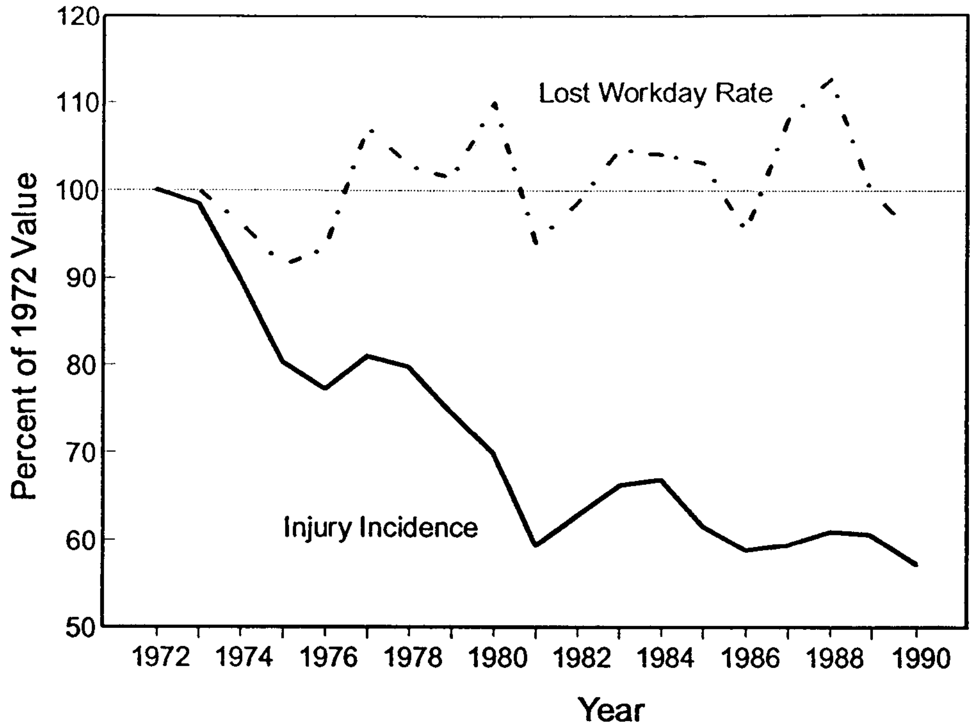

Figure 1. Trends in the incident and lost workday rates for logging (Rummer 1992).

systems. Many of these have been adapted from general industrial safety. While many of these models provide useful insights into logging safety, it is also important to understand where they fall short. The objective of this report is to review existing models of industrial safety and to describe the necessary components of an integrated model of logging safety that can be used as an appropriate context for logging safety research and logging safety engineering efforts.

LOGGING SAFETY MODELS

The Heinrich Model

An early model of accident causation was published by H.W. Heinrich in 1931. Heinrich viewed preventable injuries as the culmination of a series of events that "may be compared with a row of dominoes placed on end and in such alignment in relation to one another that the fall of the first domino precipitates the fall of the entire row" [11]. The five key factors in the accident sequence envisioned by Heinrich were : (1) ancestry and social environment, (2) personal fault, (3) unsafe act and/or mechanical or physical hazard, (4) accident, and (5) injury. Each factor depends on the preceding ones. An injury, for example, must be preceded by some kind of accident.

Based on this model, Heinrich suggested that injuries could be prevented by removing any single "domino," thus interrupting the accident sequence and preventing its completion (Figure 2). This model suggests a focus on a single factor in the accident sequence. He also identified the unsafe act of the worker as the source of 88% of industrial accidents. Consequently, accident analysis using the Heinrich model tends to centre on identifying what the worker did incorrectly.

This model has been adopted and promoted by the American Pulpwood Association (APA) and is included on the banner of APA *Safety Alerts*. A typical example of Heinrich accident analysis is outlined in *Safety Alert* 92-S-28 [2]. A cutter was working in a select cut in a mixed hardwood stand on a mild summer day (background). The 34-year old worker was very experienced and was using all proper protective equipment (personal characteristics). The worker had examined the area and flagged all hazard trees. However, he failed to notice a dead snag that had retained its bark (unsafe act). The worker

