Occupational Injuries among Construction Workers at the Chep Lap Kok Airport Construction Site, Hong Kong: Analysis of accident rates, and the association between injuries, error types and their contributing factors

A thesis presented in partial fulfilment of the requirements
for the degree of

Master
in
Aviation

at Massey University, Palmerston North,
New Zealand.

Kee Sin Yeung

2007

ACKNOWLEDGEMENTS

I would like to thank Mr. Kenny Hui (the previous director of Aviation Medical Services in Hong Kong) for allowing me utilizing the accident investigation reports for this research. In addition, I am indebted to Professor Graham Hunt (Thesis Adviser) for his precious guidance and advice in formulating, structuring and convalescing my work, Professor K.Y. Fung (Course Organiser) for his assistance in statistical processing and Dr. Andrew Gilbey (Thesis Supervisor) for his valuable opinion and supervision on the progress of my study.

CONTENTS

ABSTRACT

Accidents on construction sites are a major cause of morbidity and mortality in Hong Kong. This study investigated the likely causes of occupational injuries that were present among the construction workers during the construction of the new Chep Lap Kok (CLK) Airport in Hong Kong. In order to accumulate the requisite information, 1648 accident investigation reports in a four-year period (1993-1996) were reviewed. The first part of the study described the pattern and magnitude of occupational injuries among the CLK construction workers and compared the accident rates of the CLK workers with those of the construction industry as a whole in Hong Kong. The study examined the effects of the workplace infrastructure at CLK in order to explain why this site presented fewer work place injuries and accidents than other workplaces. The second part of the research used these injury and accident occurrences as the basis to construct the causes of accidents and injuries within an error causation classification system. The results showed that at CLK, the commonest workplace injury was contusion & crushing which appeared to be due to mistakes made through lapses in memory often caused by pressure of work being imposed on the employee. This section also indicated what types of errors were most closely associated with what kinds of injuries and what conditions were most likely to trigger these types of events. Among the major associations were links between contusion and crushing and violation error, perceptual error; between memory lapse and work pressure, equipment deficiencies, poor working environment, fatigue, and between violation error and work pressure. The research suggested that work pressure was an important contributing factor to construction injury and it increased the prevalence of a human error type namely, memory lapse many fold.

The outcomes from this study provide important new information on the causes and types of errors which have led to occupational injuries among construction workers in Hong Kong. A better understanding of the human factors-based causes of accidents and injuries in the construction industry and an inculcation of a safety culture on construction sites are critically important in the reduction of the rate of construction accidents and improvement of workers' human performance. The results should assist the construction industry in the designing accident prevention training and education strategies, estimating human error probabilities, and the monitoring organizational safety performance.

INTRODUCTION

Construction industry in Hong Kong

The construction industry in Hong Kong, where the bamboo scaffolds and iron girders meet, is very unique, particularly with regard to health and safety issues. The occupational accident and mortality rates of Hong Kong construction workers are still higher than in Western countries (Lee, 1996; Lindqvisdt, 1989; Snashall, 1990). Perhaps due to better information, instruction and training in safety issues and more enforceable local laws and regulations (Construction Site Safety Regulations, Safety Officers and Safety Supervisors Regulations, etc.), between the years 1993 and 1996, the annual accident rate per 1000 workers dropped from 294 in 1993 to 220 in 1996 (Hong Kong Government, 1993, 1994, 1995, 1996). The mortality rate per 1000 construction workers per year also reduced from 1.4 in 1993 to 0.628 in 1996 (Hong Kong Government, 1993, 1994, 1995, 1996). However, when one compares these Hong Kong figures with those from the construction industry in the United Kingdom (about 10 fatality for every 100,000 employed a year) (Snashall, 1990), the corresponding accident rates in Hong Kong are at least six times higher (Lee, 1996). The construction industry is one of the major economic pillars of the Hong Kong economy, with a workforce of 56,226 (6.0% of total full-time workforce) in 1993 (Hong Kong Government, 1993). Yet this industry accounted for more than one-third of all industrial injuries (16,573 injuries, 35.4%) and more than three-quarters of all fatal industrial accidents (80 deaths, 87.0%) in the same year (Hong Kong Government, 1993).

Construction is considered to be one of the most dangerous industries (Snashall, 1990). Many accidents and injuries happened onsite can cost human lives and a lot of human sufferings. In addition, they are enormous financial burdens to the society. The Compensation for Injured Workers Scheme, Employee's Compensation Division, Hong Kong estimated that the mean health cost per each injured worker was in the region of HK$ 10,000 and the compensation costs for loss of earning capacity and sickness absence amounted to HK$40,000 per person (Hong Kong Government, 1997). Other social costs were not included. Evidently, construction accidents and injuries must be reduced without delay as they continuously cause human lives and sufferings and are huge financial burdens to the society.

Why do construction site accidents happen?

The answer may not be as straightforward as one thinks. In the early years of the construction industry it could reasonably be said that machinery was largely responsible for the majority of construction site accidents. Similarly, early aircraft were seen to be intrinsically unsafe and were blamed for causing many accidents. However, as building machinery and aircraft became more and more reliable, humans, rather than the technology inherent in the aircraft's construction were seen to be more pivotal to the causes of aviation accidents.

In the early 1990s, the decision to build a new airport at Chep Lap Kok (CLK) in Hong Kong attracted thousands of skilled and unskilled workers from developing as well as industrialised countries. With a massive labour force, the total number of construction workers on site could be as high as 20,000 a day. The Airport Authority employed many safety consultants to provide, guidance and recommendations on how to reduce, onsite accidents and injuries. These included: compulsory health and safety (H&S) introduction course for all new recruits, adoption of occupational and H&S guidelines, deployment of a H&S team to monitor and review work environment and work processes, regular H&S meetings and reports, workshops and tool box talks, financial incentives for good H&S practices and penalties for poor H&S performers (Airport Authority, 1995). However, no formal comparative study was commissioned to investigate if these CLK workers with the alleged better training in health and safety practice systems actually resulted in fewer injuries at work, when compared to construction sites lacking in support systems

Over the past few decades there has been increasing research evidence that unsafe behaviour among human operators is one of the most pressing threats to the safety of complex technological systems. It has been estimated that human error is involved in 58% of all medical misadventures (Leape et al., 1991), 70% of aircraft accidents (Hawkins, 1993), and 80% of shipping accidents (Lucas, 1997). However, there has been far less research devoted to human factors-based causes of accidents and injuries in the construction industry, and almost no research at all in relation to Hong Kong's industry. If parallels can be drawn between adverse events in the aviation industry and construction industry then it behoves the construction industry to urgently understand what human factor issues are critically important to any reduction in the rate of these negative occurrences and how improvements to workers' human performance can be planned.

The development of the human factors concept

In recent years cognitive error models have provided insights into the unsafe acts that lead to many accidents and a variety of generic cognitive taxonomies have been used to account for errors in safety-critical environments (Senders, 1991). The major ones include the cognitive, ergonomic, behavioural, aeromedical, psychological and organizational perspectives. They all have distinct advantages and disadvantages.

From the cognitive perspective, it is assumed that the construction worker's mind can be conceptualized as essentially an information processing system. Once information from the environment makes contact with one of the senses (e.g., vision, touch, smell, etc.), it progresses through a series of stages or mental operations, culminating in a response. Wickens and Flach (1988) have described a basic model of information processing as shown in Figure 1.

