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

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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.

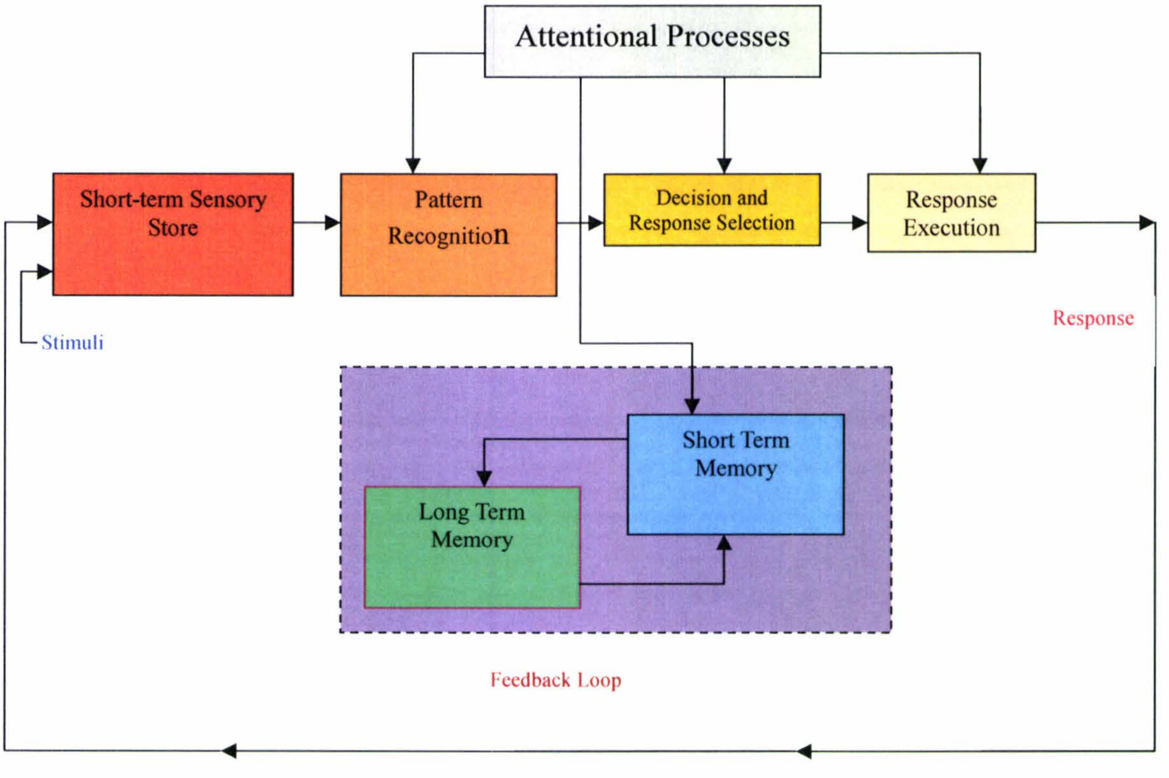

Figure 1. **Basic model of information processing.**
Source: Adapted from Wickens and Flach (1988).

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.

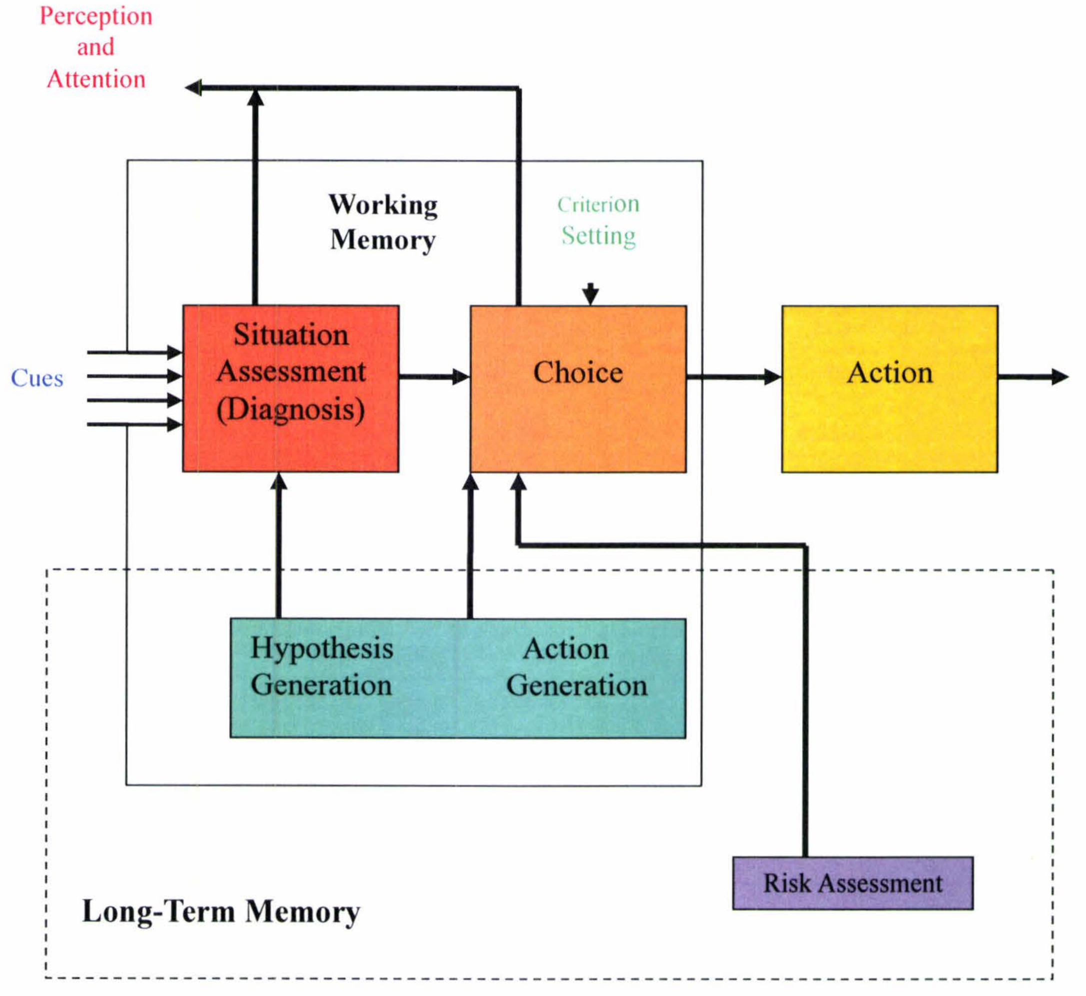

Figure 2. **Decision-making model.**
Source: Adapted from Wickens and Flach (1988).

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.

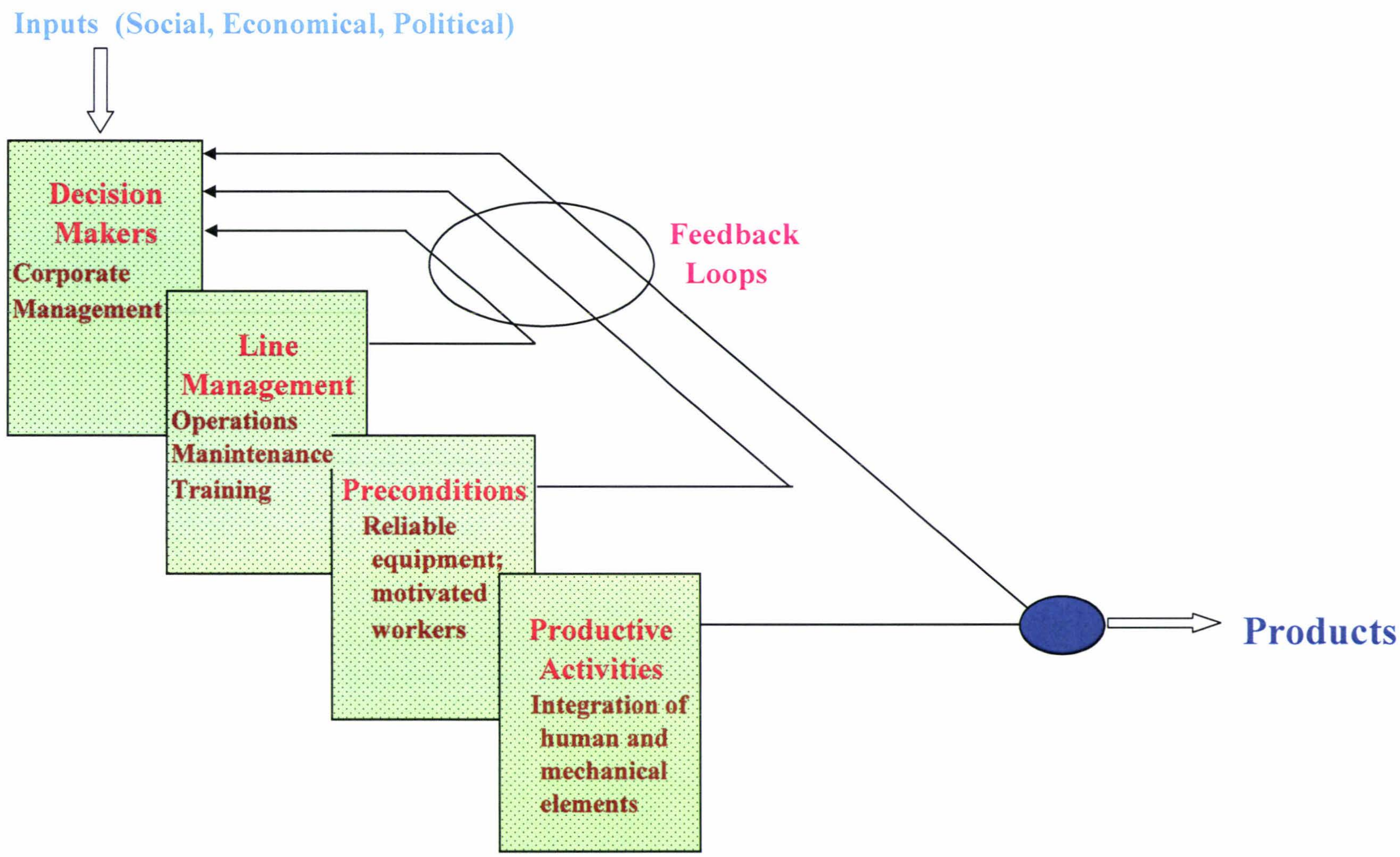

Figure 3. Components of a productive system.
Source: Adapted from Reason (1990).

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.

