Models of Causation: Safety

Core Body of Knowledge for the Generalist OHS Professional

Safety Institute of Australia Ltd

Australian OHS Education Accreditation Board

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OHS Professionals has been developed under the
auspices of the **Health and Safety Professionals Alliance**

haspa

The Technical Panel established by the Health and Safety
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The Technical Panel comprised representatives from:

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The Safety Institute of Australia supported the development of
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through the Australian OHS Education Accreditation Board which
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Synopsis of the OHS Body of Knowledge

Background

A defined body of knowledge is required as a basis for professional certification and for accreditation of education programs giving entry to a profession. The lack of such a body of knowledge for OHS professionals was identified in reviews of OHS legislation and OHS education in Australia. After a 2009 scoping study, WorkSafe Victoria provided funding to support a national project to develop and implement a core body of knowledge for generalist OHS professionals in Australia.

Development

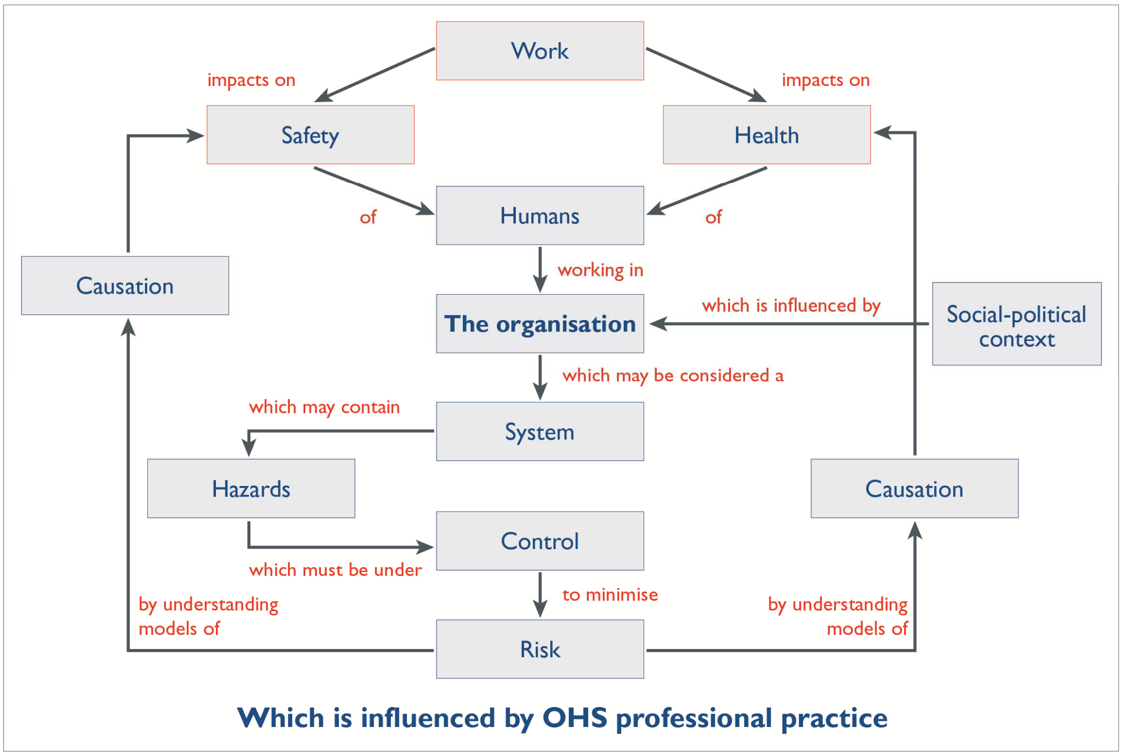
The process of developing and structuring the main content of this document was managed by a Technical Panel with representation from Victorian universities that teach OHS and from the Safety Institute of Australia, which is the main professional body for generalist OHS professionals in Australia. The Panel developed an initial conceptual framework which was then amended in accord with feedback received from OHS tertiary-level educators throughout Australia and the wider OHS profession. Specialist authors were invited to contribute chapters, which were then subjected to peer review and editing. It is anticipated that the resultant OHS Body of Knowledge will in future be regularly amended and updated as people use it and as the evidence base expands.

Conceptual structure

The OHS Body of Knowledge takes a ‵conceptual′ approach. As concepts are abstract, the OHS professional needs to organise the concepts into a framework in order to solve a problem. The overall framework used to structure the OHS Body of Knowledge is that:

> **Work** impacts on the **safety** and **health** of humans who work in **organisations**. Organisations are influenced by the **socio-political context**. Organisations may be considered a **system** which may contain **hazards** which must be under control to minimise **risk**. This can be achieved by understanding **models causation** for safety and for health which will result in improvement in the safety and health of people at work. The OHS professional applies **professional practice** to influence the organisation to being about this improvement.

This can be represented as:



Audience

The OHS Body of Knowledge provides a basis for accreditation of OHS professional education programs and certification of individual OHS professionals. It provides guidance for OHS educators in course development, and for OHS professionals and professional bodies in developing continuing professional development activities. Also, OHS regulators, employers and recruiters may find it useful for benchmarking OHS professional practice.

Application

Importantly, the OHS Body of Knowledge is neither a textbook nor a curriculum; rather it describes the key concepts, core theories and related evidence that should be shared by Australian generalist OHS professionals. This knowledge will be gained through a combination of education and experience.