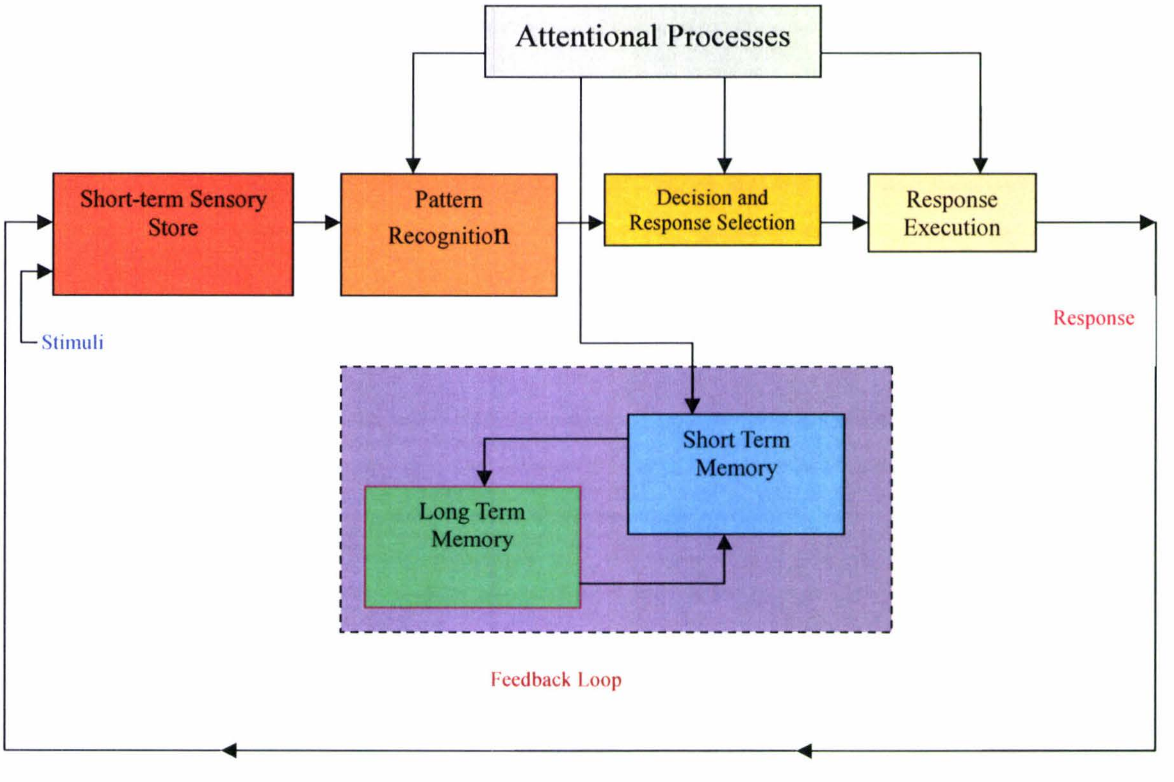

***Figure 1.* Basic model of information processing.**
Source: Adapted from Wickens and Flach (1988).

They also suggested that stimuli from environment (e.g., light or sound) are converted into neural impulse and stored temporarily in a short-term sensory store (e.g., iconic or echoic memory). Provided sufficient attention is devoted to the stimulus, information from the short term sensory store is then compared with a previous pattern held in long-term memory to create a mental representation of the current state of the world. From there, an individual must decide if the information they collected requires a response or can simply be ignored until something significant occurred. The response action taken should normally ensure the situation was resolved. If not a feedback loop would stimulate the system to make the necessary modification and an adjustment until the situation was resolved. Using this information processing mock-up, Wickens and Flach (1988) further proposed a decision-making model as displayed in Figure 2.

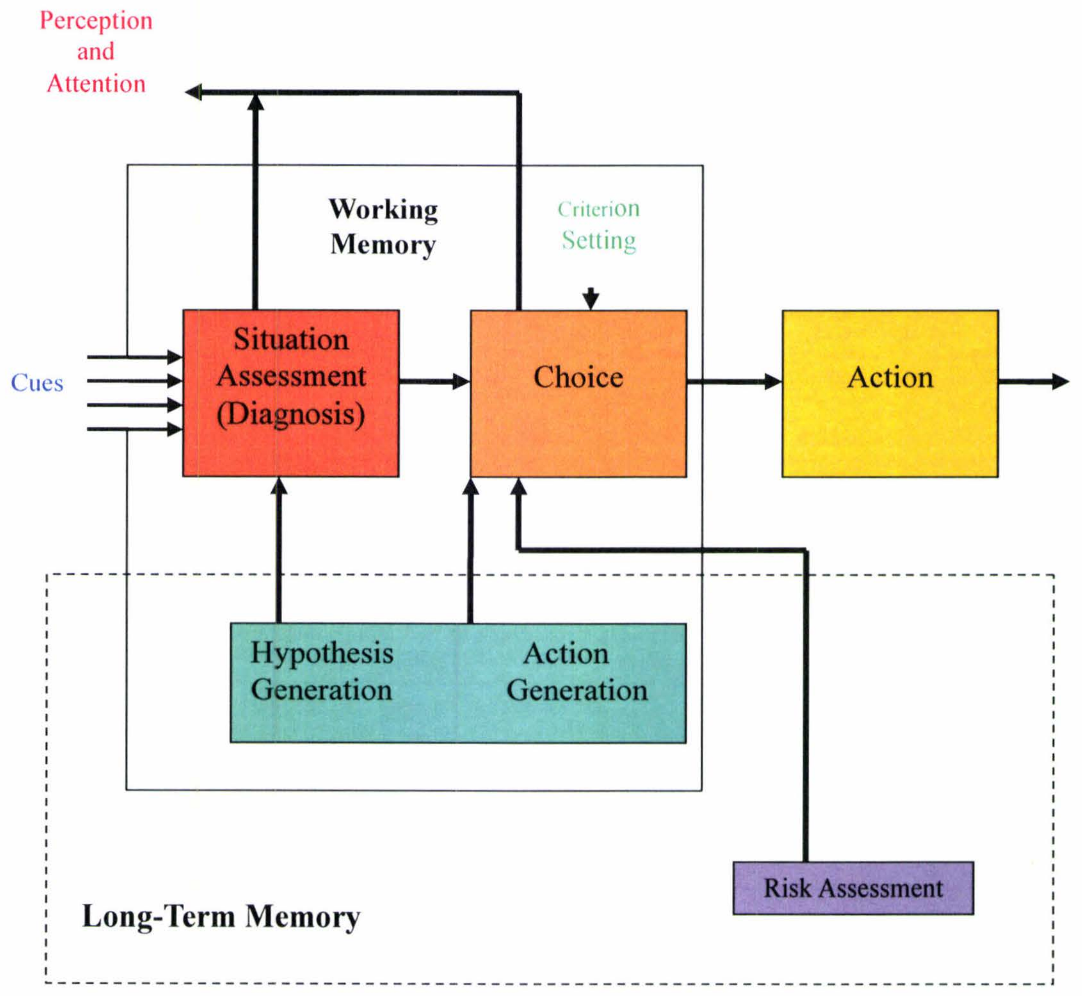

Figure 2. **Decision-making model.**
Source: Adapted from Wickens and Flach (1988).

An individual will sample a variety of cues in the environment to assess a given situation. These cues are then compared against a knowledge base contained within long-term memory so that an accurate diagnosis of the situation can take place. Given that a problem has been identified, choices have to be made regarding what action, or actions, should be taken.