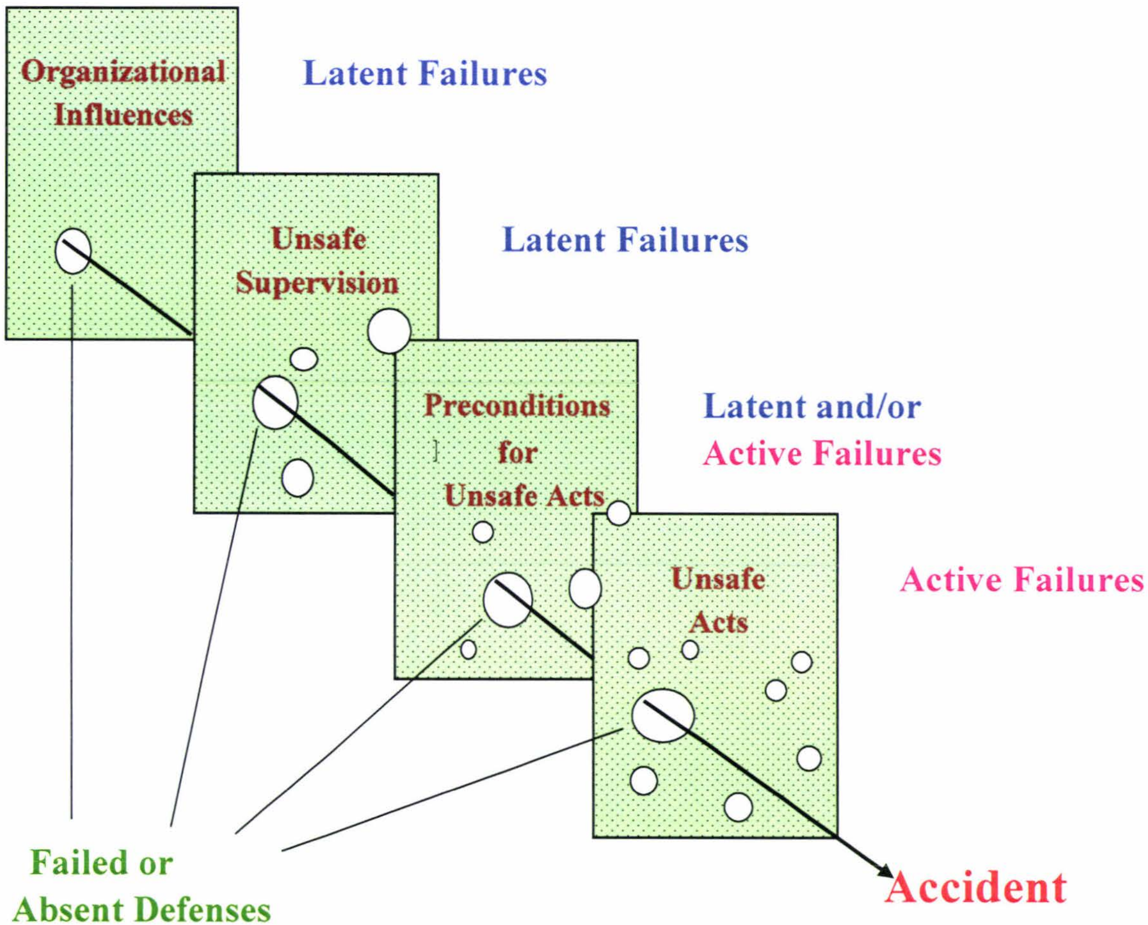

Figure 4. The "Swiss cheese" model of accident caustion.
Source: Adapted from Reason (1990).

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.

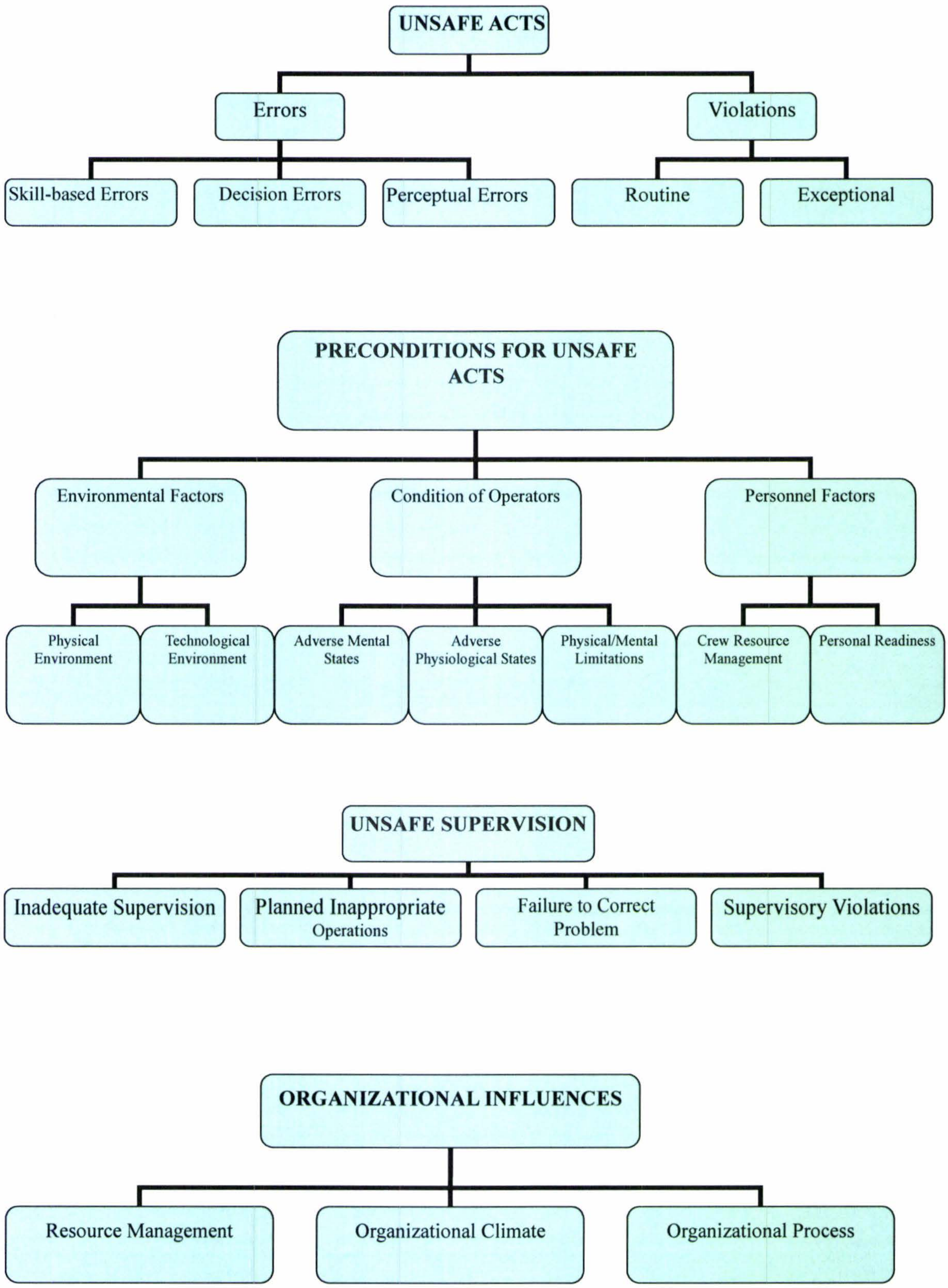

Figure 5. **The Human Factors Analysis and Classification System (HFACS).**
Source: Adapted from Shappell and Wiegmann (2000a).

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 medical reports were used in this study. The data-base did not contain personal identification information such as the names and addresses of the individuals concerned.

Procedures

The data was identified by a sequential code number and included the date and time of the occurrence, the age and gender of the individual and the past and current (at the time of the incident) occupational category of the person. The data is anonymous and no identification of any of the subjects in this study can be made.

All the incident/accident investigation reports for this study were stored in a locked warehouse in Hong Kong. The researcher was given permission from the director of the medical group who previously provided medical services to the CLK site to read and retrieve data from these reports. The information was only able to be accessed in the warehouse. No documents of any kind were allowed to be removed or photocopied. The researcher read the reports and collected the appropriate information for the study in the warehouse.

Data was summarised and analysed according to: age, gender and occupation, past history of work injury, accident rate, nature of injury incurred, and part of body injured. The definitions as specified in the International Classification of Diseases by the World Health Organization (1977) were used to classify the injuries. Simplified definitions of injury were used in this study and are shown in Table 2.

Table 2. ***Definitions for the nature of the injury.***

Nature of injury	Definition
Contusion & crushing	Bruise & soft tissue injury with intact skin and bone
Laceration	Tear in the flesh producing a wound
Fracture	Breakage of a bone
Muscular strain	Overstretching of muscle and/or ligament resulting in pain and swelling
Eye injury	Superficial &/or deep injuries to either or both eyes

Comparison of accident rates of CLK workers with those of the Hong Kong construction industry

The research hypothesised that, compared to control rates (the accident rates for the construction industry elsewhere in Hong Kong in the study period), CLK workers with better training in health and safety practices would sustain fewer injuries at work. In order to make the comparison, the accident rates of the CLK workers for the study period were calculated and then compared with the corresponding accident rates for the whole Hong Kong construction industry. The latter were obtained from Labour Department, Hong Kong Special Administrative Region (HKSAR). As the accident rates were used as categorical (qualitative), ordinal variables, and assumed to be distribution-free, the Mann-Whitney U test was chosen. Alpha was set to 0.05 for this analysis. This is a non-parametric statistic which compares the distributions of two independent and unpaired groups of observations.

Analysing the association between workplace injuries, human error types and their causal factors at CLK

Work injury data from accident investigation reports was collected and analysed in a similar manner to that described in maintenance error occurrences by Hobbs and Williamson (2003), and the human errors and contributing factors leading to each injury were analysed. The circumstances leading up to each workplace injury were analyzed using a similar methodology to that described by Feyer and Williamson (1991). Their approach allowed occurrences to be broken down into a sequence of events: environmental, hardware-related or behavioural events. Environmental events were defined as those that resulted from the physical location of the injury; hardware-related events were those in which a tool or component broke or malfunctioned. Behavioural events were those human errors identified in Reason's error taxonomy (1990) but with the addition of two additional categories proposed by Feyer and Williamson (1997). The first of the additional categories, perceptual error, has been demonstrated to be an important class of error in other aviation environments (Wiegmann & Shappell, 2001) and was considered particularly relevant in aircraft maintenance, given the importance of visual inspection in aircraft systems (Drury, 1999), and for similar reasons in the construction industry. The second category, called mischance was added by these authors to the taxonomy to cover occasions in which an unsafe action nevertheless constituted "correct" behaviour, for example, those in which a person accurately followed a deficient procedure (Feyer & Williamson, 1991). Commonly agreed with definitions of types of errors have been used in this study. They are shown in Table 3.

Table 3. ***Error taxonomy used in the current study.***

Error	Definition
Perceptual error	A failure to detect a sign that the person was attempting to detect.
Memory lapse	The omission of an action that the person intended to perform.
Slip	The performance of a familiar skill-based action at a time when this action was not intended, or the failure to carry out such an action correctly. It included fumbles and trips.
Ruled-based error	A failure to correctly invoke familiar rules or procedures, either written or based on experience, when dealing with routine problems or when making decisions in familiar situations.
Violation	An intentional deviation from procedures or good practice.
Knowledge-based error	An error in a situation that was unfamiliar or that presented new problems for the person, for which neither automatic mappings nor rules existed.
Mischance	The person adhered to correct procedures but his or her behaviour was nevertheless instrumental in leading to the occurrence

When appropriate, contributing factors were also linked with each workplace injury. The contributing factor taxonomy used in this study was intended to capture the broad range of error-producing conditions identified in previous maintenance research, without resulting in excessively fine-grained descriptions of factors. The resulting taxonomy was based on that developed by Feyer and Williamson (1991) but with three additional factors identified as coordination, fatigue, and work pressure.

Data was summarised and analysed according to: percentage of human errors and percentage of factors contributing to workplace injuries. Cross tabulations of errors and contributing factors as well as workplace injuries and error were produced. Mann-Whitney U Test and chi-square analysis were used to compare accident rates and to demonstrate the associations between contributing factors and human error types respectively. In order to examine the relationships between these categorical variables, each table was analysed using correspondence analysis. Correspondence analysis is an exploratory procedure which has been developed to visually demonstrate the relationship between categories of two or more variables. This statistical technique has made it possible to convert complex data tables into a visual form that was easier to interpret and understand (Clausen, 1998). Correspondence analysis is primarily a multivariate descriptive analysis of the relations between rows and columns in a frequency table, graphically presented as points in a common two-dimensional space based on the chi-square distances between categories. The technique required no assumptions about the data other than that the values were not negative. Categories that appeared together on the correspondence analysis bi-plot had a stronger association than categories that appeared apart. The disadvantage of method was that the distance between the points of different sets could not be defined and so no statistical significance of the effects of the interactions could be stated. For each contributing factor, a chi square was calculated to determine whether the prevalence of all error types changed uniformly when a particular factor was present as compared to when that factor was not present. The strength of the association between contributing factors and each human error type was calculated using a series of logistic regression analyses; in each case, contributing factors were entered simultaneously to predict the presence or absence of each human error type. In logistic regression, given data on a dependent variable "y" and one or more independent variables "x1", "x2", etc, the process can find the best mathematical model (within some restricted class of models) to describe "y" as a function of the "x's", or predict "y" from the "x's" (Menard, 2002). An advantage of logistic regression is that the exponent of the beta weight for each predictor is an odds ratio.