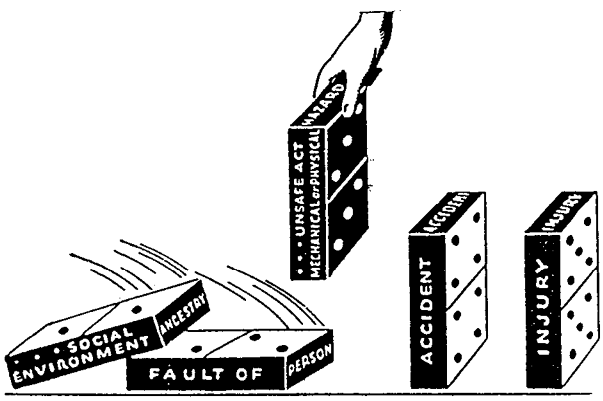

Figure 2. The Heinrich Accident Model (from Heinrich 1941)

was bucking another tree when the snag fell from behind (accident), killing him (injury). The investigation concluded that workers must check and double-check for hazard trees.

Although the Heinrich approach was generally accepted for many years and proved useful for identifying safety countermeasures, it has several drawbacks. Murphy [14] notes that the emphasis on locating a primary cause may neglect the investigation of significant underlying factors. The focus on primary cause also tends to generate a single-intervention solutions leaving safety dependent on the efficacy of a single countermeasure.

The Three E's

Another early (1916) industrial safety model envisioned safety supported by three primary components: engineering, education, and enforcement [1]. Engineering ensures that hazards are eliminated or guarded, education enables workers to understand safe methods, and enforcement guarantees compliance with safe practices. If any one of these elements is lacking, safety suffers. Initially, this approach was successful in identifying and correcting unsafe conditions. Eventually, however, the reduction in accident frequency and severity began to level off and it became apparent that there was more to safety than Three E's.

Nevertheless, logging safety efforts today look very much like the Three E approach. The proposed OSHA logging safety standard specifies engineering requirements such as seat belts, access, lockout, ROPS, FOPS, and OPS. In addition, the OSHA standard involves education by requiring general as well as job-specific safety training. Finally, OSHA will enforce the logging safety standard in order to motivate compliance with the safety provisions of the rule. Several model training programs are being developed and evaluated to determine their effectiveness in conveying safety information to loggers.

It is important to understand the limitations of the Three E model in order to assess the application of current safety efforts. Murphy [14] suggests that a key to success with this model is the degree of management control. In general industry, where specified workplaces and highly predictable processes are the norm, management selects equipment, specifies methods, and exercises relatively close supervision of the process. These managerial roles can support a Three E approach. In logging however, management (the independent contractor) has limited resources for equipment, workplaces and processes are highly variable, and individual workers exercise a high degree of self-direction. Organizationally, the small contractor will have difficulty directing a Three E effort.

In addition, an implicit assumption of this model is that even if workers know the safe practice through education, they will occasionally elect to behave unsafely. Thus enforcement is necessary. Enforcement must keep unsafe practices from becoming habits. In general industry, management can observe enough of the production operation to detect unsafe behaviour and enforce corrective actions. In logging, however, due to the dispersed work and self-direction, many employees are not directly monitored. Enforcement of safe behaviour in the woods comes on a random basis. This is especially true for OSHA inspection and enforcement: OSHA inspections will be relatively infrequent for any given worker, and citations are "enforced" against the employer rather than the employee. Moreover, the basic OSHA safety standards represent minimum acceptable safe practices.

Given the experience of general industry with the Three E approach, logging may expect some safety gains from correction of obvious hazards and renewed emphasis on safety. However, this model depends heavily on management control of workers and the work environment conditions not common to most logging work. Thus it is unlikely that a Three

E approach to logging safety will yield significant, long-term improvement.

The Behavioral Model

A more recent evolution of the focus on worker actions is the Behavioural Model [13]. Like Heinrich, behavioural accident prevention emphasizes worker actions. The premise is that most accidents are preceded by some worker action that placed the worker at risk. Thus, accidents can be prevented by reducing unsafe behaviours.

The basic scientific theory is that worker behaviour is a response to a situation (the antecedent) and is reinforced by the consequences of the behaviour. An important insight from behavioural science is that the consequences of behaviours are much more important in determining the behaviour than the antecedent that provoked the response. A well-known illustration of this is the doorbell example: We answer the doorbell because we expect to see someone there. If the doorbell kept ringing but no one was there, we would soon stop responding to it. Many logging safety efforts focus on antecedents (e.g., training, specifying safe methods). Behavioural theory suggests that these efforts will be less effective than focusing on what happens to the worker as a result of unsafe behaviour.