Accessing and using the OHS Body of Knowledge for generalist OHS professionals

The OHS Body of Knowledge is published electronically. Each chapter can be downloaded separately. However users are advised to read the Introduction, which provides background to the information in individual chapters. They should also note the copyright requirements and the disclaimer before using or acting on the information.

Models of Causation: Safety

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Core Body of Knowledge for the Generalist OHS Professional

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Models of Causation: Safety

Abstract

Understanding accident causation is intrinsic to their successful prevention. To shed light on the accident phenomenon, over the years authors have developed a plethora of conceptual models. At first glance they seem as diverse and disparate as the accident problem they purport to help solve, yet closer scrutiny reveals there are some common themes. There are linear models which suggest one factor leads to the next and to the next leading up to the accident and there are complex non linear models which hypothesise multiple factors are acting concurrently and by their combined influence, lead to accident occurrence. Beginning with a look at the historical context, this chapter reviews the development of accident causation models and so the understanding of accidents. As this understanding should underpin OHS professional practice the chapter concludes with a consideration of the implications for OHS professional practice.

Key words

accident, occurrence, incident, critical incident, mishap, defence/s, failure, causation, safety

Note from the Body of Knowledge Technical Panel and the authors of this chapter:
The development of theories and modeling of accident causation is a dynamic field with the result that there is often a gap between the theoretical discussion and practice. This chapter has taken on the difficult task of collating a selection of models and presenting them in a format that should facilitate discussion among OHS professionals. It is considered 'version 1' in what should be a stimulating and ongoing discussion. It is anticipated that this chapter will be reviewed in the next 12 months.

Contents

1 Introduction

Accidents have been broadly defined as:

> a short, sudden and unexpected event or occurrence that results in an unwanted and undesirable outcome é and must directly or indirectly be the result of human activity rather than a natural eventâ (Hollnagel, 2004, p. 5)

Accident prevention is the most basic of all safety management paradigms. If safety management is effective, then there should be an absence of accidents. Conversely, if accidents are occurring then effective safety management must be absent. Therefore, understanding how accidents occur is fundamental to establishing interventions to prevent their occurrence. A simple nexus it would seem, yet the reality is accidents are complex events, seldom the result of a single failure, and that complexity has made understanding how accidents occur problematic since the dawn of the industrial revolution.

In an attempt to unravel the accident causation mystery, over the years authors have developed a plethora of conceptual models. At first glance they appear to be as diverse and disparate as the accident problem they purport to help solve, yet closer scrutiny reveals there are some common themes. There are linear models which suggest one factor leads to the next and to the next leading up to the accident, and complex non linear models which hypothesise multiple factors are acting concurrently and by their combined influence, lead to accident occurrence. Some models have strengths in aiding understanding how accidents occur in theory. Others are useful for supporting accident investigations, to systematically analyse an accident in order to gain understanding of the causal factors so that effective corrective actions can be determined and applied.

> Accident models affect the way people think about safety, how they identify and analyse risk factors and how they measure performance é they can be used in both reactive and proactive safety management é and many models are based on an idea of causality ... accidents are thus the result of technical failures, human errors or organisational problems. Hovden, Albrechtsen and Herrera, 2010, p.855).

This chapter builds on the discussion of hazard as a concept[1] to trace the evolution of thinking about accident causation through the models developed over time thus it forms a vital foundation for developing the conceptual framework identified as an essential component of professional OHS practice[2]. The importance of models of causation to OHS professional practice is highlighted by Kletz:

> To an outsider it might appear that industrial accidents occur because we do not know how to prevent them. In fact, they occur because we do not use the knowledge that is available. Organisations do not learn from the past é and the organisation as a whole forgets. (1993.)

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[1] See *OHS BoK* Hazard as a Concept

[2] See *OHS BoK* Practice: Model of OHS Practice

2 Historical context

Perhaps the earliest well documented application of accident causation knowledge is that of the Du Pont company which was founded in 1802 with a strong emphasis on accident prevention and mitigation. Klein (2009), in a paper entitled ñTwo Centuries of Process Safety at DuPontò reported that the company founder E.I. Du Pont (1772 ï 1834) had once noted ñwe must seek to understand the hazards we live withò. The design and operation of Du Pont explosives factories, over the next 120 years, were gradually improved as a result of a consistent effort to understand how catastrophic explosions were caused and prevented. In that period many of the principles of modern accident prevention theory were formulated. By 1891 management accountability for safe operations was identified as a necessary precept to such an extent that the original Du Pont plant design included a requirement for the Directorôs house, in which Du Pont himself, his wife and seven children lived, to be constructed within the plant precinct, a powerful incentive indeed to gain an understanding of accident causation. As described by DeBlois (1915), the first head of DuPontôs Safety Division, elimination of hazards was recognised as the priority in 1915 and a goal of zero injuries was also established at that time. Amongst a list of other safety management initiatives which would still be considered appropriate in todayôs companiesô safety programs, the Du Pont Safety Division was established in their Engineering Department in 1915 and carried out plant inspections, conducted special investigations and analysed accidents.