This expressed the increase in prevalence of the human error type that was noted when the contributing factor was present, as opposed to when the factor was not present. Odds ratios can range from 0 to infinity. A value of 1 indicates that the presence of the contributing factor was not associated with a change in the prevalence of the human error type. A value greater than 1 indicated the degree to which the human error type became more prevalent when the contributing factor was present. A value less than 1 could be taken to indicate that the contributing factor was not related to an increase in prevalence of the human error type, but not necessarily that the factor provided protection against the error.

RESULTS

Age, gender and occupation

The majority of construction workers in Hong Kong are aged between 29 and 39 years, and 95% are male (Employment, Wages and Material Prices in Hong Kong Construction Industry, 1993). Of 1236 injuries in this study 889 (71.9%) occurred in the 29 - 39 age range, and 1224 (99%) in males (mean age 30.8 years; range 16 - 64 years). The study group represented a typical construction population in Hong Kong. It was therefore not necessary to consider any psychological and physical problems in the CLK workers that are well known in an aging work force.

The injured CLK workers engaged in a large variety of trades. A summary can be inspected in Figure 6 and a full description of the data can be inspected in

Appendix 1. In 1993, the highest accident rate was among concreters at 33.9 per 100,000 man-hours, followed by carpenters and joiner, and welders. In the following year, fitters/mechanics sustained the highest accident rate. In 1995, riggers held the highest accident rate record. In the final year, the accident rates for all trades were well below 10 per 100,000 man-hours. This showed that accident rates varied in different occupations during the study period and an overall downward trend of accident rates occurred.

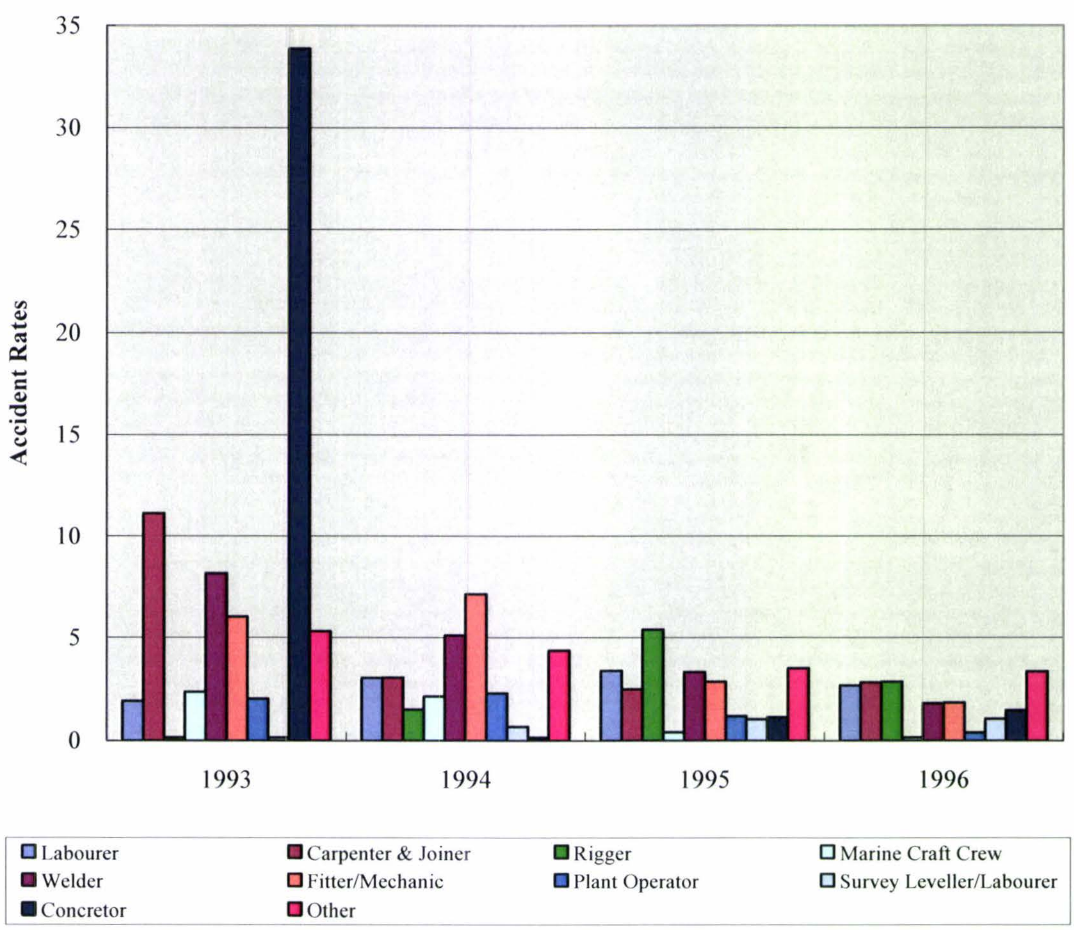

Figure 6. **Accident Rates per 100,000 Man-hours in Relation to Occupation and Trades in 1993-1996.**

Past history of work injuries

Seven hundred and seventy eight workers (62.9%) had had one or more occupational injuries in the past, while 458 (37.1%) had no previous history of injuries. Nearly half of the injured workers had a past history of a previous injury, either at CLK or elsewhere.

Accident rates

In 1993, the accident rate in CLK was 63.62 (per 1000 workers per year). In 1994 and 1995, the accident rates increased (71.70 in 1994 & 74.18 in 1995) but in 1996 it declined to 59.04. The fatal accident rates in CLK ranged from zero to 0.26 (per 1000 workers per year) while those in the Hong Kong construction industry as a whole were between 0.68 and 1.4 for the same period. The accident rates in CLK and the corresponding accident rates for the construction industry in Hong Kong (excluding the CLK data) are shown in Figure 7, 8 and a full description of the data can be inspected in Appendix 2.

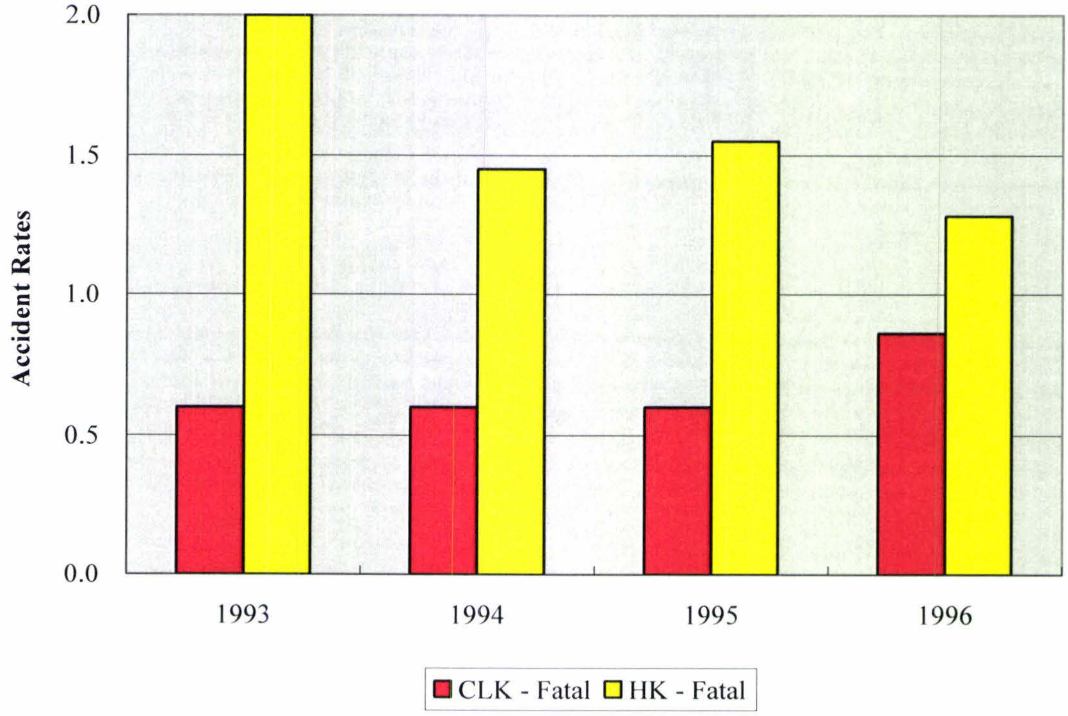

Figure 7. **Comparison of fatal accident rates at CLK and in the construction industry in Hong Kong.**

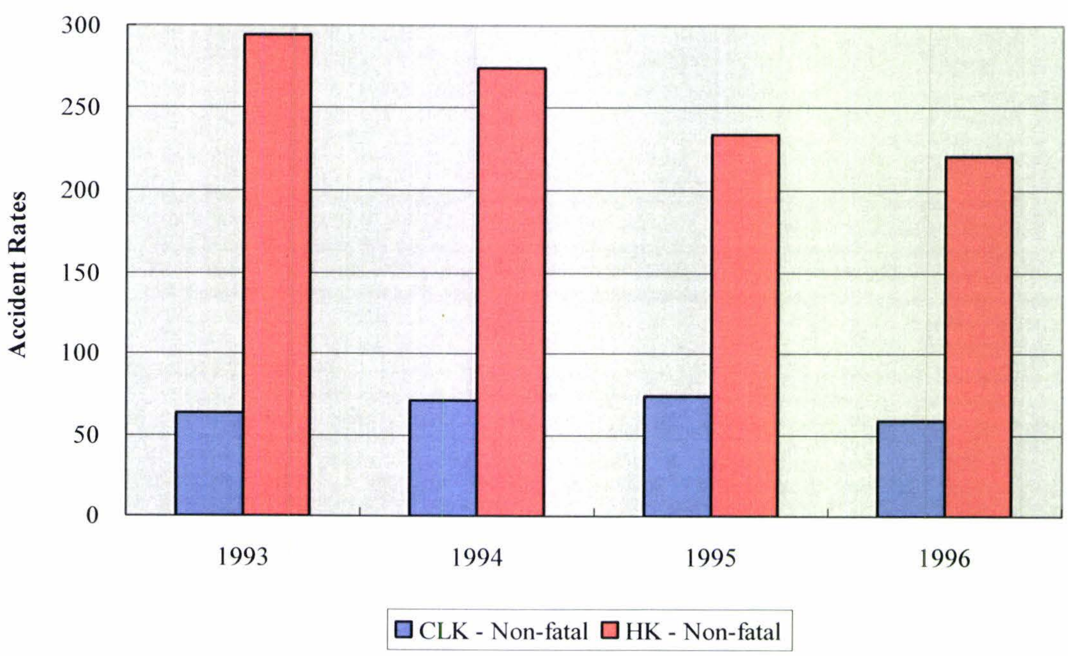

Figure 8. **Comparison of non-fatal accident rates at CLK and in the construction industry in Hong Kong.**

The Mann-Whitney U Test was carried out between the CLK construction workers and their Hong Kong counterparts on accident rates and showed that there was a statistically significant difference between the CLK construction workers and the construction workers elsewhere in Hong Kong, $U = 10$, $P < 0.05$. The mean rank of construction workers elsewhere in Hong Kong is higher than the mean rank of CLK construction workers and so construction workers elsewhere in Hong Kong had a higher accident rates than did the CLK construction workers.