In this model an evaluation and assessment of the possible risks that such actions might create should be inherent within the execution of appropriately learned behaviour. Unfortunately, errors can arise at many points during this process. Individuals may correctly assess their current state of affairs but choose the wrong solution or take unnecessary risks resulting in failure. Or the worker may not have the skills necessary to avert disaster. Likewise, Rasmussen (1982) developed a detailed taxonomic algorithm for classifying information processing failures. This algorithm includes stimulus detection, system diagnosis, goal setting, strategy selection, procedure adoption and action stages, all of which can either fail independently or in conjunction with one another to cause an error. This algorithm has been employed widely within the context of aviation (e.g., O'Hare et al., 1994; Wiegmann & Shappell, 1999; Zotov, 1997). These cognitive models allow seemingly unrelated errors to be analyzed based on fundamental cognitive failures and scientific principles. Wiegmann and Shappell (1999) analyzed over 4500 pilot-causal factors associated with nearly 2000 U.S. Naval aviation accidents. Judgment errors (e.g., decision making, goal setting and strategy selection errors) were associated more often with major accidents, whilst procedural and response execution errors were more likely to lead to minor accidents. According to the cognitive perspective (Wickens & Flash, 1988), any intervention should target the construction workers' information processing capability. However, the information processing hardware of humans (i.e., the brain) is generally fixed. Therefore, in order to improve performance, cognitive psychologists can attempt to capitalize on the manner in which workers process information. For example, examining how expert engineers solve problems or distribute their attention in the construction site can help scientists develop better methods for training novice workmen. Another way of improving information processing is through the standardization of procedures and use of checklists. These methods often facilitate information processing by reducing mental workload and task demands during normal operations and emergencies, thereby reducing the potential for error and accidents. However, many cognitive theories are quite academic and difficult to translate into the applied world of error analysis and accident investigation (Wiegmann, & Shappell, 2001). They rely a lot on speculation and intuition. They do not address contextual or task-related factors such as equipment design or environmental conditions like temperature, noise and vibration. Nor do they consider fatigue, illness and motivational factors impacting on workers decision-making and information processing. Perhaps more importantly, supervisory and other organizational factors that often impact performance are also overlooked and consequently, the operators are often blamed as the cause of the error and the accident.

From the ergonomic or systems perspective, humans are rarely the sole cause of an error or accident. Edwards (1972) proposed a SHEL model. "S" represents software or rules and regulations. "H" refers to the hardware such as equipment, material, and physical assets. "E" refers to environment and is created to account for the physical working conditions that human ("L" or liveware) is faced with. He recognized that there were interactions between these four components and felt that it was at the boundaries of these interfaces that many problems or mismatches occurred (e.g., in the live-hardware interface, better known as the human-machine interface). More recently, another "L" (liveware) and a "C" (culture) have been added to the SHEL model to become the SCHELL model (Edwards, 1988). The liveware-liveware interface is between people. The individual who makes up the liveware is subject to limitations of human performance. Some of these limitations will vary from day to day and between individuals whereas other absolute limitations vary little between different people. The liveware-culure interface is the organizational and cultural shell that provides interpretative differences for the way in which individual behave and the values and expectations they hold for the hardware-software-environment manipulations that they make. Helmreich (1991) found that there was a great variability among crew operating the same type of aircraft. Even greater variability was found between companies and countries. The interpretation by crews of the policies and practices of airline management, government regulatory agencies and international authorities and associations is many and varied. As a consequence, many well-conceived initiatives, training, safety procedures fail because what is taught or what is attempted to be introduced is poorly designed with the culture of the organization where the work is done. However, in day-to-day operations, multi-dimensional models are more typical than the two-dimensional interfaces as described. Unfortunately, these multi-dimensional interactions are often hidden from the operator, producing opaque systems, which if not designed properly, can detract from the monitoring and diagnosis of system problems, thereby producing accidents. Firenze (1971) suggested that humans would make decisions based upon information they had acquired. He predicted that system failure occurred when there was a mismatch between the human, machine and environment components. Furthermore, problems arose when stressors such as anxiety, fatigue and hazardous attitudes could distort or impede the decision making process and lead to an accident. Therefore, efforts must focus on the system as a whole, not just the human component. As these system models focus on the interaction among components, emphasis is placed almost exclusively on the design aspects of the man-machine interface as well as the possible mismatch between the anthropometric requirements of the task and human characteristics. The effects of cognitive, social and organizational factors receive little consideration, giving the impression that these components of the system are relatively unimportant. The ergonomic perspective tends to promulgate the notion that all errors and accidents are design-induced and can therefore be engineered out of the system. Behm (2005) reviewed 224 fatality investigation reports and showed that 42% of fatalities were linked to designed-induced construction accidents. Hazards should be designed out such that they are eliminated or reduced before workers are exposed and then forced to react to minimize these hazards.

From a behavioural perspective, followers believe that performance is guided by the drive to obtain rewards and avoid unpleasant consequences or punishment (Skinner, 1974). Peterson (1971) expressed the view that performance depended upon one's innate ability and motivation, which in turn was dependent on a number of other factors (i.e., job climate, personal achievement, promotion, peer group pressure, previous training, selection for the job, etc.). However, motivation and ability alone cannot fully explain how people behave. In Peterson's model, he talked about the extent to which individuals felt satisfied about their performance, which in turn was largely dependent on the rewards they received within the organization. Ultimately, it is this feeling of satisfaction that motivates individuals to perform the same action again and again. When an individual's lack of motivation to perform safely, or when conditions exist that reward unsafe actions, rather than those that are safe, accidents will likely occur. However, in the construction industry, with heavy equipment, often located in difficult operational spaces the consequences of unsafe behaviour can be fatal. Individuals probably do not knowingly want to performance at anything less than their best. The consequences for performing the tasks badly are too risky.

Aviation has taught us much about how to approach human factors. From an aeromedical perspective, errors are thought to be merely systems of an underlying mental or physiological condition such as illness or fatigue. When they are triggered by environmental conditions or situations that promote their manifestation, accidents occur. Reinhart (1996) suggested that physiology affected virtually all aspects of safe behaviour. Suchman (1961) proposed an epidemiological model of accident causation, in which the investigator sought an explanation for the occurrence of an accident within the host (accident victim), the agent (injury or damage deliver), and environmental factors (physical, social and psychological characteristics of a particular accident setting). The physiological state of the pilot (i.e., the host) plays an important role in safe performance and flight operations (Lauber, 1996), yet many investigators have not always taken the aeromedical perspective seriously. Furthermore, training in physiology within the construction industry has been noted to be very limited, and understanding of the impact of adverse physiological states such as fatigue, noise, heat, etc. on worker performance is poor.

From the psychosocial perspective, supporters view flight operations as a social endeavour that involves interactions among many individuals including pilots, air-traffic controllers, dispatchers, ground crew, maintenance personnel and flight attendants. Helmreich and Foushee (1993) suggested that pilot performance was directly influenced by the nature or quality of the interactions among group members.

The interactions in turn were influenced not only by the operating environment but also by the personalities and attitudes of individuals within each group. As there is a much larger variety of trades and disciplines in a construction site, the interactions among themselves will be enormous. It is only when the delicate balance between group dynamics and interpersonal communication and coordination breaks down that errors and accidents occur. Lautman and Gallimore (1987) found that over 70 percent of all civilian aviation accidents resulted from aircrew coordination and communication problems. Wiegmann and Shappell (1999) and Yacavone (1993) also discovered that aircrew coordination failure has been the major cause of military aviation accidents. These complex issues of human interpersonal relationships must be addressed and intervention strategies should aim at improving construction site communications.

From the organizational perspective, the role organizations (not just workers and machinery but managers, supervisors and others in the construction site) play in accident causation and in the management of human error is important. Even as long ago as the 1970's, Bird (1974) proposed a domino theory of accident causation and described the cascading nature of human error as beginning with the failure of management to control losses within the organization. If management fails at any of their managerial tasks (e.g., identifying and assigning work, establishing performance standards, measuring performance, making corrections to ensure that the job gets done) basic or underlying personal (e.g., inadequate knowledge/skill, physical and mental problems) and job-related factors (e.g., inadequate work standards, abnormal usage.) will begin to appear. These basic causes often lead to what Bird referred to as immediate causes such as unsafe acts or conditions committed by employee/operators like the unauthorised use of equipment, misuse of safety devices or other unsafe operations. Ultimately, it is these immediate causes that lead to accidents and injury. Adam (1976) renamed and expanded Bird's domino theory. He included elements of management structure, operational errors and tactical errors, and operationalised Bird's original ideas for use in industry. Weaver (1971) exposed operational error by examining not only what caused the accident, but also why the unsafe act was permitted and whether the management had the safety knowledge to prevent the accident. Degani and Wiener (1994) proposed the four "P's" for operations on the flight deck. They focused on the relationship between the four "P's": 1) Management's philosophy or broad-based view about how they would conduct business; 2) Policies regarding how operations were to be performed; 3) Procedures and/or specifications concerning how certain actions were to be executed; and 4) Practices of aircrew as they performed flight-related duties. All of these factors interact to enhance work safety. However, the entire system can break down if for example, the philosophy of the organization drives policies that are motivated more by profit than safety (e.g., an on-time departure at all cost, an on-time completion of a building at all cost, etc.). Misguided corporate attitudes can also lead to poor or misinterpreted procedures. As little is known about the types of organizational variables that actually cause specific types of errors in the cockpit or in the construction site, the practicality of an organizational approach for reducing or preventing operator error would be difficult. Furthermore, organizational models tend to focus almost exclusive on a single type of causal-factor, (i.e. the managers and supervisors) rather than the worker themselves. They also tend to foster the extreme view that every accident is a failure of the organization or its management.