Accident research was also reported as being part of the work of the British Industrial Health Board between the two World Wars (Surry, 1969). Surry cited Greenwood and Woodsô (1919) statistical analysis of injuries in a munitions factory and Newboldôs (1926) study of thirteen factories which also reviewed injuries purported to be the first research work into industrial accidents. Various other studies around the time (Osborne, Vernon & Muscio 1922; Vernon 1919;1920; Vernon, Bedford & Warner 1928) examined previously unresearched areas of working conditions such as humidity, work hours, workers age, experience and absenteeism rates. Surry also reported that the appearance of applied psychologists influenced research studies to focus on ôhuman outputô and during the 1930s attention was directed towards the study of individual accident proneness. Surry noted that ñpure accident research declined after 1940 while the study of performance influencing factors has flourishedò (p. 17).

The history of accident modelling itself can be traced back to the original work by Herbert. W. Heinrich, whose book *Industrial Accident Prevention* in 1931 became the first major work on understanding accidents. Heinrich stated that his fundamental principles for applying science to accident prevention was that it should be: ñ(1) through the creation and maintenance of an active interest in safety; (2) be fact finding; and (3) lead to corrective action based on the factsò (Heinrich, 1931, p. 6). Heinrichôs book, now in its 5th edition, attempted to understand the sequential factors leading to an accident and heralded in what can be termed a period of simple sequential linear accident modelling. While sequential linear models offered an easy visual representation of the ópathô of causal factor development leading to an accident they did not escape the widely accepted linear time aspect of events which is tied into the ñWestern cultural world-view of past, present and future as being part of everyday logic, prediction and linear causationò (Buzsáki, 2006, p. 8).

3 Evolution of models of accident causation

The history of accident models to date can be traced from the 1920s through three distinct phases (Figure 1):

- Simple linear models
- Complex linear models
- Complex non-linear models. (Hollnagel, 2010).

Each type of model is underpinned by specific assumptions:

- The simple linear models assume that accidents are the culmination of a series of events or circumstances which interact sequentially with each other in a linear fashion and thus accidents are preventable by eliminating one of the causes in the linear sequence.
- Complex linear models are based on the presumption that accidents are a result of a combination of unsafe acts and latent hazard conditions within the system which follow a linear path. The factors furthest away from the accident are attributed to actions of the organisation or environment and factors at the sharp end being where humans ultimately interact closest to the accident; the resultant assumption being that accidents could be prevented by focusing on strengthening barriers and defences.
- The new generation of thinking about accident modelling has moved towards recognising that accident models need to be non-linear; that accidents can be thought of as resulting from combinations of mutually interacting variables which occur in real world environments and it is only through understanding the combination and interaction of these multiple factors that accidents can truly be understood and prevented. (Hollnagel, 2010).

Figure 1 portrays the temporal development of the three types of model and their underpinning principle. The types of model, their evolution, together with representative examples are described in the following sections.

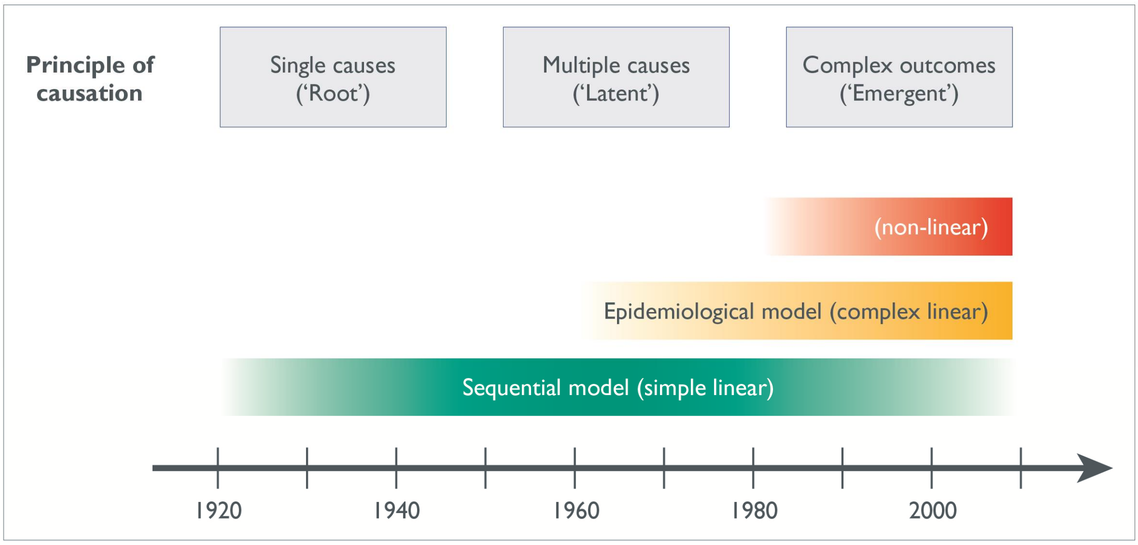

Figure 1: Summary of a history of accident modelling (Hollnagel, 2010, slide 7)

3.1 Simple sequential linear accident models

Simple sequential accident models represent the notion that accidents are the culmination of a series of events which occur in a specific and recognisable order (Hollnagel, 2010) and now represent the ñcommonest and earliest model of accident research ... that describing a temporal sequenceò where the ñaccident is the overall description of a series of events, decisions and situations culminating in injury or damage .. a chain of multiple eventsò (Surry, 1969).