Nature of Injury Incurred

The workplace injuries are illustrated in Figure 9 and a full description of the data can be inspected in Appendix 3. The most common workplace injury at CLK was contusion and crushing, followed by laceration, and then fracture and muscular strain. Of the total 1236 injuries on duty, two-thirds (n = 824) sustained single injuries. The remaining 412 injured workers had two injuries each. None had more than two injuries. The total number of injuries was 1648.

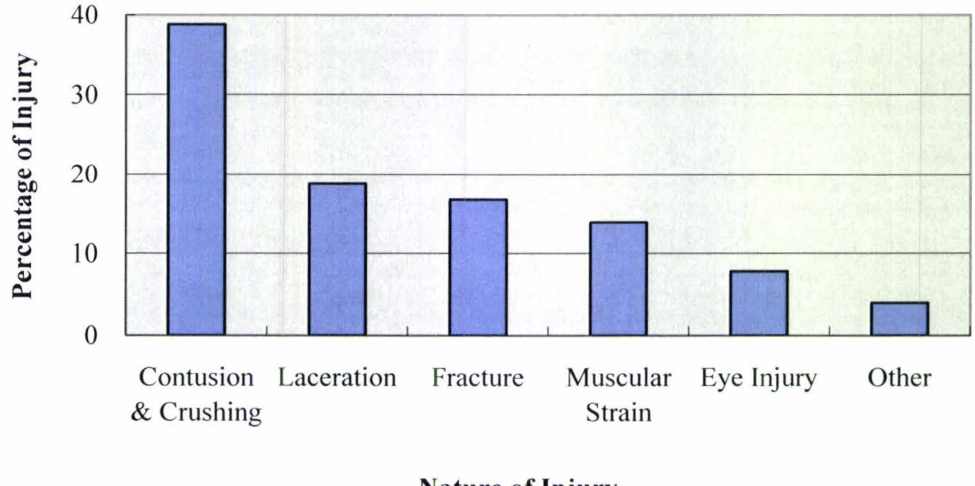

Figure 9. **Percentage of the nature of injury.**

Upper limbs were the commonest part of the body to be injured (30%), followed closely by lower limb injuries (26%). Back and head injuries accounted for 8% and 6 % respectively. As much as 32% of these injuries were caused by being struck by moving objects or by flying/falling objects. Slips, trips or falls on the same level accounted for 14% of these work accidents. Other serious injuries recorded were: sunstroke (n = 48), electrocution (n = 8), and falls from a height of 2 or more metres (n = 124). The three fatal cases in 1996 were as the result of drowning (n = 1), electrocution (n = 1) and road traffic accident (n = 1).

Nature of accidents

The circumstances leading to the occurrence of accidents were analysed with reference to two components: "human errors" and "contributing factors", which comprised a number of unsafe acts, unsafe conditions, and personal factors.

The most commonly identified errors were memory lapses, violations, and slips, followed by rule-based and knowledge-based mistakes (Figure 10 and a full description of the data can be inspected in Appendix 4). These results were very similar to that of the Hobbs and Williamson's (2003) study in aircraft maintenance. Furthermore, they concurred with the findings in the research of Feyer and Williamson (1991) that human error was the commonest prime cause of accidents, it frequently exited in the precursor event sequence, and each error types might not equivalent in causal significance of workplace accidents.

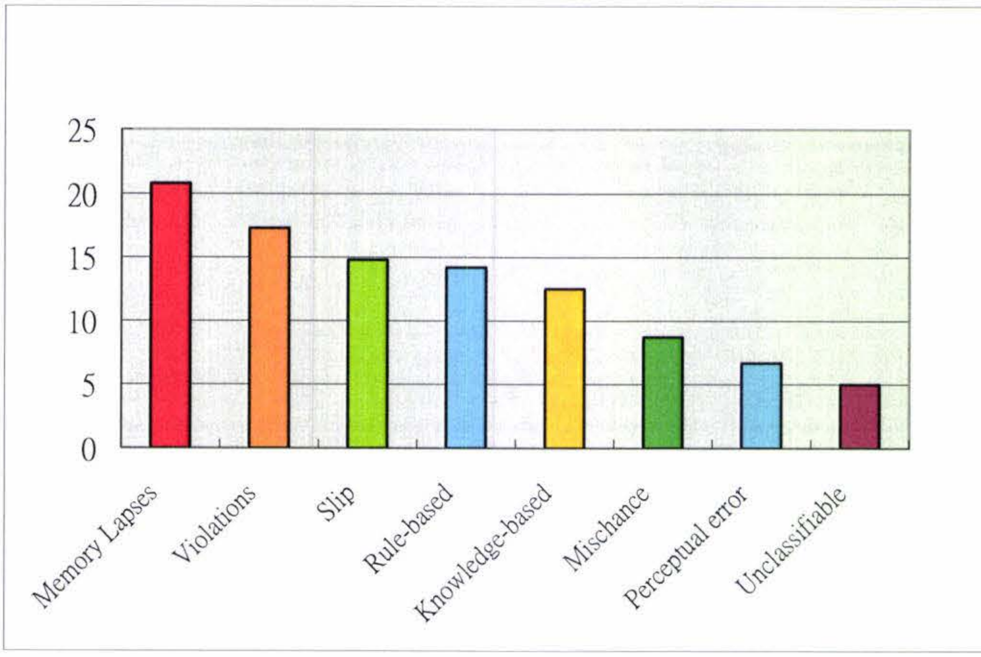

Figure 10. **Percentage of human error types amongst injured workers.**

Common memory lapse was forgetting to perform a task, such as not using safety devices, or failing to secure sharp hand tools. Violations frequently took the form of decisions to omit task procedures, the use of unapproved procedures, or failure to use correct tools or equipment. Examples of error types are given in Table 4.

Table 4. *Examples of human error types.*

Human error types	Examples
Memory lapses	Omitting to adopt a safe position or posture, or to secure objects.
Violations	Failure to use protective gear (eye protection, proper footwear), operating or working at an unsafe speed.
Slip	Incorrectly selected the wrong gears in driving a vehicle, turned switch on the conveyor belt backward instead of forward.
Rule-based error	Failure to move to safe area during filling in of excavations, to shut the water gate, or to close the barrier.
Knowledge-based error	Lack of knowledge or skills to operate new machines, improper procedures for fire evacuation.
Perceptual error	Failure to detect oncoming vehicles, to see or hear hazard warning signals.
Mischance	Unsafe layout of job and traffic, poor housekeeping,, unsafe act by another person

Associations between errors and injuries

The correspondence analysis bi-plot is shown in Figure 11 (refer to Appendix 5 for an expanded visual representation of this figure) displays the relationships between errors and the most frequent workplace injuries. It is apparent that error types were not evenly distributed across workplace injuries. Rule-based errors, memory lapse and mischance were on the extreme ends of dimension 2.

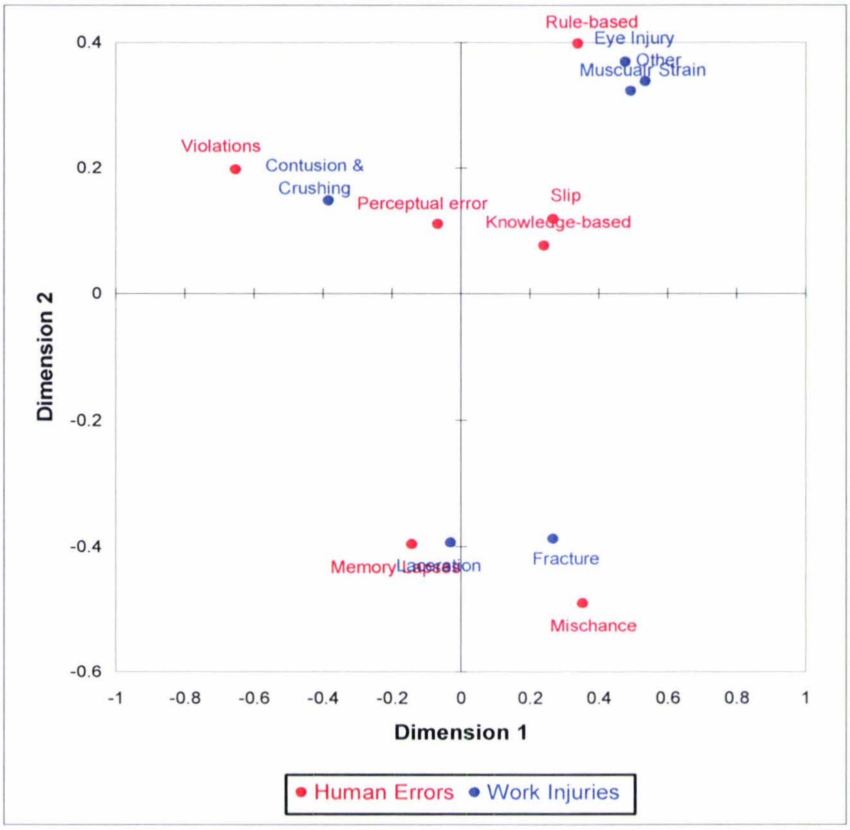

Figure 11. **Errors and injuries.**
(Refer to Appendix 5 for an expanded visual representation of this figure).

Three main clusters of errors and workplace injuries emerged:

1. Muscular strain and eye injury cluster together under rule based errors.
2. Laceration and fracture were clustered with memory lapse and mischance.
3. The third cluster of injuries, including contusion and crushing was associated with violation and perceptual error and, to a lesser extent, with slips and knowledge based mistakes.

The role of contributing factors

The most commonly found contributing factor was work pressure, which was involved in nearly one-quarter of all reported incidents, followed by equipment, procedures, training, environment, and fatigue (Figure 12 and a full description of the data can be inspected in Appendix 6). The other factors: previous deviation involved in relatively few workplace injuries and physiological was nil.

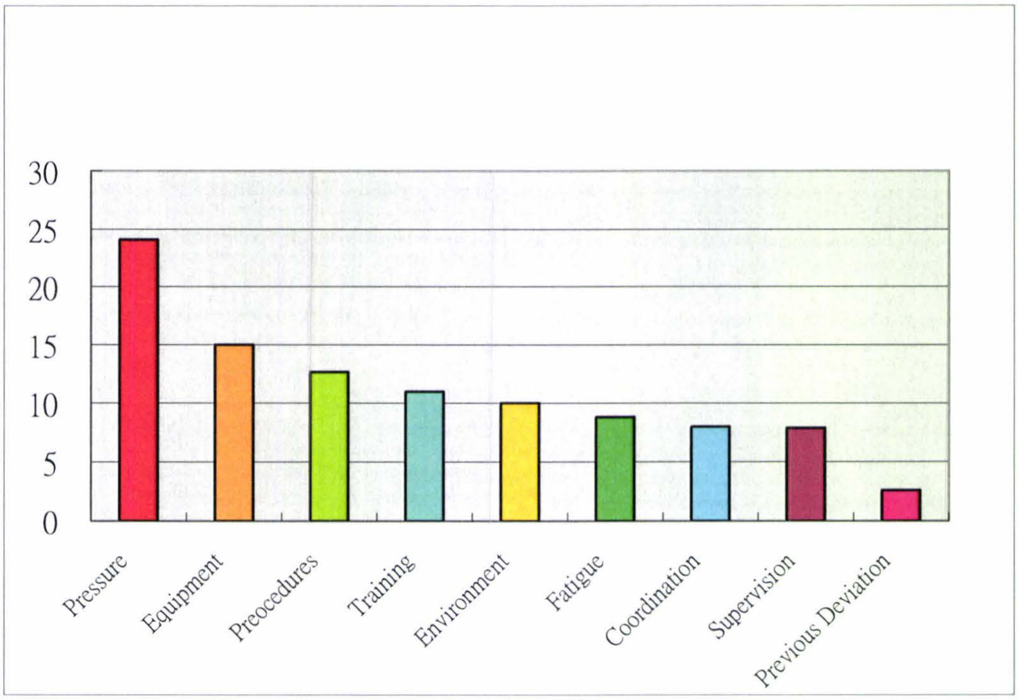

Figure 12. **Percentage of contributing factors amongst CLK injured workers.**

Chi-square analysis indicated that with the sole exception of environment, each contributing factor was significantly associated with increases in specific errors, not with uniform changes in the prevalence of all error types. It is apparent that each contributing factor (pressure, equipment, procedure, training, environment, fatigue, coordination, supervision, previous deviation) played a role in the increase of human errors. The alpha was set at .001, and most p-values (except for environment) were much less than that. The results were as follows: pressure, X^2 (6, n = 1564) = 31.18, $p<.001$; equipment, X^2 (6, n = 1564) = 42.07, $p<.001$; procedure, X^2 (6, n = 1564) = 13.14, $p<.001$; training, X^2 (6, n = 1564) = 24.77, $p<.001$; fatigue, X^2 (6, n = 1564) =

133.63, p<.001; coordination, X^2 (6, n = 1564) = 20.85, p<.001; supervision, X^2 (6, n = 1564) = 49.78, p<.001; previous deviation, X^2 (6, n = 1564) = 25.99, p<.001; environment, X^2 (6, n = 1564) = 5.91, p=.0151.