It appears that none of the perspectives described previously were able to address all the plethora of human causal factors associated with construction accidents. It was not until 1990 when James Reason published his model on human error that radical new thinking on performance in safety critical industries such as aviation, health, and high technology endeavours began to emerge.

Reason's Model of human error

Reason's Model of human error leading to accident causation was originally developed for the nuclear power industry. This approach was based on the assumption that there were fundamental elements of all organizations that must work together harmoniously if efficient and safe operations were to occur. These elements comprised a "productive system" as showed in Figure 3.

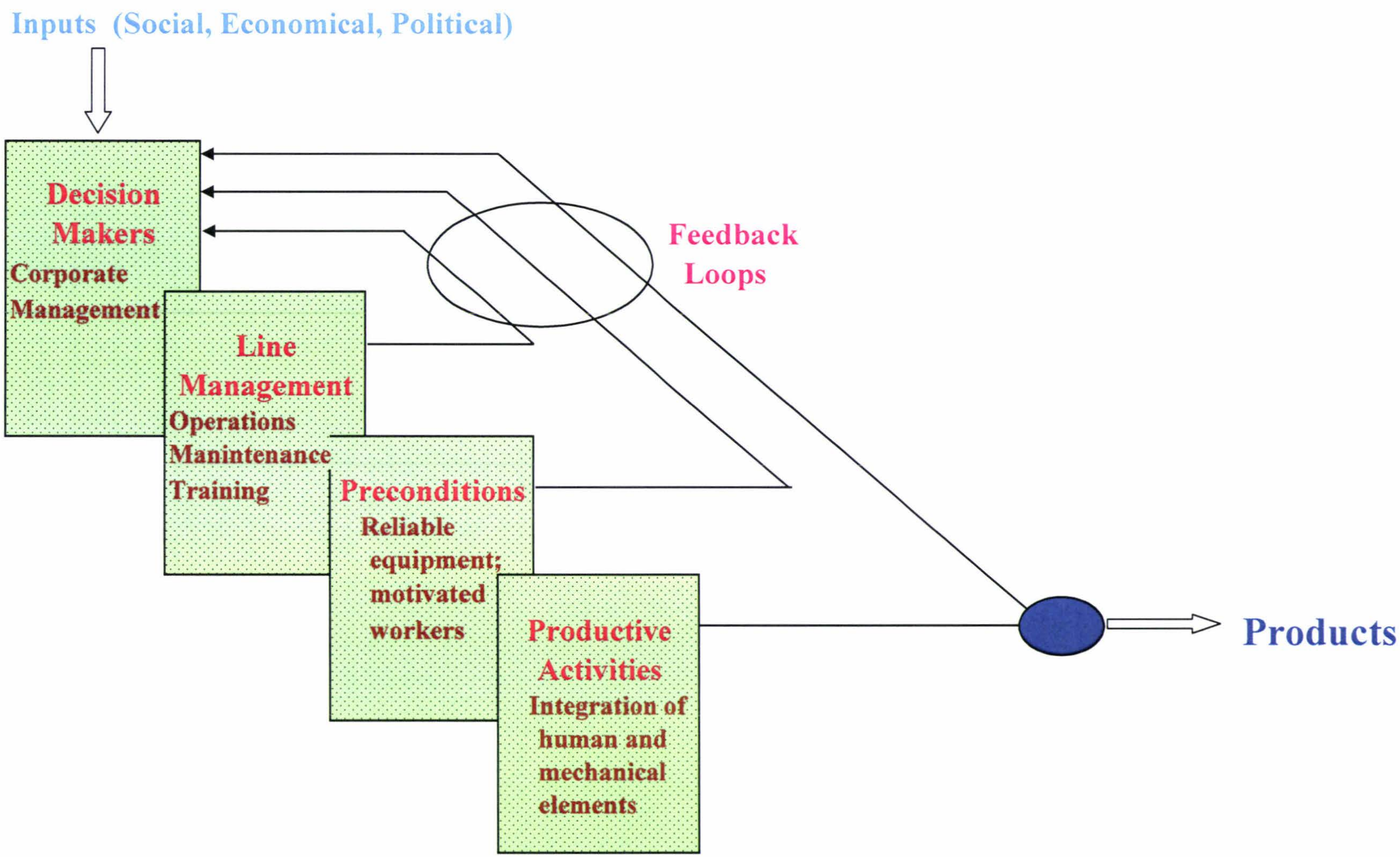

Figure 3. Components of a productive system.
Source: Adapted from Reason (1990).

The construction industry can be viewed as a complex productive system whose "product" is the safe conduct of building operations. One of the key elements is the activity of builders, the front line operators. The "productive activities", in turn, require the effective integration of human and mechanical elements within the system (e.g., the effective worker-construction machine interfaces) so that safe building operations can take place. Before productive activities can occur, certain "preconditions" such as reliable and well-maintained equipment, and a well-trained and professional workforce, need to exist. Airport builders work within a highly structured organization that requires effective management and careful supervision. And such management and supervision is needed across numerous departments within the organization including operations, maintenance and training. Most managers need guidance, personnel, and resources to perform their duties effectively. This support comes from decision-makers who are further up the chain-of-command, charged with setting goals and managing available resources. They have the job of balancing oft-competing goals of safety and productivity, which for construction companies includes safe, on-time, cost-effective operations. Corporate decision are made based on social, economic, and political inputs coming from outside the organization as well as feedback provided by managers and workers from within. Reason proposed that accidents occur when there was a breakdown in the interactions among the components involved in the production process. These failures corrupted the integrity of the system making it more vulnerable to operational hazards, and hence more susceptible to catastrophic failures. These failures he described as the "holes" within the different layers of the system; thereby transforming what was once a productive process into a failed or broken down one. This theory is often referred to as the "Swiss cheese" model of accident causation and is showed in Figure 4.