3.1.1 Heinrichôs Domino Theory

The first sequential accident model was the óDomino effectô or óDomino theoryô (Heinrich, 1931). The model is based in the assumption that:

> the occurrence of a preventable injury is the natural culmination of a series of events or circumstances, which invariably occur in a fixed or logical order é an accident is merely a link in the chain. (p. 14).

This model proposed that certain accident factors could be thought of as being lined up sequentially like dominos. Heinrich proposed that an:

> é accident is one of five factors in a sequence that results in an injury é an injury is invariably caused by an accident and the accident in turn is always the result of the factor that immediately precedes it. In accident prevention the bullôs eye of the target is in the middle of the sequence ï an unsafe act of a person or a mechanical or physical hazard (p. 13).

Heinrichôs five factors were:

- Social environment/ancestry
- Fault of the person
- Unsafe acts, mechanical and physical hazards
- Accident
- Injury.

Extending the domino metaphor, an accident was considered to occur when one of the dominos or accident factors falls and has an ongoing knock-down effect ultimately resulting in an accident (Figure 2).

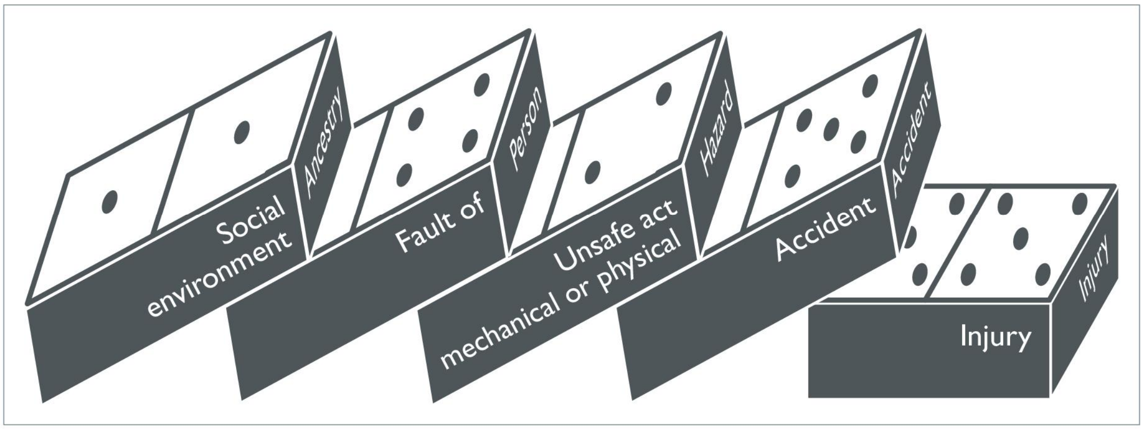

Figure 2: Domino model of accident causation (modified from Heinrich, 1931)

Based on the domino model, accidents could be prevented by removing one of the factors and so interrupting the knockdown effect. Heinrich proposed that unsafe acts and mechanical hazards constituted the central factor in the accident sequence and that removal of this central factor made the preceding factors ineffective. He focused on the human factor, which he termed ñMan Failureò, as the cause of most accidents. Giving credence to this proposal, actuarial analysis of 75,000 insurance claims attributed some 88% of preventable accidents to unsafe acts of persons and 10% to unsafe mechanical or physical conditions, with the last 2% being acknowledged as being unpreventable giving rise to Heinrichôs chart of direct and proximate causes (Heinrich, 1931, p.19). (Figure 3)