Logistic regression was used to predict the outcome of the presence or absence of the error on the basis of contributing factors. In all cases, factors as a set were able to predict the presence or absence of errors at a statistically significant level. The odds ratio presents the exponent of the beta weights for each factor in relation to each error (Appendix 7). Figure 13 (refer to Appendix 8 for an expanded visual representation of this figure) presented the correspondence analysis plot showing the relationships between errors and factors.

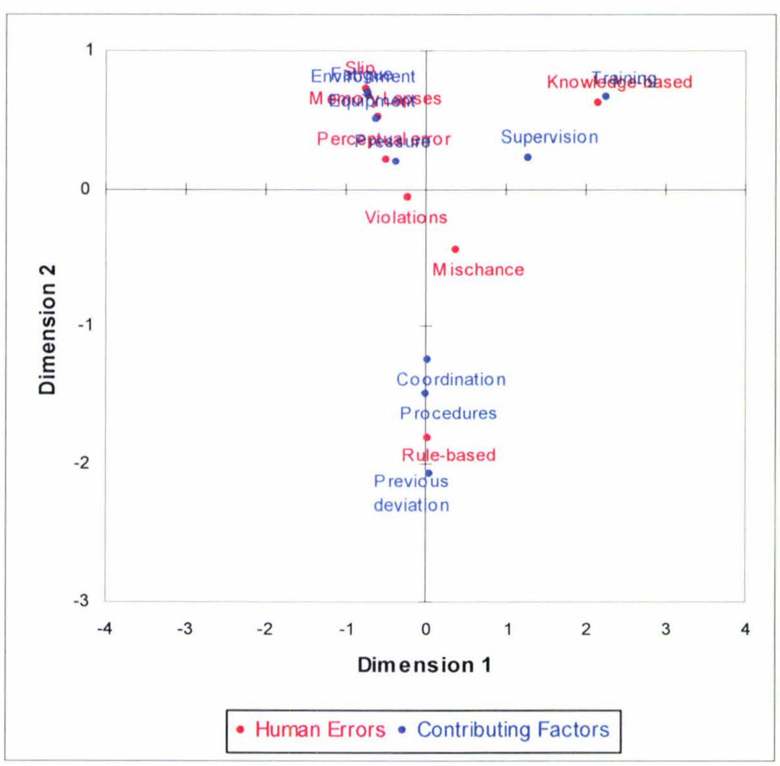

Figure 13. **Errors and contributing factors.**
(Refer to Appendix 8 for an expanded visual representation of this figure).

Figure 13 showed the following associations between error types and contributing factors:

1. Memory lapse was found to be the commonest error type. It was associated with work pressure, equipment deficiencies, poor working environment and fatigue. When pressure was listed as a contributing factor, the odds of a memory lapse were 4.35 times higher than when pressure was not a factor (Appendix 7). Pressure, however, was not associated with an increase in the prevalence of slips, rule-based, and knowledge-based errors. Appendix 7 also indicated that when fatigue was listed as a factor, the odds of a memory lapse were 4.75 times higher than when fatigue was not a factor. Fatigue, however, was not associated with an increase in the prevalence of violations, rule-based and knowledge-based errors.
2. Rule-based errors clustered with previous deviations, procedures, and coordination. Appendix 7 shows that when previous deviation was listed as a contributing factor, the odds of a rule-based error were 141 times higher than when previous deviation was not a factor. Procedure was associated with a nearly 22 times increase in the odds of rule-based errors and coordination an almost 9 times increase.
3. Knowledge-based error was common amongst migrant workers in CLK. There was a very strong association between knowledge-based error and training. When training was listed as a contributing factor, the odds of a knowledge-based error were approximately 300 times higher than when training was not a factor (Appendix 7).
4. Slips (as a human error type) were most closely related to environment factors, equipment deficiencies and fatigue. Appendix 7 illustrates that when

environment was listed as a contributing factor, the odds of a slip error were 8 times higher than when environment was not a factor. Equipment deficiencies were associated with a 7-fold increase in the odds of slip errors and fatigue nearly 5 fold.

5. Violation error was found to be closely associated with pressure. Appendix 7 demonstrates that when work pressure was listed as a contributing factor, the odds of a violation error were 4 times higher than when work pressure was not a factor. Perceptual error was associated with a 2-fold increase in the incidence of violation error.

DISCUSSION

Construction is considered to be one of the most dangerous industries (Snashall, 1990). However, Hong Kong construction workers have even higher accident and mortality rates than other developed countries. Of the industrial accidents reported to the Hong Kong Factory Inspectorate, the factory inspectors only investigate fatal industrial accidents, those involving multiple victims and those caused by faulty equipment or machinery. For accidents other than the above, little information is available. This study provides important new information on the causes and types of errors which have led to occupational injuries among construction workers in Hong Kong. The research demonstrated that accident rates among workers at the CLK construction site were significantly lower than at other construction sites in Hong Kong. It also showed that at CLK, the commonest workplace injury, human error type and contributing factor were contusion & crushing, memory lapses and work pressure respectively. Furthermore, the results indicated some relationship between what types of human error were most closely linked with what kinds of injuries and what conditions were most likely to trigger workplace accidents/incidents. Among the associations were links between memory lapses and work pressure, equipment deficiencies, poor working environment and fatigue; between knowledge-based error and inappropriate training; and between rule-based error and previous deviations, procedures and coordination.

The age range of the CLK workers

The age range of the CLK workers was very similar to that of the majority of Hong Kong construction workers (29 - 39 years) (Lee, 1996). Similarly, male workers at the CLK site constituted about 95% of the workforce, which was similar to the gender composition on construction sites across Hong Kong. There was no evidence that the CLK workers were engaged in activities dissimilar in kind from other construction as defined under the Hong Kong Factories and Industrial Undertakings Ordinance Cap. 59. Therefore, the CLK and Hong Kong workers appeared to be similarly matched for age, gender and occupational categories.

Accidents in relation to occupational trades

In 1993, the CLK concretors had the highest accident rate. Cement and concrete were made on site to build roads, buildings, taxi ways and runways and for filling-in excavations. It was particularly risky for the CLK concretors when they worked in unsupported excavations and confined spaces. For example, the sides collapsed, trapping or burying the workers, the spoil (soil and rock taken out of the ground while digging an excavation) fell back into the excavation because it was piled too near to the top edge, the workers did not move fast enough to safe areas when concrete was tipped into excavations. All employers must ensure that the sides of excavations are supported and guard-rails are fitted around the top of excavation, arrange authorised persons to inspect their excavations regularly, provide safe entrances and egresses of their excavations, etc. The workers must follow the safety system of work and report to their employers anything that they consider to be unsafe.

Accident rates

The accident rates for the CLK construction workers were statistically lower than for construction workers elsewhere in Hong Kong. This could be due to the fact that the new airport authority made significant efforts to reduce hazardous working conditions and to promote health and safety among CLK workers. The accident rates increased during 1994 and 1995 but declined in 1996. This might have been due to the nature of the preparatory groundwork such as using explosives to flatten hills on three islands, reclamation of land and excavations in 1994/5, which were more hazardous than later construction work, and to the less well developed transportation system, organizational and training arrangements in the earlier years. Such accidents could be prevented by applying strategies such as the design for construction safety concept. Behm (2005) defined it as the consideration of construction site safety in the design of a project. He showed that 42% of fatalities reviewed in his study were linked to poor designs and suggested that 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. Accident prevention can be both proactive and reactive. Proactive measures can improve the physical environment, machines, tools, working methods and work organization, while reactive efforts aim at the workers and help them to cope with the risks more effectively. These include the provision of information to workers on occupational injury risks, for example, "do not attempt to operate any item of plant if you are not competent and authorised; after dark and at other times when the light is not so good, remember that you will be more difficult to see; be aware of plant moving close to you, etc."; and training in safety behaviour and human factors.

Nature of Injury Incurred

The commonest injuries were contusion and crushing and the most frequently affected body parts were hand, arm and shoulder injuries. Road traffic accident, slips (as in lose balance/footing), trips, and falls on level ground or from a height were common workplace accidents in CLK, resulting in head injuries and/or contusion and crushing injuries. In addition, many contusion and crushing injuries happened when the conveyor belt system for transportation of luggage and the escalators for travellers were tested. A number of CLK workers took their rest breaks on the belts and on the escalators as their breaks were usually short (five to ten minutes) and they did not want to spend any time walking to the rest rooms some distance away. When these machines were put on test modes, some of these workers could not get out of the way fast enough and were trapped. Apart from these workers violated the rules on-site; such incidents also highlighted the deficiencies of communication and supervision. Hands and fingers are the most frequently used body parts in the construction industry. Sanchez (1990) has also shown that finger and thumb injuries account for 11-14% of the total in all industries, and found them to be second in frequency to trunk injuries. Lack of stringent safety regulations and lack of training were two important factors contributing to hand and finger injuries in CLK. All employers must not allow the workers to use any hand tool, whether powered or not, unless it is safe to use and the workers are trained and competent to do so. All tools with sharp edges should be properly guarded and stored after use. All employers must also supply their workers with appropriate gloves whenever there is a hazard to the hands and fingers that can only be controlled by the used of them. It is the "last resort" method of controlling any risk.

Nature of accidents

Being struck by moving objects was noted to be the most common type of accident. A majority of these in CLK were road traffic accidents. CLK Island is huge and transport is essential. In 1993 and 1994, there were no proper roads as they were still under construction. In the later years, (1995, 1996) the finished roads were very busy and usually very congested. Moreover, the vehicles used in CLK were very old and poorly maintained, and the drivers often inexperienced. Workers with these types of accident were noted to sustain contusion and crushing injuries and fracture. Being struck by flying and falling objects was the second commonest type of accident. A lack of protective machine covers caused such incidents. In CLK, the general practice was to surround structures with plastic sheeting or nets to catch waste and rubbish or objects accidentally falling from buildings under construction. No code of practice or guideline was available to CLK contractors on what to use under different circumstances. It might be that the whole structure should be enveloped in canvas or sheets of plastic to prevent objects from falling outside the immediate work area. Slips, trips or falls on the same level, and being struck by fixed objects were ranked the third and the sixth most frequent accidents in CLK respectively. These were related to the nature of the work and method of construction being used by contractors. Temporary works were not well designed and built and once no longer of use were regarded as rubbish but not removed in an orderly and tidy manner in CLK. A worker falling from a height (2 meters or higher) was noted to be the fourth commonest type of accident in CLK but there were no fatalities from this cause. Two common factors contributed to this kind of incidents: firstly the support failed and secondly, the workers tripped on objects. Both these situations were commonly encountered in CLK when work was in progress. Whenever, there is a need to work at height, all employers should try to find another way of doing it. Working at height can also mean getting to the place where workers are going to work, for example, crossing a roof or climbing a ladder. Workers should never be put in a position where they could be injured by falling. They must speak to their employers in these circumstances. If working at height is unavoidable, all employers must carry out a risk assessment and put systems in place to prevent workers from falling, or at least must ensure that when the workers fall, they are not injured, or they do not fall further than can be avoided. Safe systems of work may include guard-rails on scaffold platform, guard-rails around the deck or basket of a mobile elevating work platform, catch-barriers at the eaves of a sloping roof, restraint system such as a harness and short lanyard to keep the workers away from the edge of a flat roof, proper anchorage points, etc. Moreover, the workers must use safety equipment provided and follow any instructions that are given ensuring that the employers' safe systems of work are effective. They must keep the workplace clean and tidy and help in good house keeping. This adds to creating a "stable and organized" working environment.