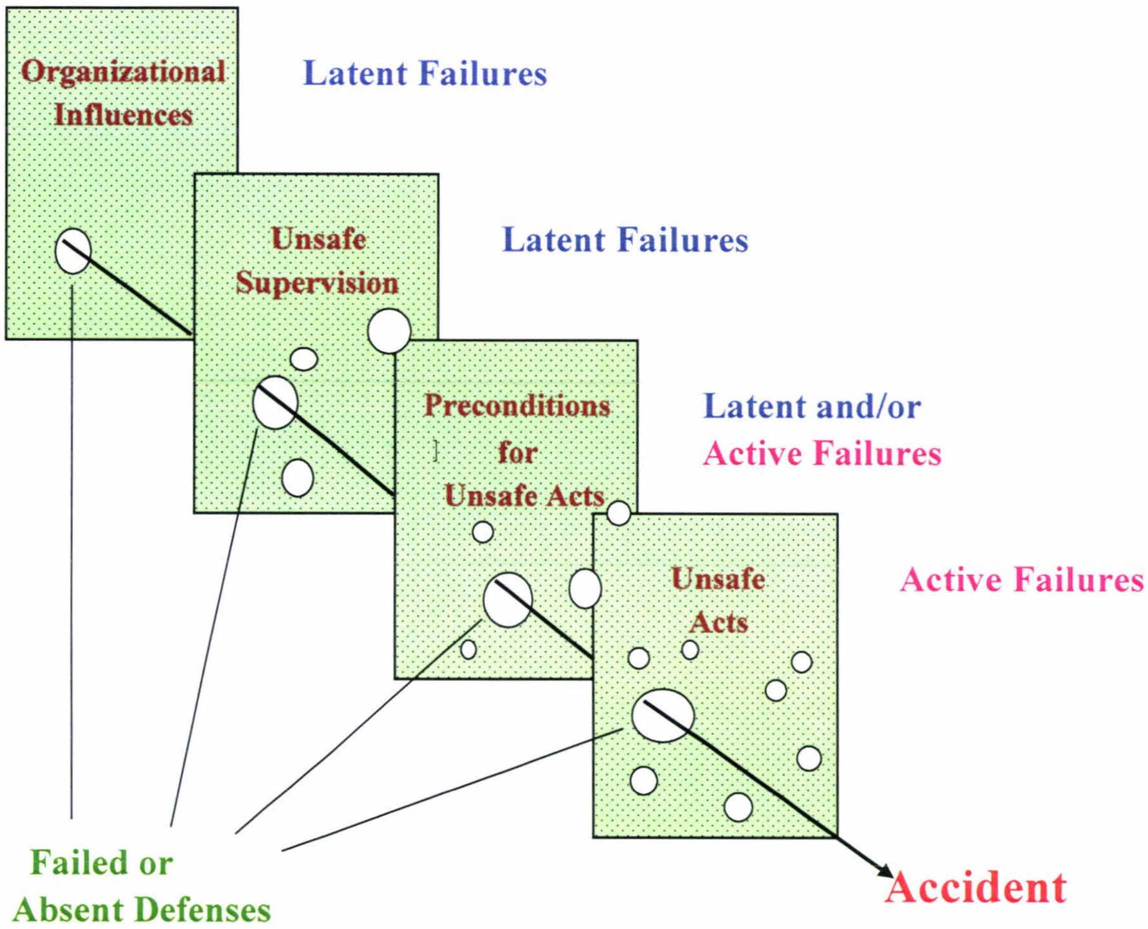

Figure 4. The "Swiss cheese" model of accident caustion.
Source: Adapted from Reason (1990).

According to Reason's (1990) "Swiss cheese" model, accident investigators must analyze all areas and levels of the system to understand fully the causes an accident. For example, working backwards in time from the accident, and assessing the unsafe acts of operators that have ultimately led to the accident, etc. The latter can be referred as worker errors, and these active failures can be directly linked to the event. For instance, failing to clear the area before excavation work may yield relatively immediate, and potentially grave, consequences. Represented as failed defences or "holes" in the cheese, these active failures are typically the last unsafe acts committed by the excavator. This model also forces investigators to address latent failures within the causal sequence of events. Latent failures may lie dormant or undetected for some time until one day they adversely affect the unsuspecting construction worker. Investigators may easily overlook them. Consequently, Reason described three more levels of human failure that contribute to the breakdown of a productive system. The first level involved conditions that directly affect operator performance. The second level, referred to as preconditions for unsafe acts, concern conditions such as mental fatigue or improper communication and coordination practices. If fatigued construction workers fail to communicate and coordinate the activities with others in the construction site or individuals outside the site (e.g., electricity supply, gas supply, water supply), poor decisions are made and errors often result. Communication and coordination break down could also be traced back to instances of unsafe supervision, the third level of human failure. For example, two inexperienced welders are paired with each other and sent on a job in an open area in rain. If they have inadequate training in cooperation, the potential for miscommunication and ultimately, welder errors, is magnified. It appears that intervention and mitigation strategies may lie higher at the supervisory level within the system. In addition, Reason's model showed that the organization itself could impact performance at all levels. For instance, in an economic recession where money is limited, organizations are highly financially motivated to cut costs. Training is invariably a key target. Organization's wrongly believe that they can reduce a training budget with little consequence to productive outcomes. Any expense cutting activity is justified in terms of the "bottom line". Not only is the expenditure on training often reduced, but so too the overall time budgeted for the construction activity. Supervisors are often left with no alternative but to task poorly skilled workers with undertaking tasks beyond their level of competency. Communication and coordination failures often begin to appear as do other preconditions which affect performance and heighten the probability for construction workers' errors. Therefore, investigators and analysts must examine the accident sequence in its entirety and expand it beyond the construction site. Eventually, causal factors at all levels within the organization must be addressed.

Strengths and Limitations of Reason's Model

Reason's "Swiss cheese" model of human error integrates the human error perspectives into a single unified framework. For example, the model is based on the principle that building operations can be viewed as a complex productive system (ergonomic perspective), that often breaks down because of ill-fated decisions made by upper level management and supervisors (organizational perspective). However, the impact that these unsound decisions have on safe operations may lie dormant for long periods of time until they produce unsafe operating conditions, such as poorly maintained equipment (ergonomic perspective), as well as unsafe builder conditions, such as fatigue (aeromedical perspective) or miscommunications among operators (psychosocial perspective). All of these factors in turn affect an operators' ability to process information and perform efficiently (cognitive perspective). The result is an incident or accident. However, Reason's model fails to identify the exact nature of the "holes" in the cheese. It is important to know what these system failures or "holes" are so that they can be identified during accident investigations or better yet detected and corrected before an accident occurs. Reason's model is primarily descriptive and not an analytical paradigm. It is so theoretical that analysts, investigators and other safety professionals would have a difficult task applying it to the real world.

The Human Factor Analysis and Classification System (HFACS)

Reason's human error "Swiss cheese" model provides a comprehensive theory of human error and accident causation. It does not provide an operational means for rectifying the reasons for the "holes". In contrast, the Human Factor Analysis and Classification System (HFACS) was designed to define the "holes in the cheese", the latent and active failures facilitating the application of this model to accident investigation and analysis (Shappell & Wiegmann, 1997a; 1998; 1999; 2000a; 2001). Although designed originally for use within the context of military aviation, HFACS can also be effective within the civil aviation arena (Wiegmann & Shappell, 2000b) and construction industry. HFACS describes four levels of failure, each of which corresponds to one of the four layers contained within Reason's model. These include: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organizational Influences, and they are showed in Figure 5.