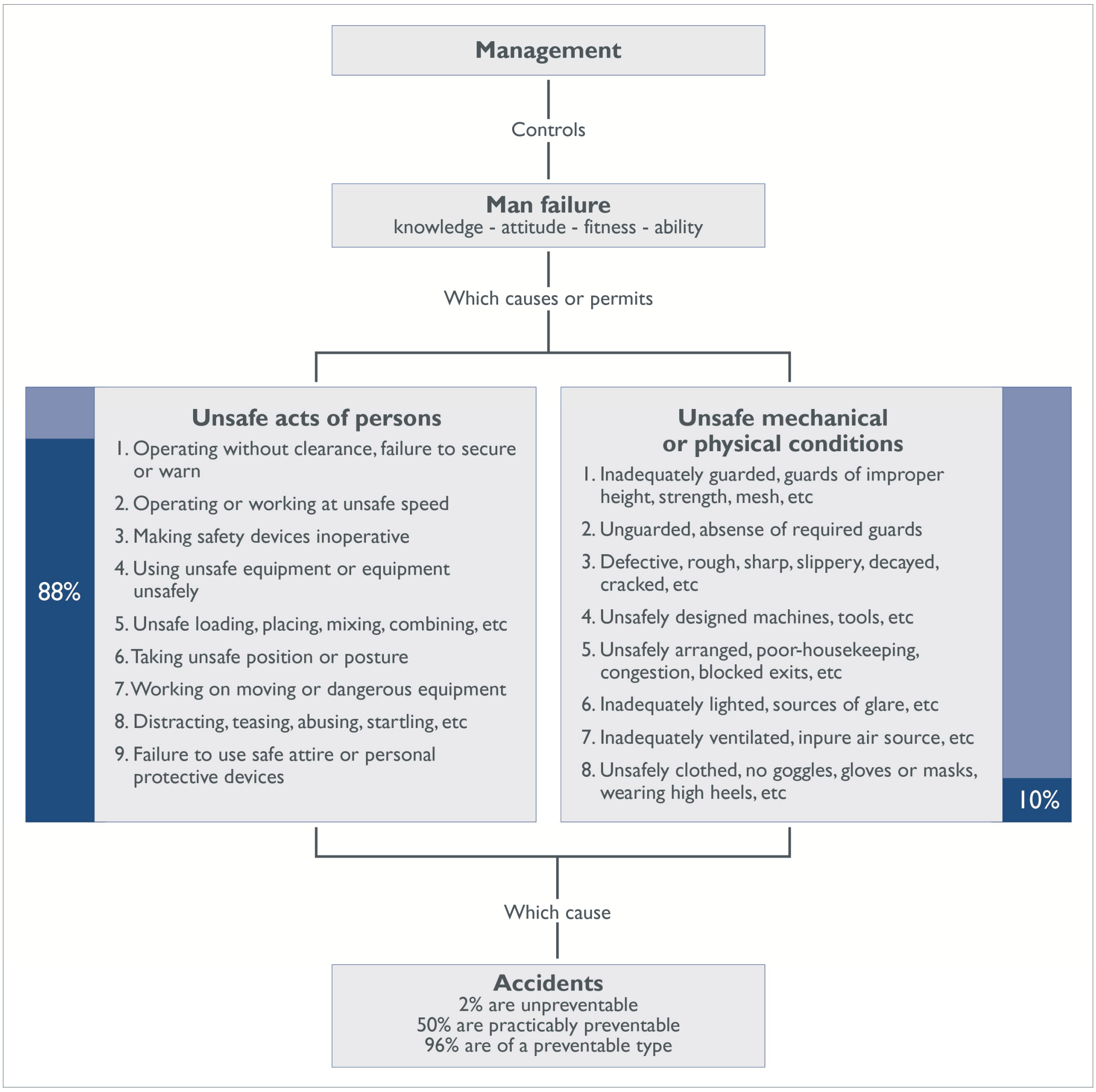

Figure 3: Direct and proximate accident causes according to Heinrich (1931)

3.1.2 Bird and Germainôs Loss Causation model

The sequential domino representation was continued by Bird and Germain (1985) who acknowledged that the Heinrichôs domino sequence had underpinned safety thinking for over 30 years. They recognised the need for management to prevent and control accidents in what were fast becoming highly complex situations due to the advances in technology. They developed an updated domino model which they considered reflected the direct management relationship with the causes and effects of accident loss and incorporated arrows to show the multi-linear interactions of the cause and effect sequence. This model became known as the *Loss Causation Model* and was again represented by a line of five dominos, linked to each other in a linear sequence (Figure 4).

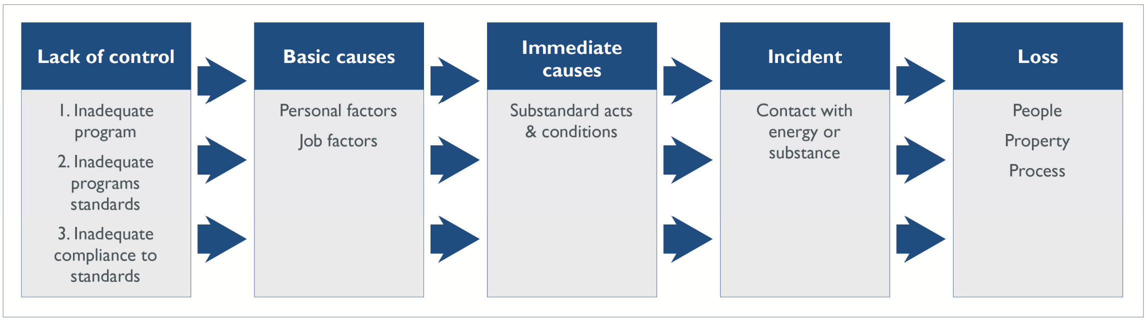

Figure 4: The International Loss Control Institute Loss Causation Model (modified from Bird and Germaine, 1985)

3.2 Complex linear models

Sequential models were attractive as they encouraged thinking around causal series. They focus on the view that accidents happen in a linear way where A leads to B which leads to C and examine the chain of events between multiple causal factors displayed in a sequence usually from left to right. Accident prevention methods developed from these sequential models focus on finding the root causes and eliminating them, or putting in place barriers to encapsulate the causes. Sequential accident models were still being developed in the 1970ôs but had begun to incorporate multiple events in the sequential path. Key models developed in this evolutionary period include energy damage models, time sequence models, epidemiological models and systemic models.

3.2.1 Energy-damage models

The initial statement of the concept of energy damage in the literature is often attributed to Gibson (1961) but Viner (1991, p.36) understands it to be a result of discussions between Gibson, Haddon and others. The energy damage model (figure 5) is based on the supposition that ñDamage (injury) is a result of an incident energy whose intensity at the point of contact with the recipient exceeds the damage threshold of the recipientò (Viner, 1991, p42).