Clusters of errors and workplace injuries

Muscular strain and eye injury cluster together rule based errors. In CLK, most construction workers had to perform some manual handling operation. Manual handling is the moving of any load by hand by lifting, lowering, carrying, pushing and pulling. This also includes for example, moving a load using a trolley or wheelbarrow. Poor manual handling operation can cause muscular strain. Nearly all of these workers had received appropriate training. They knew they had to first assess the weights and the shapes of the load before handling or moving them; and team lifting was always encouraged and highly recommended (Airport Authority, 1995). However, it was not uncommon for a CLK worker to lift or carry weights exceeding his/her capability. There were many bad examples in CLK: a worker had assessed the load and found it heavy, but he felt asking other workers to help made him inferior to them, and he might lose face and/or lose his job. There was a long wait before a worker could summon help as the other workers were not working in the close vicinity. He was working under pressure and just wanted to finish the task quickly. He thought he could either finish the job or to the worst, he could stop doing so if the object was found too heavy after the first trial run. And in this trial run, he sustained muscular strain. This was particularly true if the weight that the worker needed to handle was above his capacity and he did more than one attempt of lifting. There are many eye hazards in construction sites, such as flying debris, splashed chemicals, airborne dust and molten metal. Suitable eye protection must be worn when required. Each CLK construction worker was issued with a pair of safety goggles. They were trained when and how to use them. However, it was not uncommon to see workers not using them in very hot weather, or after getting themselves from the cold environment to the warm environment due to condensation on the goggles.

Laceration and fracture were clustered with memory lapse and mischance. In CLK, there were significant numbers of accident caused by the movement and operation of vehicles and site plants. These accidents involved not only the driver or operator but also people on foot who were working close at hand or only passing by. These "mobile plants" included dumper trucks, mobile cranes, lorries, mobile excavators and road rollers. Generally these plants are large and the drivers have restricted views. Some plants do not have to be moving across the ground to be a danger to a worker. For example, a mobile crane that is slewing, an excavator digging a hole or a lorry tipping materials, while not actually travelling, can still be a danger to people on foot who get too close. When after dark and at other times when the light is not so good, the chance of a mobile plant accident increases. Furthermore, a lot of road traffic accidents resulted in injuring the workers with lacerations and fractures. At the early stage, the roads and the vehicles were in fairly poor conditions; the road signs were almost absent; and the driving standards varied from poor to reasonable depending on where the workers received their coaching. Some injured drivers believed that the reason they crashed onto the other vehicles or obstacles was a mischance. Some admitted that they had omitted stopping at the junctions or give ways; checking blind spots before over taking, etc. The reasons of memory lapse included: they were too tired at work, the weather was too hot, they were thinking about the next job, etc. On the other hand, the injured pedestrians often blamed the drivers for their brief absence mindedness just before the accidents. None of the injured pedestrians at CLK (e.g., workers walked across the road, workers walked along the pavement, etc.) admitted that the accidents were the results of their own fault.

The third cluster of injuries, including contusion and crushing was associated with violation and perceptual error and, to a lesser extent, with slip and knowledge-based mistakes. Slips (as in lose balance/footing), trips, and falls on level ground or from height were common workplace accidents in CLK resulting in head injuries and/or contusion and crushing injuries. These injured workers often claimed that they had missed a step on the stairs or had not seen the edge of a platform, had not spotted the obstacles, had not perceived the warning signals (visual or aural), etc. Only a few workers admitted that they had broken any rules. They believed that their ways of working were far more effective than to follow the normal procedures. In order to get in and out of a constructing tunnel quicker or to get up and down of scaffold faster, safety helmets were not worn and safety harnesses were no utilised. Slip (as a human error type) errors such as when the conveyor belt was switched on but in the reverse mode and went backwards, escalators were turned on but ran in the wrong direction, etc. happened in the CLK workers. As previous discussed, a lot of training was conducted for the CLK construction workers but the official languages were Chinese and English. Many migrant workers might not fully understand content of the teaching and the instructions; and the worst scenario was that they pretended they understood them in order to stay in the posts. This would attribute to some of knowledge-based mistakes found in this research.

Clusters of errors and contributing factors

Memory lapse was associated with work pressure, equipment deficiencies, poor working environment and fatigue. In CLK, many projects had to meet deadlines. Moreover, bad weather such as heavy rains and storms delayed building work.

When work is performed under unusual/unreasonable time pressure, workers would not only want to complete the tasks quickly and on time, their body and mind were also affected. Their heart rates and breathing rates would increase, their blood pressure would go up, their stressor chemicals and hormones would be released. This is now commonly called work stress. It can affect the brain causing it momentary failure and results in omitting an intended action, which might play a part in a workplace accident. Many CLK construction workers preferred to use their own hand tools. Besides the many power tools such as those driven by petrol, electricity and compressed air used on site, there are also non-powered hand tools such as handsaws, hammers, spades, trowels and pipe benders. They all have their inherent risk of causing injury. Apart from choosing the right tool for the job, the workers must also conduct a safety inspection before using these equipments. This study also showed that when workers had no equipment for work or poorly designed and maintained work tools to help performing their duties, memory lapse did occur. It could be the result of the workers constantly thinking of new ways conducting the jobs without the necessary equipment instead of concentrating in the chores. It is known for a long time that adverse work conditions (e.g., darkness, glare, height, excessive noise, poor ventilation, etc.) and fatigue (e.g., mental or physical or both) can affect work performance and cause workplace accident. This study also showed that both work environment and fatigue were associated with memory lapse and workplace accidents in CLK. In summary, the research suggested that work pressure was an important contributing factor to workplace injury and it increased the prevalence of a human error type namely, memory lapse many time. However, work pressure was not found to be associated with an increase in the frequency of slip or rule-based error or knowledge-based error. Furthermore, this study indicated that fatigue also increased the occurrence of memory lapse but not the frequencies of violation, rule-based and knowledge-based errors.

Rule-based error clustered with previous deviations, procedures, coordination. Previous deviations, for example, an early incorrect task that also involved in a subsequent accident, are quite common in the construction sites. Construction work is very dynamic and the building structures change continuous as the time past. Old temporary buildings have to torn down and debris removed from the sites. In CLK, these kinds of work were not always correctly completed or followed the set rules leaving potential safety hazards behind that might cause latent accidents. Keeping the work area clean and tidy is an important part of working safely. However, in CLK waste materials were not always cleaned away and disposed of properly. Spilt liquids such as diesel oil and liquid waste such as paints or chemicals were carelessly allowed to sink into ground or get into a drain or sea. It is a common sense that poorly designed and/or documented work procedures could cause workplace accidents and in this study, it was showed to be associated with rule-based errors. In order to carry out a large construction project such as the CLK airport, team work is essential; and to make the team as an effective working force, good communication between the team members is paramount. Good communication of health and safety information is essential to control risks and prevent accidents and ill health. This study demonstrated that good communication and coordination could reduce rule-based error. In brief, previous deviation is an important contributing factor to workplace injury, which was found to be associated with an increase in the prevalence of three human error types, namely, rule-based error, procedure and coordination, but to different degrees.

Knowledge-based error was common amongst migrant workers in CLK as their command of English and Chinese were poor, which made teaching and coaching them ineffective. This study showed a very strong association between knowledge-based errors and training. As stated previously, a lot of traditional training was provided to CLK workers. Different training methods and media such as refresher courses, guidelines, booklets, talks, posters, pamphlets, etc. had also been tried and the whole onsite infrastructure had improved, yet workplace accidents still happened. This research showed that there were other contributing factors and human error types that were in association with these adverse events and indicated that training perspective is only one of the many approaches that can reduce construction site injury.

In this study, slip as a human error type, was most closely related to environment factor, equipment deficiencies and fatigue. Each of them was associated with the augmentation of the incidence of slip but to different extent. Adverse working conditions (e.g., darkness, glare, height, excessive noise, poor ventilation, etc) are common in construction sites and CLK made no exception. As all CLK projects were worked under tight schedules, the workers had to perform hard and fast. When a worker had to work under these situations, the person might have difficulty concentrating and focusing on the job he/she was doing. Equipment deficiency would merely amplify these shortcomings and contributing to an incident/accident.

The research showed that pressure was closely associated with violations and perceptual errors and it would increase the prevalence of violation and perceptual error to different levels.

Implications of the associations between contributing factors, human error types and injuries

Accidents are caused by a complex web of situation and behavioural factors (Kjellen, et al., 1990). In this study, many injuries were wholly or partly a result of the behaviour of CLK construction workers. The most frequent error was memory lapse. There were four other important types of human error in this study including violation, slip, knowledge-based error, and rule-based error. In most cases, particular contributing factors were associated with an increased incidence of particular errors rather than with an overall increase in all forms of error. Although some of the associations (e.g., between training and knowledge-based errors, and between pressure and perceptual errors) would be expected by definition, in other cases the current findings represent new information.

Skill-based errors (e.g., slip, memory lapse, and perceptual errors), rule-based and knowledge-based errors were each associated with different clusters of contributing factors. Some of these factors (e.g., fatigue, pressure, and the environment) that were associated with the skill-based errors could be considered local or transitory in nature. Knowledge-based and rule-based errors were linked with lack of training and poor procedures respectively. These factors may represent longstanding organizational issues. Fatigue was found to be associated with failures to carry out intentions such as memory lapses and perceptual errors but was not associated with knowledge-based or rule-based errors. The reasons were that there was an easier or quicker way than the formal procedures or that the procedure was unclear. McDonald, et al., (2000) also found that 34% of routine maintenance tasks at airlines were conducted contrary to procedures. In this study, the injured persons did not mention procedural problems when explaining why violations occurred. It could be due to the fact that each study used different definitions of violation. The violations in the study of McDonald et al. were "routine" violations as reported by Lawton (1998), whilst the workplace injuries described in this study are "exceptional" violations (rare actions that occur in unusual situations).

Although this study did not allow causal inferences to be drawn from the patterns of errors, factors and workplace injuries, associations among contributing factors, particular errors, and workplace injuries could be established. For example, the close relationship between rule-based errors and eye injury suggests that a useful way to reduce this injury would be to target rule-based errors and the conditions that promote them such as inadequate training and supervision. In general, the specific links between errors and contributing factors can provide guidance for managers seeking to reduce the incidence of human error. It appears that human error reduction strategies would be best tailored to specific errors and their particular contributing factors rather than to human error in general. Rule-based errors could be addressed by improvements in coordination between workers, such as through team training. Taylor and Christensen (1998) made a similar suggestion. Focus on the management of worker fatigues and production pressures may help to reduce the incidence of memory lapses, the most common form of error. Similarly, violations could be addressed by better management of situational factors such as production pressures and equipment deficiencies. Although it is highly unlikely that factors such as fatigue or pressure can be entirely eliminated from the workplace, it may be helpful to train workers in strategies to cope with time pressures and to ensure that shift rosters are designed in such a way that fatigue is kept to absolutely minimum. The associations between contributing factors and particular errors also have the potential to assist with the prediction of human reliability. For example, fatigued personnel can be expected to be at particular risk of memory lapses and a job environment in which workers are denied correct or properly functioning equipment might be expected to increase the odds of slip and violation.