Another behavioural concept is that soon, certain, and positive consequences are more motivating than later, uncertain, and negative consequences. Consider the example of a worker leaving an unmarked hung-up tree during a break. The consequence "getting a longer break" is soon, certain, and positive. The consequence "boss gets onto me" is later, uncertain, and negative. A worker choosing to perform an unsafe act then executes a conscious decision based on weighing the potential consequences. Accident prevention through behaviour modification tries to alter that decision by introducing or modifying the consequences of worker actions.

Krause et al. [13] focus on management action to shift the balance of consequences. Their prescription for reducing accidents is to develop a checklist of unsafe behaviours, monitor and chart unsafe behaviour rates, and report rates to workgroups. Constant monitoring and frequent updating of the rate chart is offered as a soon, certain, and positive consequence. Cohen et al. [5] describe several industrial applications of behavioural modification for safety and note that some consequences have relatively short life-spans. For example, one firm using charting as feedback observed a dramatic increase in safe behaviour for a six-month period. However, as soon as the monitoring and charting were stopped, behaviours began to revert to the original levels.

The Behavioural Model offers valuable insight into why people act the way they do and thus is helpful in accident analysis. However, the general industrial prescription for behaviour modification is difficult to apply in logging situations. In small crews and in work situations where the workers are physically separated, the supervisor may have difficulty observing and providing effective behaviour reinforcement. As evidenced by the recidivism cited previously, safe behaviour must be constantly reinforced in order to remain effective. The challenge for logging safety specialists is to identify effective, readily available reinforcers in the logging work environment.

The Sociological Model

In the foreword to his book **Modern Accident Investigation and Analysis** (1988), Ferry offers the following quote: "Every accident, no matter how minor, is a failure of organization." This concept of industrial safety perceives accidents as primarily a product of organizational decisions and interactions. With this focus the International Labor Office (ILO) declared, "The responsibility for safety and health rests with governments, employers, and workers. However, the main responsibility rests with the employer" [12]. Workers have little control over or input into many organizational decisions that affect safety (Figure 3).

While Heinrich's model focuses on worker actions as the primary cause of accidents, the Sociological Model holds that the underlying conditions for the accident are established by management actions before the incident. Dwyer and Rafferty [7] claim that industrial social interactions related to the organization of work produce most accidents in advanced industrial nations. Their exploratory sociological investigation of accidents found that greater worker autonomy (called auto-control) in decisions regarding task structure, division and assignment of labour, and task demands was associated with reduced accident rates.

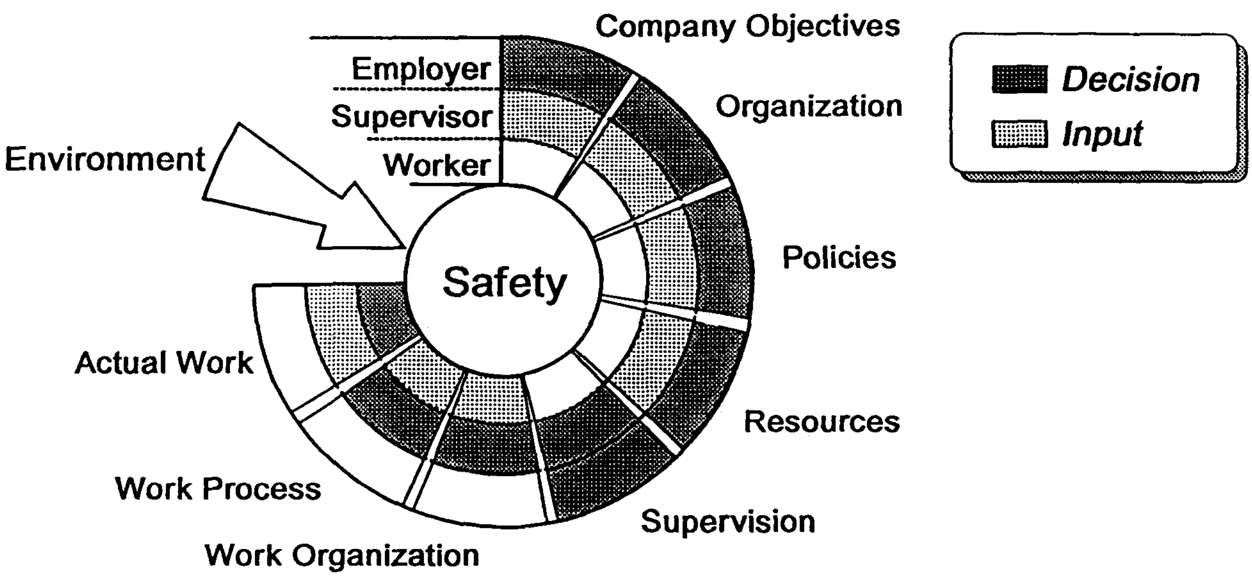

Figure 3. Organizational factors affecting industrial safety (Poschen 1993).