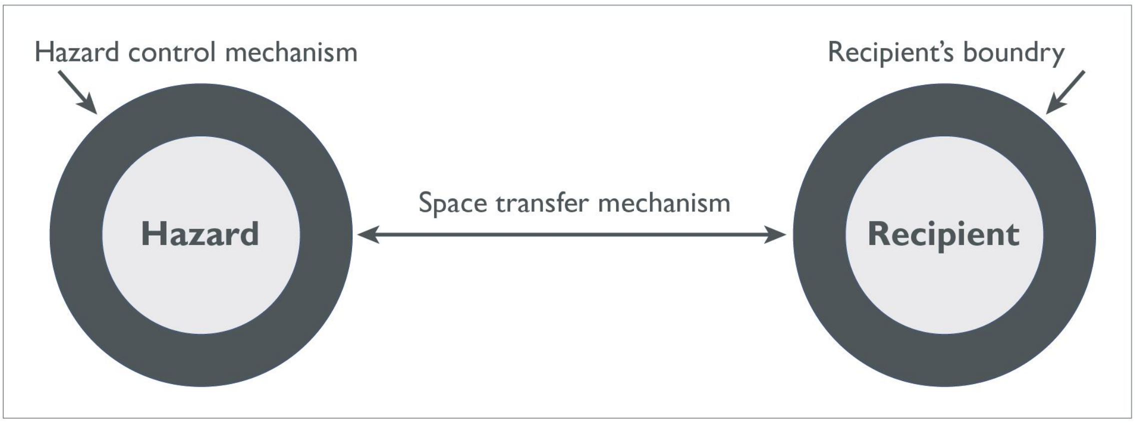

Figure 5: The Energy Damage Model (Viner, 1991, p.43)

In the Energy Damage Model the *hazard* is a source of potentially damaging energy and an accident, injury or damage may result from the loss of control of the energy when there is a failure of the *hazard control mechanism.* These mechanisms may include physical or structural containment, barriers, processes and procedures. The *space transfer mechanism* is the means by which the energy and the recipient are brought together assuming that they are initially remote from each other. The *recipient boundary* is the surface that is exposed and susceptible to the energy. (Viner, 1991)

3.2.2 Time sequence models

Benner (1975) identified four issues which were not addressed in the basic domino type model: (1) the need to define a beginning and end to an accident; (2) the need to represent the events that happened on a sequential time line; (3) the need for a structured method for discovering the relevant factors involved; and (4) the need to use a charting method to define events and conditions. Vinerôs Generalised Time Sequence Model is an example of a time sequence model that addresses Bennerôs four requirements. (Figure 6)

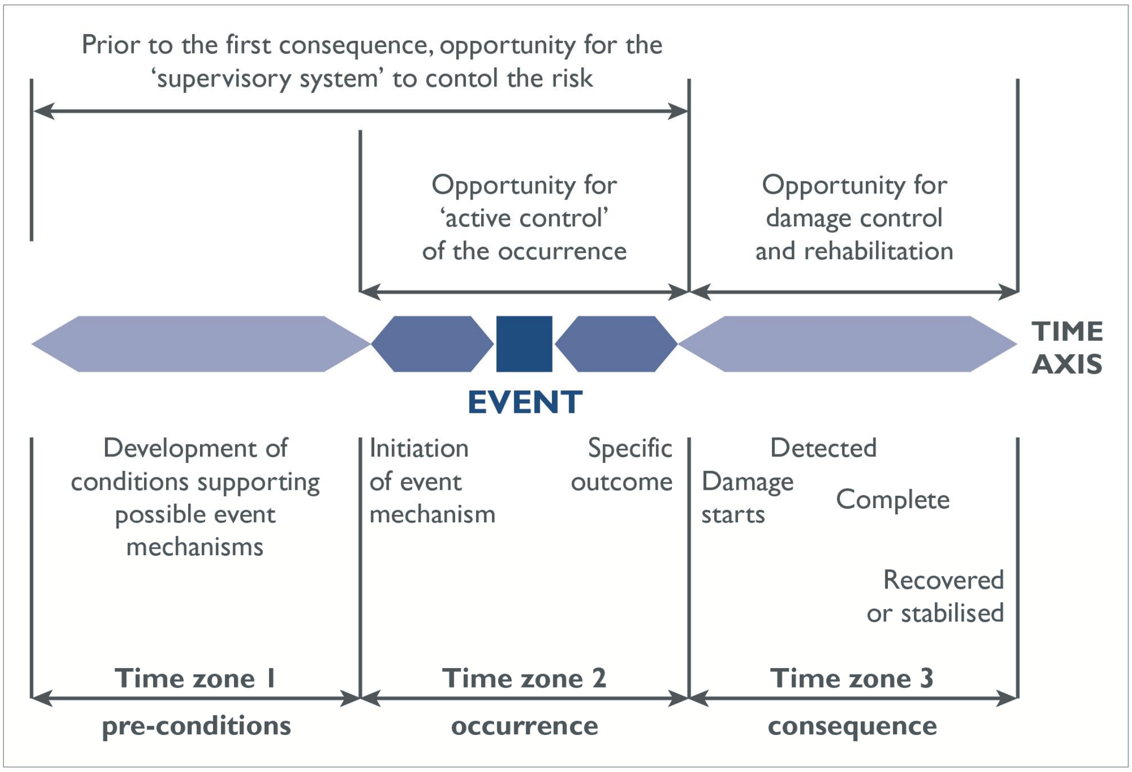

Figure 6: Generalised Time Sequence Model (Viner, 1991, p.58)