Limitations of the study

This research is a retrospective study. The information was accrued from reviewing all accident investigation reports but not the more detailed medical records for ethical reason. Furthermore, the data was not originally collected in a way that allowed for easy investigation into error causation. Interpretation error might happen.

The accident and fatality rates were not expressed in million man-hour worked, which is a more accurate and reliable means of measuring accident and fatality rates. However, the Hong Kong government has never represented these rates in million man-hour worked.

Selection bias might occur. This study was conducted in CLK and hence is limited in its representativeness. The incidents they reported might have been atypical. However, CLK is the one and the only one new airport built in Hong Kong in recent years. Fatal injuries were not studied, nor were those treated in outpatient clinics if any.

There are many differences in building types between constructing an airport and building skyscrapers, and these needs to be considered. The researcher has tried to obtain similar data from the new Singapore International Airport and the new Thailand International Airport for comparisons but have been unsuccessful.

Information bias and motivational influences (Safren & Chapanis, 1960) might have happened in this study. Injured worker might have been unaware of some of the circumstances surrounding the accident they described, or they might have filtered or elaborated their statement on the basis of preconceived notions concerning errors and their causes. However, when information was sought on the environmental conditions of the work-site and the availability and use of safety equipment, workers were generally keen to report irregularities and to offer explanations for accident causation.

This study was based on reports of work discrepancies and no information was available on the occasions when tasks were completed without injury. Observations of pilot behaviour during routine flights have helped to put in context the behaviour of cockpit crews during abnormal situations (Helmreich, et al., 2001). Such an approach may also be useful in the construction site, where evaluating the level of error-producing conditions during normal construction tasks could help to establish more clearly their role in error production.

CONCLUSIONS AND RECOMMENDATIONS

This research described the pattern of injuries sustained by the CLK construction workers treated in an onsite medical centre and the circumstances leading to their accidents. Several environmental and human factors were highlighted.

The average age of native Hong Kong construction workers has increased since the 1980's (Lee 1996). Aging workers and aging population are now worldwide concerns. As there are many psychological and physical problems in an aging workforce, work on evaluating health and other disabling risks for older construction workers and assessing the range of rehabilitation provisions that might mitigate serious or permanent disabilities among this sector of the workforce population has become very important (Kowalski-Trakofler, et al., 2005; Wong, 1998). Further research in aging workforce is encouraged.

Nearly half of the injured workers at CLK had a past history of a previous workplace injury. In a search for the "accident prone" several studies have shown that the neurotic extravert is more likely to be involved in a driving accident than the stable introvert (Shaw & Sichel, 1971) and that those identified in the questionnaire studies as "adventurous" have a much greater probability of being involved in a flying accident (Levine, et al., 1976). Further research into the associations between personality traits and workplace injury is recommended.

Being struck by moving objects was noted to be the most common type of accident in CLK. A majority of these were road traffic accidents. It is also one of the most common causes of lost time injuries in the U.S. and Canada (Pekka, 1998). It is advisable that good access roads should be built in the early phrase of a construction project with appropriate signage, the vehicles should be in good working order and well maintained, and operated by the experienced drivers.

Temporary works in a construction site are not normally well designed and built and once no longer of use are regarded as rubbish. However, they were not removed in an orderly and tidy manner in CLK or elsewhere in Hong Kong (Lee, 1996). Housekeeping on most sites needs improvement in Hong Kong. Singapore has taken more positive action in dealing with the problem, involving mandatory removal of rubbish and clean-up action before proceeding with further construction.

A worker falling from a height (2 meters or higher) was noted to be the fourth commonest type of accident in CLK and there were no fatalities from this cause.

However such falls are commonly fatal in the U.S. and the Canadian construction industries (30%) (James, 1998) and in Hong Kong (29%) (Labour Department, 1998). James (1998) suggested two common factors contributing to people falling at workplaces: firstly the support may fail and secondly, the workers may trip on objects. Nevertheless, in Hong Kong, construction workers not wearing safety belts and safety harnesses when work at height are not uncommon. In CLK, workers who needed to work at height were instructed to use safety belts and safety harnesses. In addition, classroom and practical trainings on use of safety belts and safety harnesses were available, and no one was allowed to work at height without this training. Yet CLK safety officers could still find workers without belts and harnesses at height during their frequent patrols. Why did these workers violate the rules? Has training contributed to reduce injury as a result of fall at height? If so, by how much? And how much training is adequate? These are interesting questions for the future research.

Workers in construction need to participate in improving health and safety standards on site. By contributing to the consultation process with their employer and with principal contractors, workers can help to prevent dangerous conditions from developing on site. For example, if the danger of any hand tool is fed back to and addressed by the designers, some of the hand tool injuries could be avoided. Lim and Oishi (1996) reported that a two-handed screwdriver with a longer handle increases torque on the object and reduces stress on the wrists. Workers should be encouraged to participate in the design of safety systems within the construction industry. Safety must be treated as an integral element in a holistic approach to production in order to minimize construction project risk and enhance worker safety. Workers in construction still need to develop their skills in identifying risks and be confident in speaking out when they see something wrong.

Conversely, stringent safety regulations should be followed in the construction industry and workers should be adequately trained in their jobs as well as in the application of safety measures. CLK workers with better training in health and safety practices sustained significantly less injury at work. This reduction should also lessen medical costs, compensation costs, insurance premiums, etc and provide excellent incentives for owners and financiers to invest in occupational safety and health.

Much still needs to be done in improving the work environment and promoting safety education among construction site workers in Hong Kong. Moreover, better understanding of the human factors-based causes of accidents and injuries in the construction industry and the inculcation of a safety culture on construction sites require urgent attention. They are critically important in reducing the rate of construction accidents and improving workers' human performance.

This study suggested that there were important relationships between human error types and contributing factors. The current findings showed that the particular circumstances in which errors occur should be a key target for safety interventions. This may help in assisting the design of accident prevention strategies, the estimation of human error probabilities, and the monitoring of organizational safety performance. Future research is needed to determine whether the associations found between human error and contributing factors in this study (construction site) and in the study of Hobbs and Williamson, (2003) in aircraft maintenance would also be evident in other industries. Eventually, stimulated tasks in the laboratory may be able to provide the best opportunity to control the presence or absence of error-producing conditions and to examine the relationships between errors and contributing factors.

This research is a retrospective study. The information was accumulated from reviewing all accident investigation reports, in which the data was not originally collected in a way that allowed for easy investigation into error causation. Interpretation error might happen. And if these accident investigation reports were reviewed by more than one researcher, inter-observer variability would occur, which could further amplified the interpretation error. Alternatively, if the researcher limited the number of observers, there would be a long wait until the results could be obtained, particularly in large studies. It is recommended that prospective study should be performed, but with newly designed medical records or investigation reports, in which only seven human error types and the ten contributing factors as described in this study could be chosen. This will allow quick and uncomplicated analysis into human error related accidents in large study in and in different industry.

Thorough research is needed into the means by which to launch an effective programme to promote work-site safety. The audience for such programmes should include the Labour Department, company directors and managers, the unions and the workforce.

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Appendix 1: Accident in relation to occupation trades in CLK.

Trade	Percentages of Accidents (& Accident Rates per 100,000 Man-hours)				
	1993	1994	1995	1996	Average in 4 years
Labourer	7 *(1.87)*	20 *(3.01)*	29 *(3.38)*	26 *(2.63)*	21 *(2.82)*
Carpenter & Jointer	<3 *(11.09)*	3 *(3.02)*	11 *(2.44)*	15 *(2.79)*	8 *(2.72)*
Rigger	0 *0*	<3 *(1.47)*	9 *(5.41)*	11 *(2.83)*	6 *(3.2)*
Marine Craft crew	43 *(2.3)*	21 *(2.09)*	<3 *(0.41)*	0 *0*	16 *(1.85)*
Welder	12 *(8.17)*	8 *(5.12)*	3 *(3.31)*	3 *(1.76)*	7 *(2.98)*
Fitter/Mechanic	4 *(6.04)*	6 *(7.14)*	5 *(2.83)*	3 *(1.79)*	5 *(2.70)*
Plant operator	6 *(1.97)*	7 *(2.25)*	4 *(1.16)*	<3 *(0.39)*	5 *(0.90)*
Survey leveller/labourer	0 *0*	<3 *(0.67)*	<3 *(1.02)*	<3 *(1.03)*	<3 *(0.98)*
Concretor	5 *(33.89)*	0 0	<3 *(1.12)*	3 *(1.43)*	3 *(1.61)*
Other	20 *(5.34)*	29 *(4.36)*	30 *(3.50)*	33 *(3.34)*	28 *(4.14)*

Appendix 2: Overall accident statistics for CLK.

Period	No. of Fatalities	No. of non-fatal reportable accidents	Accident rate (per thousand workers per year)	
			Fatal	Non-fatal
1993	0	93	0 (1.4)*	63.62 (294)*
1994	0	163	0 (0.85)*	71.7 (274)*
1995	0	308	0 (0.95)*	74.18 (233)*
1996	3	669	0.26 (0.68)*	59.04 (220)*

(*Note: corresponding accident rates for the construction industry in Hong Kong excluding CLK figures are in brackets).

There was a statistically significant difference between the accident rates of the CLK construction workers and the HK counterpart ($U = 10$, $P = 0.021$).

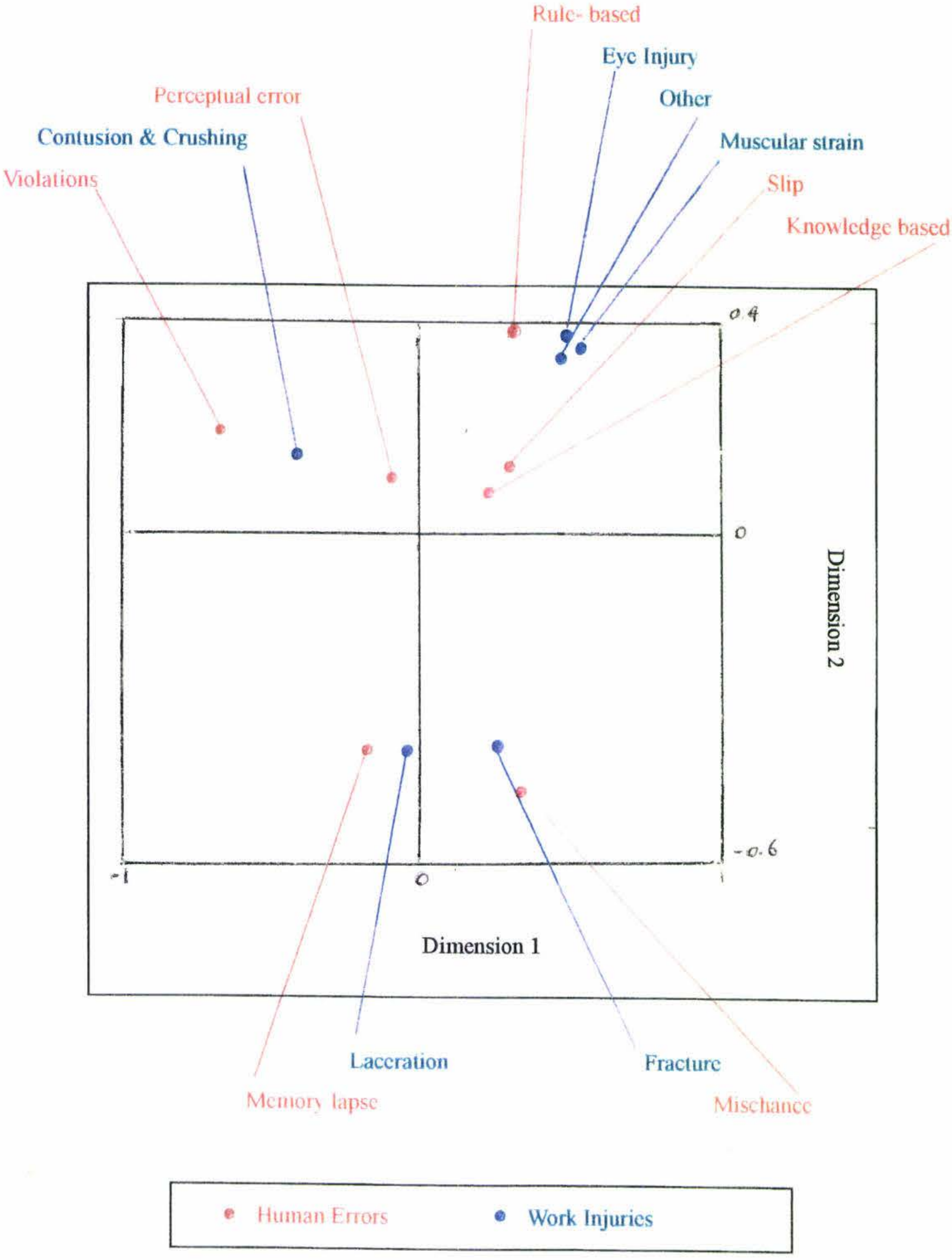
Appendix 3: Nature of injury.