The Sociological Model would examine the logging accident described above and seek to identify the interactions between the injured worker and management decisions related to the job. For example, how had the cutting pattern been decided? What was the standard practice for the crew to identify hazard trees? Ferry [8] lists 15 broad categories of potential management failures that can contribute to accidents.

The Ergonomics Model

The Ergonomics Model looks at an industrial job as an integrated human-machine system. Like the Sociological Model, a basic assumption is that management makes decisions that affect the structure of the human-machine system (i.e., staffing, scheduling, output goals, capitalization). The structure of the human-machine system will in turn affect the efficiency of the conversion of inputs into outputs. Outputs of the human-machine system are both desirable (profit and product) and undesirable (scrap and injuries). Just as scrap product can result when a machine is being used for something it was not designed for, human scrap (injuries) occur when the human in the system is required to do something that is beyond human capabilities.

Safety evaluation using an ergonomics approach starts with a thorough task analysis, enumerating the individual task demands and comparing them with the range of expected human capabilities. Ergonomic problems that could lead to injury occur when job requirements exceed human limits in any of a number of areas (Figure 4). For example, a traumatic back injury can result when the job requires lifting that exceeds a worker's strength capability. Heat stress is a safety problem that occurs when environmental conditions exceed human limitations. Recent reports of cumulative trauma disorders in forest machine operators indicate job conditions that exceed the human capability to repetitively manipulate controls. Ergonomic analysis can be used reactively in accident investigations to identify causal factors. It can also be used proactively to evaluate logging system designs and job requirements before accidents and injuries occur.

The Ergonomics Model offers insight into possible accident causes that may be overlooked in con-

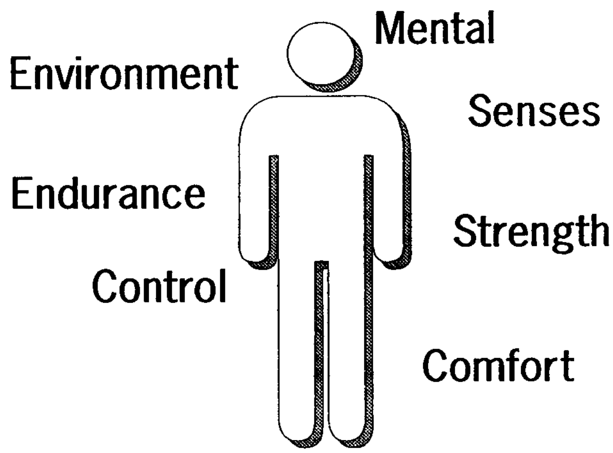

Figure 4. Classes of human capabilities.

ventional safety models. A Heinrich investigation, for example, may conclude that the worker failed to see a hazard. An ergonomic approach would extend the investigation to determine whether the perceptive requirement of the job exceeded human capabilities. Was there enough lighting? Was the hazard in the field of view? In the accident example described earlier, the worker was cited for failing to notice a dead tree that was still sheathed in bark. An ergonomist would ask, "Could the worker have actually perceived that the tree was dead?"

The Ergonomics Model is most useful in short-cycle, repetitive tasks, where the job demands can be measured with some certainty. Long-cycle tasks, such as most logging jobs, are more difficult to analyze because the range of potential job demands is much greater. The strength requirements of a chainsaw feller, for example, include moving a wide variety of limbs, short sections of logs, and odd pieces of wood. These felling-related tasks are performed in a range of postures, further complicating the strength analysis. In addition, cumulative ergonomic stressors, such as repetitive lifting, are still poorly understood. Thus, because of the variability of logging tasks and the variability in human capabilities, ergonomic analysis will not generate definitive limits, but rather broad guidance.

Haddon's Matrix

The final safety model to be considered here is Haddon's Matrix, an analysis tool originally developed to evaluate traffic safety. Murphy [14] provides a comprehensive review. The Haddon Matrix displays four primary factors (human, equipment, environment, and socio-economic) over time (Figure 5). The array is developed by considering a specific event and detailing the contributing factors that either led to or resulted from the incident. Like Heinrich, Haddon looks at a chronological series of actions in an accident sequence. However, Haddon extended the time frame beyond the accident itself, recognizing that even after an accident there are opportunities to prevent or reduce loss. For example, fire extinguishers installed on forest machines can minimize damage after a belly pan fire has started. Key to this model is minimizing loss, not necessarily preventing accidents [9]. Haddon felt strongly that an overemphasis on highway accident *prevention* had overlooked many opportunities to reduce losses during and after an accident.