Viner considers that the structure for analysing the events in the occurrence-consequence sequence provided by the time sequence model draws attention to counter measures that may not otherwise be evident. In Time Zone 1 there is the opportunity to prevent the event occurring. Where there is some time between the event initiation and the event, Time Zone 2 offers a warning of the impending existence of an event mechanism and the opportunity to take steps to reduce the likelihood of the event while in Time Zone 3 there is an opportunity to influence the outcome and the exposed groups. (Viner, 1991)

While Viner takes a strictly linear approach to the time sequence Svenson (1991; 2001) takes a more complex approach in his Accident Evolution and Barrier Function (AEB) model. The AEB model analyses the evolution of an accident as a series of interactions between human and technical systems and is visualised as a flow chart. Svenson considers that the required analysis can only be performed with the simultaneous interaction of human factors and technical experts. (Svenson, 2001)

3.2.3 Epidemiological models

Epidemiological accident models can be traced back to the study of disease epidemics and the search for causal factors around their development. Gordon (1949) recognised that ñinjuries, as distinguished from disease, are equally susceptible to this approachò, meaning that our understanding of accidents would benefit by recognising that accidents are caused by:

> a combination of forces from at least three sources, which are the host ï and man is the host of principal interest ï the agent itself, and the environment in which host and agent find themselves (p. 506)

Recognising that doctors had begun to focus on trauma or epidemiological approaches, engineers on systems, and human factors practitioners on psychology Benner (1975); considered these as only partial treatments of entire events rather than his proposed entire sequence of events. Thus Benner contributed to the development of epidemiological accident modelling which moved away from identifying a few causal factors to understanding how multiple factors within a system combined. These models proposed that an accident combined agents and environmental factors which influence a host environment (like an epidemic) that have negative effects on the organism (a.k.a. organisation). See for example Figure 7.

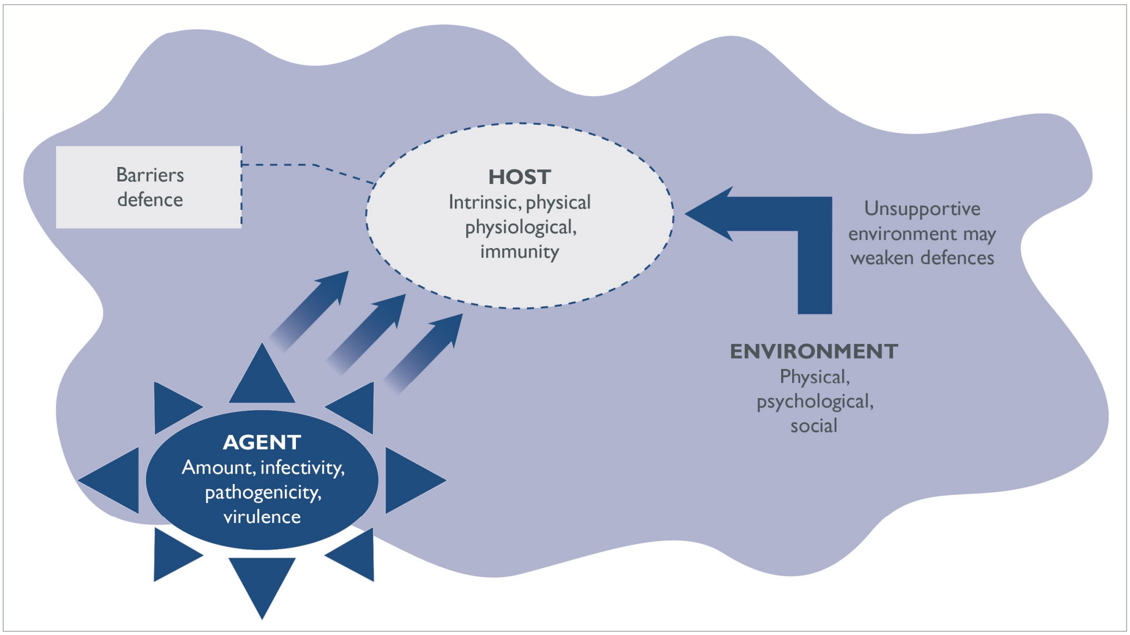

Figure 7: A generic epidemiological model (modified from Hollnagel, 2004, p.57)

Reason (1987) adopted the epidemiological metaphor in presenting the idea of óresident pathogensô when emphasising:

> the significance of causal factors present in the system before an accident sequence actually begins é and all man-made systems contain potentially destructive agencies, like the pathogens within the human body (1987, p.197).

The term became more widely known as ólatent errorsô, then changed to ólatent failuresô evolving further when the term ólatent conditionsô became preferred (Reason, 1997).

Accident prevention methods matching an epidemiological accident model focus on performance deviations and understanding the latent causes of the accident. These causes might be found in deviations or unsafe acts and their suppression or elimination can prevent the accident happening again. Errors and deviations are usually seen by OHS professionals in a negative context, and programs such as ósafe behaviourô methodologies attempt to ensure that strict rules and procedures are always followed. However safety prevention thinking is moving to an understanding that systems should be resilient enough to withstand deviations or uncommon actions without negative results.