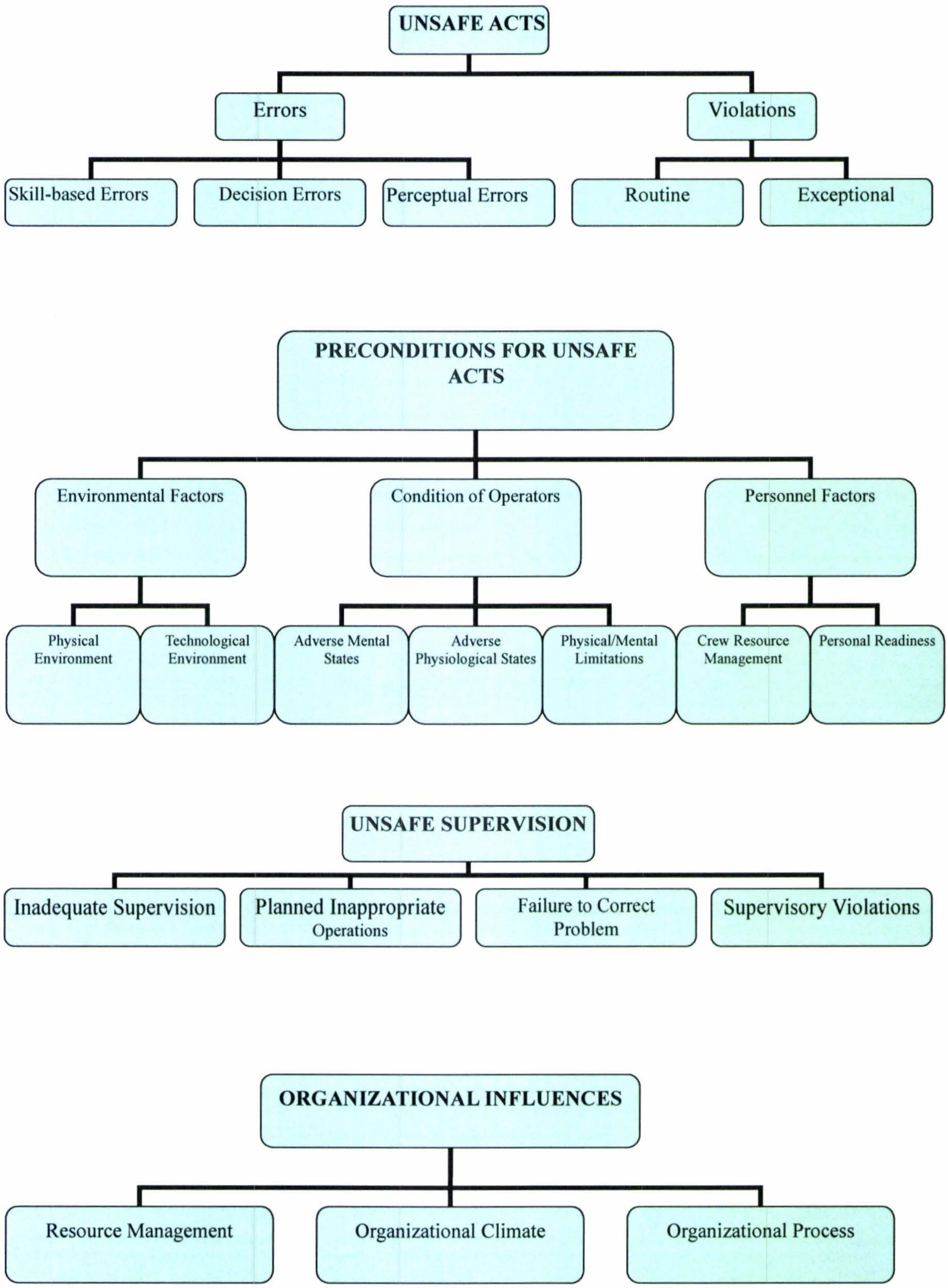

***Figure 5.* The Human Factors Analysis and Classification System (HFACS).**
Source: Adapted from Shappell and Wiegmann (2000a).

The unsafe acts of operators have two main categories: errors and violations. Errors can represent the mental or physical activities of individuals that fail to achieve their intended outcomes. Humans by their nature make errors and these unsafe acts dominate most accident occurrences. Violations refer to the wilful disregard for the rules and regulations that govern safety. It is a difficult issue to be dealt with as violations are hard to predict. Rasmussen (1982) and Reason (1990) suggested three error types: skill-based, decision and perceptual errors and two form of violations: routine and exceptional. Skill-based errors occur without significant conscious thought and are particularly vulnerable to failures of attention and/or memory. When under stressful situations, skill-based errors are more apparent. Decision errors represent intentional behaviour that proceeds as planned yet the plan itself proves inadequate or inappropriate for the situation. These are "honest mistakes" but the individuals did not have the appropriate knowledge or simply chose poorly. Decision errors have three general categories: procedural errors, poor choices and problem-solving errors. Procedural decision errors (Orasanu, 1993), and rule based errors (Rasmussen, 1982) occur during highly structured tasks (e.g., if A, then do B). Much of the shot-firers (workers use explosive to flatten hills or old houses) decision making is procedural, and error can occur when a situation is either not recognized or misdiagnosed and the wrong procedure is applied. This is particularly true when the shot-firers are placed in emergency situations. As many circumstances have no corresponding procedures to deal with them, many situations require a choice to be made among multiple response options. Sometimes one chooses well and sometimes does not. Choice decision errors or knowledge-based mistakes as they are otherwise known may occur. This is particularly true when there is insufficient experience, time or other outside pressure that may preclude safe decisions.

Decision errors differ markedly from skill-based errors in that the former involve deliberate and conscious acts while the latter entail highly automated behaviour. When one's perception of the world differs from reality, errors occur. The unsuspecting individual is often left to make a decision that is based on faulty information (e.g., in spatial disorientation or with visual illusions). Routine violations tend to be habitual by nature and often tolerated by governing authority (Reason, 1990) (e.g., drive 80 mph in a 70 mph zone). However, exceptional violations appear as isolated departures from authority, not necessarily indicative of an individual's typical behaviour pattern, nor condoned by management (Reason, 1990) (e.g., drive 120 mph in a 70 mph zone).

When analysing the preconditions for unsafe acts, factors to consider include the condition of the operators, the environmental factors and the personnel factors (Shappell, & Wiegmann, 1997b). Dangers that may affect the condition of the operators include: adverse mental states (e.g., loss of situational awareness, task fixation, distraction and mental fatigue due to sleep loss and other stressors, personality traits, malicious attitudes, etc.), adverse physiological states (e.g., visual illusions, spatial disorientation, physical fatigue, illnesses, medications, etc.) and physical/mental limitations (refers to those instances when the operational requirements exceed the capabilities of the individual, e.g., poor vision, poor hearing, lack of tolerance to compressed air work , no mental ability or aptitude to work, anthropometric reasons, etc.). Environmental factors comprise the physical environment and technological environment. The former refers to both the operational environment (e.g., weather, underground/underwater work, terrain, etc.), and the latter the ambient environment (e.g., heat, vibration, lighting, toxic substances in the workplace). The technological environment encompasses the design of equipment and controls, display/interface characteristics, checklist layouts, task factors and automation. For example, the similarities of control switches often cause confusion among machine operators. Personnel factors refer to poor communications and coordination as well as personal readiness. The former could be improved through training and for the latter, the workers must use good judgment when deciding whether they are "fit to operate" a machine (Shappell & Wiegmann, 1997b; 1999).

Unsafe supervision generally includes inadequate supervision, planned inappropriate operations, failure to correct a known problem and supervisory violations. The role of any supervisor is to provide their personnel the opportunity to succeed, and they must provide guidance, training, leadership, oversight, incentives, etc. to ensure the job is done safely, effectively and efficiently (Shappell & Wiegmann, 2000b). However, some corporations provide little if any supervision in the genesis of human factors. Planned inappropriate operations like improper underwater worker pairing can create an authoritarian gradient which may contribute to accident/incidents. If the supervisor knew that a diving worker was incapable of diving safely and allowed the dive anyway, the supervisor clearly failed to correct a known problem. Likewise, the failure to consistently correct or discipline inappropriate behaviour fosters an unsafe atmosphere and promotes the violation of rules.

Organizational factors such as resource management, organizational climate and organizational process can influence accidents/incidents. Resource management covers all the corporate-level decision-making regarding the allocation and maintenance of organizational assets like human resources, monetary assets, equipment, facilities and training. In times of economic austerity, safety and training are often cut. Excessive cost-cutting could result in reduced funding for new equipment, the purchase of low-cost but less effective alternatives, or simply no support equipment. Organizational climate can be viewed as the working atmosphere within the organization. The organizational structure as reflected in the chain of command, delegation of authority, communication channels, formal accountability for actions, etc. can all affect safety (Muchinsky, 1997). The organizational culture, the unofficial or unspoken rules, values attitudes, beliefs, customs, etc. are important variables related to climate and can influence accidents. When organizational policies are ill-defined, adversarial or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds. Organizational process refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standard operating procedures and the balance between the workforce and management. Nevertheless, any non-standard procedure can introduce unwanted variability into the operation. Likewise, operational tempo, time pressure and work schedules are all variables that can adversely affect safety. Furthermore, organizations need to address contingencies and have oversight risk management programmes.