In variations of the matrix, Haddon identified as many as 10 separate factors based on specific types of accidents. Crowe [6] used only three factors (man, machine, environment) to classify safety strategies for hardwood logging in Australia. Whether defined as three, four, or ten factors, Haddon's Matrix integrates several of the models described above. For example, Haddon's socioeconomic factor can be interpreted in light of the Sociological Model, while the human factor correlates with the Ergonomic Model.

A primary use of the Haddon matrix is in identifying appropriate countermeasures to prevent or minimize loss. Each cell of the matrix that specifies contributing factors also represents a potential countermeasure. For example, in Figure 5 the cell "*Post-Event/Socio-Economic*" lists "No one in range" as a contributing factor. The obvious countermeasure is to either work within hearing distance of other workers or carry a radio device to signal trouble. Similar analysis might suggest using chainsaw protective pants to interpose a barrier between the Human and Equipment cells during the Event phase to reduce losses. Considering each of the other cells could produce additional potential countermeasures.

Factors

Time		Human	Equipment	Environment	Socio-Economic
	Pre-event	Untrained, 2 yrs in woods	Chainsaw w/brake Std chain	Heavy brush Hardwood stand	Working alone
	Event	Cuts leg	Saw kicks back	Hidden limb catches saw	
	Post-event	Cries for help Bleeds to death			No one in range

Figure 5. A logging accident outlined in a Haddon Matrix.

The Haddon Matrix provides a framework for analyzing multiple-factor accidents that can be used to integrate the various models previously described. To fully incorporate the Behavioural Model, however, may require an additional time period. Haddon's Matrix considers human behaviour leading to an accident as the initial Pre-event. However, the Behavioural Model requires a step back to examine the antecedents which led to the behaviour associated with the accident. Figure 6 illustrates the example in Figure 5 expanded to include behavioural analysis. Antecedent conditions which contributed to the behaviour would be listed in the Pre-event phase. For example, a dull saw, one tree left, time pressure to complete the task, and two years of experience with no accidents would all be antecedents encouraging the unsafe behaviour of failing to sharpen the saw.

Factors

Time		Human	Equipment	Environment	Socio-Economic
	Pre-event/ Antecedent	Untrained, 2 yrs in woods	Chainsaw w/brake Std chain Chain becomes dull	Heavy brush Hardwood stand 1 tree left to limb	Working alone Crew lunchtime in 5 minutes
	Precursors/ Behavior	Fails to sharpen chain			
	Event	Cuts leg	Saw kicks back	Hidden limb catches saw	
	Post-event	Cries for help Bleeds to death			No one in range

Figure 6. An expanded matrix for an integrated safety analysis.

SUMMARY

Developing rational solutions to logging safety problems requires an understanding of how accidents are produced in logging systems. This brief review of existing safety models indicates the wide range of perspectives on this subject. All of the models described here seek to answer the same question: "Why did the accident occur?" Taken individually, the models can offer seemingly contradictory answers. By combining these disparate approaches, however, we can develop a much better understanding of how logging systems can produce accidents.

The complexity of the logging safety problem requires an integrated, multi-factor safety approach. An effective model must include analysis of the time history of the accident. Prior management decisions, personal behavioural antecedents, and existing equipment conditions clearly affect the occurrence of accidents. Social interactions at work are also important. Understanding how a task is structured, how tasks are assigned by supervisors or co-workers, and how the work environment is socially organized can provide insight to why an accident occurs. It is also important to examine human factors such as physical capabilities and limitations, risk-taking behaviour, and training. Finally, an integrated approach to safety has to consider the interactions between the human, environmental, social, and equipment factors.

The logging industry is currently trying hard to improve safety. Simply adopting general industry safety approaches for logging, however, may not prove effective. The Heinrich Model, which is currently used in forest industry, tends to overemphasize worker action while overlooking sociological, behavioral, and human factors. The Behavioural, Three E, and Sociological models are most effective in organizations with strong management structures and will have limited application in the logging work environment. Haddon's matrix applies the multifactor perspective, but may not include the necessary detail about prior conditions suggested by the behavioural approach. The limitations and appropriate applications of these models must be understood by those who use them.

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