Nature of injury	Number of injuries	Percentage
Contusion & crushing	639	38.8
Laceration	310	18.8
Fracture	277	16.8
Muscular strain	227	13.8
Eye injury	129	7.8
Other	66	4.0
Total	1648	100

Appendix 4: Percentage of human error.

Human errors	Number	Percentage
Memory lapses	342	20.8
Violations	285	17.3
Slip	244	14.8
Rule-based	234	14.2
Knowledge-based	206	12.5
Mischance	143	8.7
Perceptual error	110	6.7
Unclassifiable	84	5.1

Appendix 5: Expanded visual representation of Figure 11.
(Refer to Figure 11, page 51).



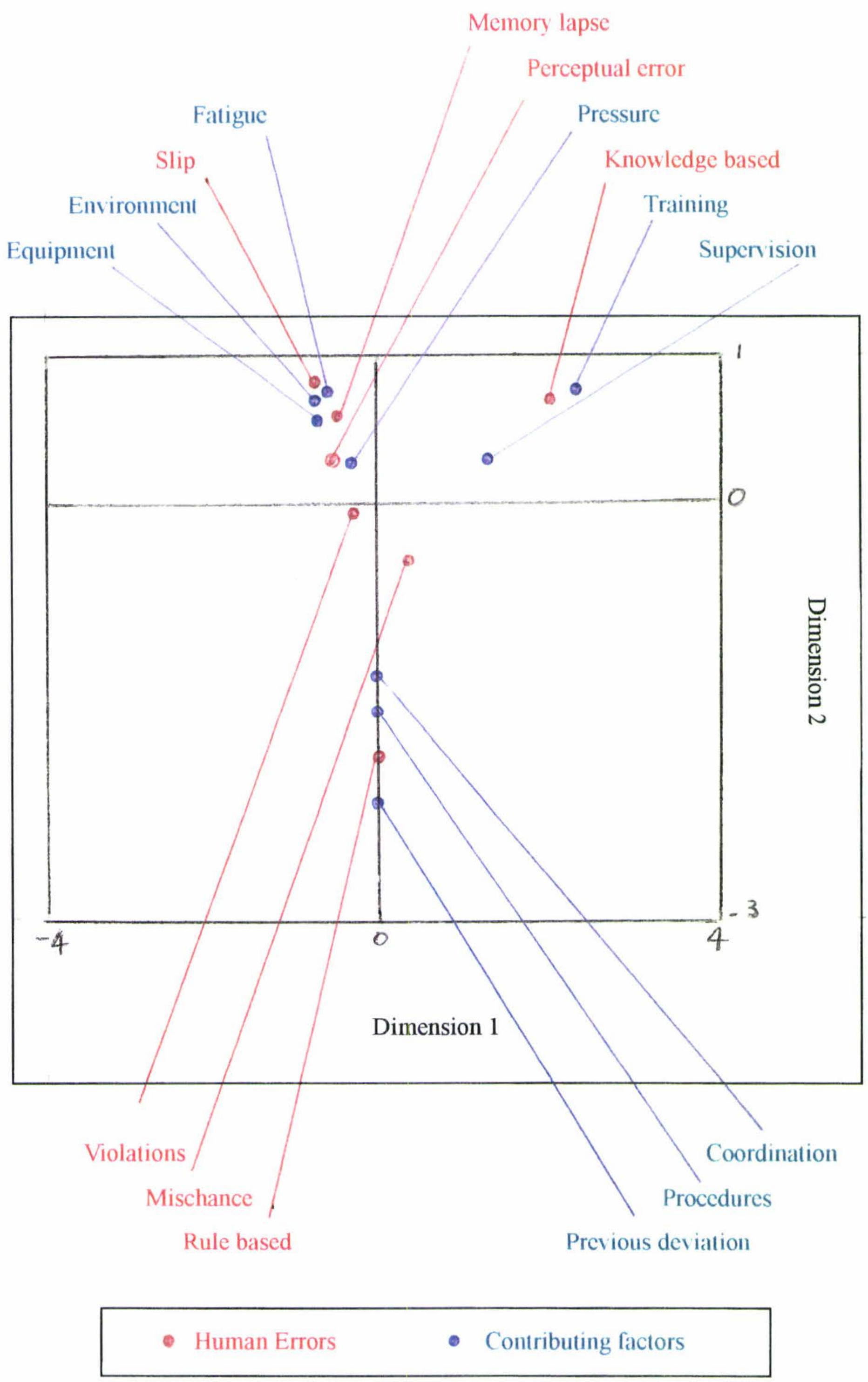
Appendix 6: Percentage of contributing factors.

Factors	Number	Percentage
Pressure	397	24.1
Equipment	247	15.0
Procedures	208	12.6
Training	181	11.0
Environment	165	10.0
Fatigue	145	8.8
Coordination	132	8.0
Supervision	130	7.9
Previous deviation	43	2.6

Appendix 7: This showed the strength of associations between factors and errors. Expressed as Frequencies and as Odds Ratios (OR).

	Memory Lapse		Violation		Slip		Rule based		Knowledge based		Perceptual		Mischance	
Contributing factors	n	OR	n	OR	n	OR	n	OR	n	OR	n	OR	n	OR
Pressure	167	4.35	136	3.74	0		0		0		40	1.82	44	1.40
Equipment	42	0.75	59	1.64	105	6.91	0		0		29	2.17	0	
Procedures	0		44	1.41	0		125	21.96	0		0		22	1.35
Training	0		0		0		0		142	299.06	0		10	0.68
Environment	61	2.33	5	0.12	83	7.78	0		0		16	1.49	0	
Fatigue	72	4.75	0		56	4.56	0		0		9	0.92	0	
Coordination	0		13	0.48	0		68	8.52	0		16	2.02	32	3.93
Supervision	0		28	1.33	0		0		64	9.58	0		33	4.33
Previous deviation	0		0		0		41	141.06	0		0		2	0.48

Appendix 8: Expanded visual representation of Figure 13.
(Refer to Figure 13, page 53).



Appendix 9: This showed the relationship between human error types and the nature of injuries in CLK. Memory lapses were the commonest errors and contusion & crushing were the commonest injuries.

	Injuries					
Errors	**Contusion & crushing**	**Laceration**	**Fracture**	**Muscular strain**	**Eye injury**	**Other**
Memory lapses (342 errors)	128	110	71	20	8	5
Violations (285 errors)	211	33	21	7	11	2
Slip (244 errors)	76	38	43	61	23	3
Rule-based (234 errors)	82	12	37	53	34	16
Knowledge-based (206 errors)	57	54	21	31	39	4
Mischance (143 errors)	29	23	65	13	9	4
Perceptual error (110 errors)	52	13	19	24	2	0
Unclassifiable (84 events)	4	27	0	18	3	32
Total 1648	**639**	**310**	**277**	**227**	**129**	**66**

Appendix 10: This showed the relationship between contributing factors and the nature of injuries in CLK. Pressure was the commonest contributing factor and contusion & crushing the commonest injuries. Work performed under unusual/unreasonable time pressure causes stress. Contusion & crushing injuries were results of road traffic accidents and slips and falls (see text).

	Injuries					
Contributing Factors	**Contusion & crushing**	**Laceration**	**Fracture**	**Muscular strain**	**Eye injury**	**Other**
Pressure (397)	169	80	71	30	43	4
Equipment (246)	91	53	41	45	14	3
Procedures (208)	84	46	31	32	13	2
Training (181)	79	34	28	30	4	6
Environment (165)	52	37	23	19	29	5
Fatigue (145)	42	29	41	27	2	4
Coordination (132)	44	22	21	31	9	5
Supervision (130)	49	2	19	11	14	35
Previous deviations (43)	29	7	2	2	1	2
Total 1684	**639**	**310**	**277**	**227**	**129**	**66**

Appendix 11: This showed the relationship of human errors and contributing factors. Memory lapses were the commonest error types and work pressure was the commonest contributing factors.

	Contributing Factors								
Errors	**Pressure**	**Equipment**	**Procedures**	**Training**	**Environment**	**Fatigue**	**Coordination**	**Supervision**	**Previous deviation**
Memory lapses (342 errors)	167	42	0	0	61	72	0	0	0
Violations (285 errors)	136	59	44	0	5	0	13	28	0
Slip (244 errors)	0	105	0	0	83	56	0	0	0
Rule-based (234 errors)	0	0	125	0	0	0	68	0	41
Knowledge-based (206 errors)	0	0	0	142	0	0	0	64	0
Mischance (143 errors)	44	0	22	10	0	0	32	33	2
Perceptual error (110 errors)	40	29	0	0	16	9	16	0	0
Unclassifiable (84 events)	10	12	17	29	0	8	3	5	0
Total 1648	**397**	**247**	**208**	**181**	**165**	**145**	**132**	**130**	**43**

Appendix 12: This showed the relationships between injuries, human error types and contributing factors. Pressure was the commonest contributing factor and might play a role in 397 workplace injuries in CLK. Out of these, 167 cases might be related to memory lapse type of human errors (see text).

Workplace injuries	Human error types	Contributing factors
397	Memory lapse = 167 Violation = 136 Mischance = 44 Perceptual error = 40 Unclassifiable = 10	Pressure
247	Slip = 105 Violation =59 Memory lapse = 42 Perceptual error = 29 Unclassifiable = 12	Equipment
208	Rule-based = 125 Violation = 44 Mischance = 22 Unclassifiable = 17	Procedures
181	Knowledge-based = 142 Mischance = 10 Unclassifiable = 29	Training
165	Slip = 83 Memory lapse = 61 Perceptual error = 16 Violation = 5	Environment
145	Memory lapse = 72 Slip = 56 Perceptual error = 9 Mischance = 8	Fatigue
132	Rule-based = 68 Mischance =24 Perceptual error = 16 Violation = 13 Unclassifiable = 11	Coordination
130	Knowledge-based = 64 Mischance = 33 Violation = 28 Unclassifiable = 5	Supervision
43	Rule-based = 41 Mischance = 2	Previous deviation
0	0	Physiological
	Unclassifiable (84)	
Total = 1648	**Total = 1564**	