Human error in occupational accidents

Feyer and Williamson (1991) used a comprehensive classification system, which allowed operational analysis of the events preceding accidents. This was applied to the analysis of information surrounding the occurrence of all traumatic work-related fatalities in Australia in 1982–1984. The coded information included factors immediately antecedent to the accident leading to the fatality and factors removed in time which contributed to the occurrence of the accident. The complex network of events leading up to the accident, their interrelationships, and their relative contribution to causing the accident were examined. The results provided information about the use of accident analysis for the formulation of preventive strategies. Human error, poor work practices and environment factors were found to be the most frequent antecedent of fatalities. Human error was not only the commonest prime cause of accidents but also frequently exited in the precursor event sequence. Other contributing factors to accidents were drugs and alcohol involvements. Their results confirmed that accidents were the outcome of a complex network of interrelated factors which were not equivalent in causal significance. They concluded that targets for prevention must be much more specifically defined.

Feyer, Williamson and Cairns (1997) analysed the information surrounding the occurrence of all traumatic work-related fatalities in Australia over the years 1982 to 1984. They further examined the nature of work practices involved in these fatalities and their relationship to subsequent behavioural events in the accident sequence. The most common work practices were those associated with procedures either originating from management or individual practices. Examination of the association of particular work practices with the occurrence of subsequent human errors revealed that the origin of the unsafe practice varied for different error types. Individual worker practices, safety equipment and personal protective equipment practices were all associated with later skill-based errors. In contrast, management practices were associated with knowledge-based errors, while general equipment practices were associated with rule-based errors. These findings provided evidence for the view that aspects of work organization provided the circumstances in which later events might precipitate the accident. Moreover, Feyer, et al., (1997) suggested that being able to identify the precursors of critical events, and, in particular, those events that were difficult to directly target could provide a specific focus for prevention. Knowledge-based errors could be directly targeted for prevention, whereas for skill-based errors the only avenue for prevention lay in targeting the surrounding circumstances. Many studies of the patterns of accident causation revealed that pre-existing poor work practices were the most common precursors of human errors precipitating fatalities. Feyer et al., (1997) named the pre-existing poor work practices contributing factors and they suggested that the combinations of these factors with human errors were the common causes for work- related fatalities. The contributing factors taxonomy used in the current study are defined and shown in Table 1.

Table 1. ***Contributing factors taxonomy used in the current study.***

Factor	Definition
Fatigue	Mental or physical fatigue, generally related to a lack of adequate night time sleep and/or transitioning on to night shift work.
Work pressure	Work being performed under unusual/unreasonable time pressure or haste.
Coordination	Inadequate teamwork and communication between workers.
Training	Knowledge based skill deficiencies.
Supervision	Inadequate supervision or support of workers.
Previous deviation	Incorrect performance of a task at an earlier time which was not noted or corrected.
Procedures	Poorly designed, poorly documented, or non-existent procedures, or when a poor deviation from correct procedures was routinely ignored or accepted by management and/or operational personnel.
Equipment	Poorly designed or maintained equipment or tools, or a lack of necessary equipment, including a lack of necessary spare parts.
Environment	The physical environment in which the work was being performed, which was beyond the control of the worker (e.g., darkness, glare, height, excessive noise, poor ventilation, etc.).
Physiological	The worker's performance was affected by drugs, alcohol, a medical condition or other adverse physiological status.

In understanding the safety climate or culture of a workplace, the perceptions and attitudes of the workforce are important factors in assessing safety needs. Safety solutions were likely to be unsuccessful if they do not take into account these prevailing attitudes and perceptions. Changes in attitudes and perceptions about safety were often expected outcomes of safety interventions. Williamson, Feyer, Cairns and Biancotti, (1997) developed a measure of worker perception and attitudes about safety as an indicator of safety culture in the workplace. Their findings concurred with the well-known beliefs about safety in the working community which need to be understood in order to progress the concept of a safety culture. DeJoya, Schaffer, Vandenberg and Butts, (2004) found that various work situation factors directly affected on perceived safety at work; safety climate influenced perceived safety at work but its role as a mediator was limited. Neal, Gri, and Hart, (2000) discovered that the effect of general organizational climate on safety performance was mediated by safety climate, while the effect of safety climate on safety performance was partially mediated by safety knowledge and motivation.

Several management practices have been cited as important components of safety programme. Vredenburgh (2002) examined the degree to which six management practices frequently included in safety programs (management commitment, rewards, communication and feedback, selection, training, and participation) contributed to a safe work environment for hospital employees. She found that hospitals that employed proactive measures to prevent accidents had low injury rates. Her study suggested that simply introducing safety training programmes was not enough. She suggested that a more effective approach for hospitals to take was in their recruitment and selection of new staff. Further, she proposed that any appointment of staff to manage safety risks within an organization should be at a relatively senior management level.

In a study by Cooper and Phillips (2004), they suggested that safety climate referred to the degree to which employees believed that real priority was given to organizational safety performance and measurement which was capable of providing an early warning of potential safety system failure(s). They further proposed that the climate-behaviour-accident path is not as clear cut as commonly assumed. This study examined the hypothesized a contributing factor-human factors-injury pathway and with its associated factors.

Associations between human error and contributing factors in the construction industry

Although Cacciabue (1997) and Hollnagel (1993) called the taxonomies based on the outward forms of errors error phenotypes, these descriptions tend to be area specific, give few insights into error causation, and provide limited guidance for corrective interventions. Cognitive models of human error, however, may help to reveal fundamental forms, or underlying error genotypes. A variety of generic cognitive taxonomies have been used to account for errors in safety-critical environments (see Senders & Moray, 1991). Reason's model of unsafe acts (1990), which is a development of his earlier generic error modelling system (GEMS; Reason, 1987), draws on the skill-rule-knowledge (SRK) distinction of Rasmussen (1983) and the slip/mistake dichotomy of Norman (1981), but it also includes rule violations as a distinct form of unsafe act. Although Rasmussen (1983) and Reason (1990) have not aimed to explain skill development, their taxonomies clearly encapsulate important distinctions between levels of cognitive control as a person deals with progressively more familiar and predictable situations (Anderson, 1982; Fitts &

Posner, 1967). The difference between skill-based errors and mistakes involving intended actions is also consistent with the automatic/controlled distinction of Shiffrin and Schneider (1977), with skill- and knowledge-based errors relating to automatic and controlled processing, respectively. Rule-based errors are associated with controlled processing lying between the extremes of skill- and knowledge-based performance. Such behaviour fits well with the concept of Bartlett (1932), in which the person possesses a previously developed solution that can be applied in familiar situations. Additionally, the identification of violations as a distinct form of error has been supported by studies of driver behaviour (Aberg & Rimmoe, 1998; Parker, Reason, Manstead & Stradling, 1995).

Reason's (1990) taxonomy has been used extensively in the analysis of accident case studies (e.g., Lucas, 1997; Maurino, Reason, Johnston & Lee, 1995) and has been adapted for use in several accident investigation models, including Tripod Beta (Shell International Exploration & Production RV., 1994), incident cause analysis method (Hayward, Lowe & Gibb, 2002; ICAM), and the human factors analysis and classification system (HFACS) of Shappell and Wiegmann (2000). Nevertheless, very few published studies have applied Reason's (1990) taxonomy to errors drawn from workplace injury databases.

As has been pointed out earlier, accidents on construction sites are a major cause of morbidity and mortality in Hong Kong. In 1993 there were 56,226 construction workers in 1993 of which 16,573 (35.4%) suffered a workplace injury. The unsafe behaviour of human operators is a well known threat to the safety of complex technological systems, and is a significant concern to the Hong Kong construction industry. The Labour Department of Hong Kong reported that the most frequent construction site errors were untidiness, causing people to fall or trip; hand tools, power tools and plants not being used properly; poor manual handling; personal protective equipment not being worn when it should be; getting too close to an operating plant and people were fooling around.

Heinrich (1941) and Reason (1990) proposed that errors occurred in response to causal factors. Hawkins (1993) and International Civil Aviation Organization (1995) showed that a great range of potential error factors were related to virtually every aspect of human performance in technological systems. Construction work is performed in an environment that contains many potential error-producing conditions and its workers also routinely contend with inadequately designed documentation and plans, time pressures, shift work, and environmental extremes. Despite the increasing interest in construction site error, limited information is currently available on the cognitive forms that these errors take and the factors that promote them. The main reason for this is that unlike aircrew errors, construction site errors can remain latent for significant periods before an accident or incident occurs, making the work of an investigator particularly difficult. Furthermore, unlike pilots or air traffic controllers, construction site personnel are not subject to data or voice recording for investigation purposes, and investigators sometimes have a difficult job establishing the circumstances surrounding construction site errors. Additionally, many of the existing data on construction site errors are stored in company files and are not available to the public.

Although information on construction site errors is scarce, errors in other industries have been studied extensively with a range of cognitive error taxonomies (e.g., O'Hare, Wiggins, Batt & Morrison, 1994; Runciman et al., 1993; Wagenaar & Groeneweg, 1987). However, the links between errors and contributing factors have received little attention. In many studies of safety databases, errors and contributing factors are analyzed independently of each other, and their frequencies are reported in separate, unlinked tables. Hence, the lessons learned in one context may not be generalized to other realm. For example, identifying that skill-based errors are the most frequent errors committed by locomotive drivers (Edkins & Pollock, 1997) may not necessarily indicate what to expect in other industries. In addition, the comprehensive lists of contributing factors found in many accident investigation frameworks, although providing useful guidance to investigators on a case-by-case basis, are less useful for database analysis. When factors are placed into a large number of categories, the differences between accident cases would be emphasized and the similarities obscured. Therefore, it is preferable to focus on the associations between categories within data sets, such as those between errors and contributing factors. This kind of information may be more readily generalizable across domains. It may help in accident prevention where strategies could be targeted at key factors that contribute to error. Human error probabilities can also be estimated with greater accuracy and organizational safety performance be monitored by evaluating the relative prevalence of conditions that are known to promote errors. Only a few studies have explored the links between errors and contributing factors. Feyer, et al., (1997) used the SRK framework to analyze data relating to more than 1000 workplace fatalities in Australia. They identified links between particular error forms and specific pre-existing work practices within the deceased workers' organizations. They found that skill-based slips were associated with pre-existing unsafe work practices in the use of personal protective equipment. Although not strictly a study of errors and contributing factors, Salminen and Tallberg (1996) linked skill, rule, and knowledge-based errors with the type of work being performed at the time of serious occupational accidents in Finland. They found that errors were not evenly distributed across work tasks. Skill-based errors were most common when workers were using manual tools, whereas errors on supervision tasks tended to be knowledge based. The purpose of the current study was to examine the associations between different human error types and the circumstances in which they occurred.

It was generally thought that error-producing factors increased the prevalence of all errors equally. However, as errors appear to reflect a range of cognitive origins, it seems more likely that specific contributing factors would be associated with particular forms of human error. For example, the conditions that promote errors of automatic performance (such as slips) would be different from those that promote mistakes involving controlled processing (such as rule-based or knowledge-based errors). Automatic performance can be expected to be highly reliable in a task environment that is consistent and predictable; however, tasks that involve variability between cues and required responses would be associated with less reliability in skilled performance (Fisk, Ackennan & Schneider, 1987). Lawton and Parker (1998) proposed that violations were likely to be associated with contributing factors different from those that promote other unsafe acts. They noted that motivational factors, unrealistic work demands, and unworkable procedures were particularly likely to lead to rule violations. Battmann and Klumb (1993) considered that work and time pressures were significant precursors of violation. At least two possibilities exist regarding the associations between errors and factors: firstly, the presence of a contributing factor will be associated with a general increase in the prevalence of all forms of error; secondly, particular contributing factors will be associated with increases in the prevalence of specific errors, rather than an overall increase in all forms of error. In order to evaluate these possibilities, data from construction site injuries was collected and analyzed using the research methodology reported by Hobbs and Williamson (2003). This approach enabled errors to be examined within their ecological context, maintaining intact the links between errors and contributing factors.

The objectives of this research

Accidents on construction sites are a major cause of morbidity and mortality in Hong Kong. This study has been designed to investigate the likely causes of occupational injuries that were present among the CLK construction workers. In order to accumulate the requisite information, over 1200 accident investigation reports in a four-year period (1993-1996) were reviewed. The first part of the investigation intents to demonstrate the pattern of occupational injuries among construction workers during the construction of the new CLK Airport in Hong Kong, causes and circumstances leading to occupational injuries, the magnitude of risk factors in occupational accident, and to compare the accident rates of the CLK workers with those of the construction industry in Hong Kong as a whole. This section examined the effects of the workplace infrastructure at CLK in order to explain why this site presented fewer work place injuries and accidents than other workplaces. It would also identify some unsafe actions and unsafe conditions and personal factors relevant to the accidents and highlight some solutions that might help to prevent or reduce workplace hazards.

It has long been observed that unsafe behaviour among human operators is one of the most pressing threats to the safety of complex technological systems. In recent years cognitive error models have provided insights into the unsafe acts that lead to many accidents and a variety of generic cognitive taxonomies have been used to account for errors in safety-critical environments (Senders, 1991). It has been estimated that human error is involved in 58% of medical misadventures (Leape et al., 1991), 70% of aircraft accidents (Hawkins, 1993), and 80% of shipping accidents (Lucas, 1997). However, the human factors causes of accident are only partially understood and most of the recent accident causation models are still based on the notion that a sequence of events or the contributing factors which lead to human error can be identified and appropriate strategies developed to mitigate the occurrence of these contributory elements. There has been little published information on possible links between specific human error types and contributing factors in workplace accidents and injuries. The second part of this research seeks to analyse the associations between the types of human errors with the kinds of occupational injuries and with the sorts of contributing factors that would most likely trigger these construction site accidents at CLK.

The research applied a similar research methodology as that reported by Hobbs and Williamson (2003) in their study of error types and contributing factors to accidents and errors in aircraft maintenance. The Hobbs and Williamson study developed a safety questionnaire to collect data on critical incidents and occurrences. This information was used to analyse the circumstances which led up to the occurrence of each adverse outcome, using a technique developed by Feyer and Williamson (1991). This approach allowed occurrences to be broken down into a sequence of events or human errors, and when appropriate, linking the contributing factors which led to each occurrence. In the Hobbs and Williamson study a very useful statistical technique known as "correspondence analysis" (Clausen, 1998) was used to illustrate the "corresponding" relationship between errors and their contributing factors. Using the technique the data could be converted into visual forms which made interpretation easier to understand.

The study would help in assisting the design of accident prevention training and education strategies, the estimation of human error probabilities, and the monitoring of organizational safety performance in the construction industry in Hong Kong.

METHODS

Participants

From 1 January 1993 to 31 December 1996, there were 19153 worksite incidents at the CLK construction site requiring consultations at the on-site medical centre. Of these, 1236 were for injuries sustained while working at the worksite.

Materials

Medical records and incident/accident investigation reports prepared by the on-site medical centre and the safety department respectively were made available for this study. The medical centre served all the workers at the CLK construction site, 24 hours a day and 365 days a year and captured all the injuries occurring on-site. It used the "Type of Occurrence Classification" as specified in the Compendium of Workers' Compensation Statistics, Australia (1996-97) to categorize the nature of injury, bodily location of injury, mechanism of injury and agents involved. However, for ethical reason, only the summary reports of the accidents and causes of the accidents which had been collated on a monthly basis from the original accident and