3.2.4 Systemic models

By the 1980s OHS researchers realised that previous accident models did not reflect any realism as to the true nature of the observed accident phenomenon. As noted by Benner:

> one element of realism was non-linearity é models had to accommodate non-linear events. Based on these observations, a realistic accident model must reflect both a sequential and concurrent non-linear course of events, and reflect events interactions over time (1984, p. 177).

This was supported by Rasmussen (1990) who, whilst quoting Reasonôs (1990) resident pathogens, acknowledged that the identification of events and causal factors in an accident are not isolated but ñdepend on the context of human needs and experience in which they occur and by definition ... therefore will be circularò (p. 451).

Systemic accident models which examined the idea that systems failures, rather than just human failure, were a major contributor to accidents (Hollnagel, 2004) began to address some of these issues (but not non-linear concepts) and recognised that events do not happen in isolation of the systemic environment in which they occur.

Accident models also developed with further understanding of the role of humans, and in particular the contribution of human error, to safety research. A skill-rule-knowledge model of human error was developed in the earlier work of Rasmussen & Jensen (1974) and has remained a foundation concept for understanding of how human error can be described and analysed in accident investigation. Research by Rouse (1981) contributed to the understanding of human memory coding, storage and retrieval. Cognitive science came to the fore in accident research, and further work by Rasmussen (1981; 1986) and Reason (1979; 1984a; 1984b; 1984c) saw the widespread acceptance and recognition of the skill-based, rule-based and knowledge-based distinctions of human error in operations.

Rasmussen (1990) wrote extensively on the problem of causality in the analysis of accidents introducing concepts gleaned from philosophy on the linkage between direct cause-effect, time line and accident modelling. Rasmussen explored the struggle to decompose real world events and objects, and explain them in a causal path found upstream from the actual accident where latent effects lie dormant from earlier events or acts. At this stage, Rasmussen recognised that socio-technical systems[3] were both complex and unstable. Any attempt to discuss a flow of events does not take into account:

> closed loops of interaction among events and conditions at a higher level of individual and organizational adaption é with the causal tree found by an accident analysis is only a record of one past case, not a model of the involved relational structureò (1990, p. 454).

In calling for a new approach to the analysis of causal connections found in accident reports Rasmussen heralded in a more complex approach to graphically displaying accidents and understanding and capturing the temporal, complex system and events surrounding accident causation.

Reasonôs early work in the field of psychological error mechanisms (Reason 1975; 1976; 1979) was important in this discussion on complexity of accident causation. By analysing everyday slips and lapses he developed models of human error mechanisms (Rasmussen 1982). Reason (1990) went on to address the issue of two kinds of errors: active errors and latent errors. Active errors were those ñwhere the effect is felt almost immediatelyò and latent errors ñtended to lie dormant in the system largely undetected until they combined with other factors to breach system defencesò (p. 173). Reason, unlike Heinrich (1931) and Bird and Germain (1985) before him, accepted that accidents were not solely due to individual operator error (active errors) but lay in the wider systemic organisational factors (latent conditions) in the upper levels of the organisation. Reasonôs model is commonly known as the Swiss Cheese Model (see Figure 6).

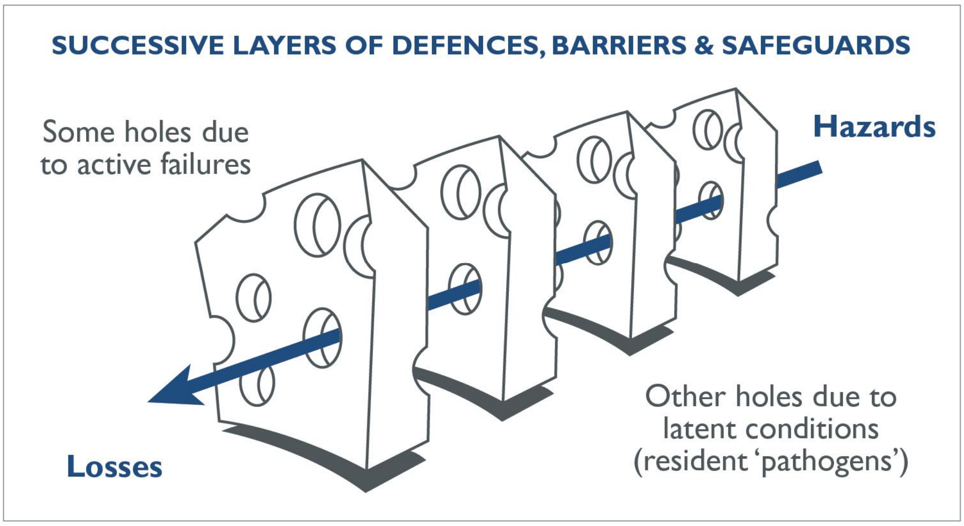

Figure 6: Reason's 'Swiss Cheese' Model (modified from Reason, 2008 p.102)

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[3] See *OHS BoK* Systems for a discussion on socio-technical systems.

Unlike the modelling work of Heinrich (1931) and Bird and Germain (1985), Reason did not specify what these holes represented or what the various layers of cheese represented. The model left the OHS professional to their own investigations as to what factors within the organisation these items might be.

The ñSwiss Cheeseò model was only one component of a more comprehensive model he titled the *Reason Model of Systems Safety* (Reason 1997) (Figure 7).

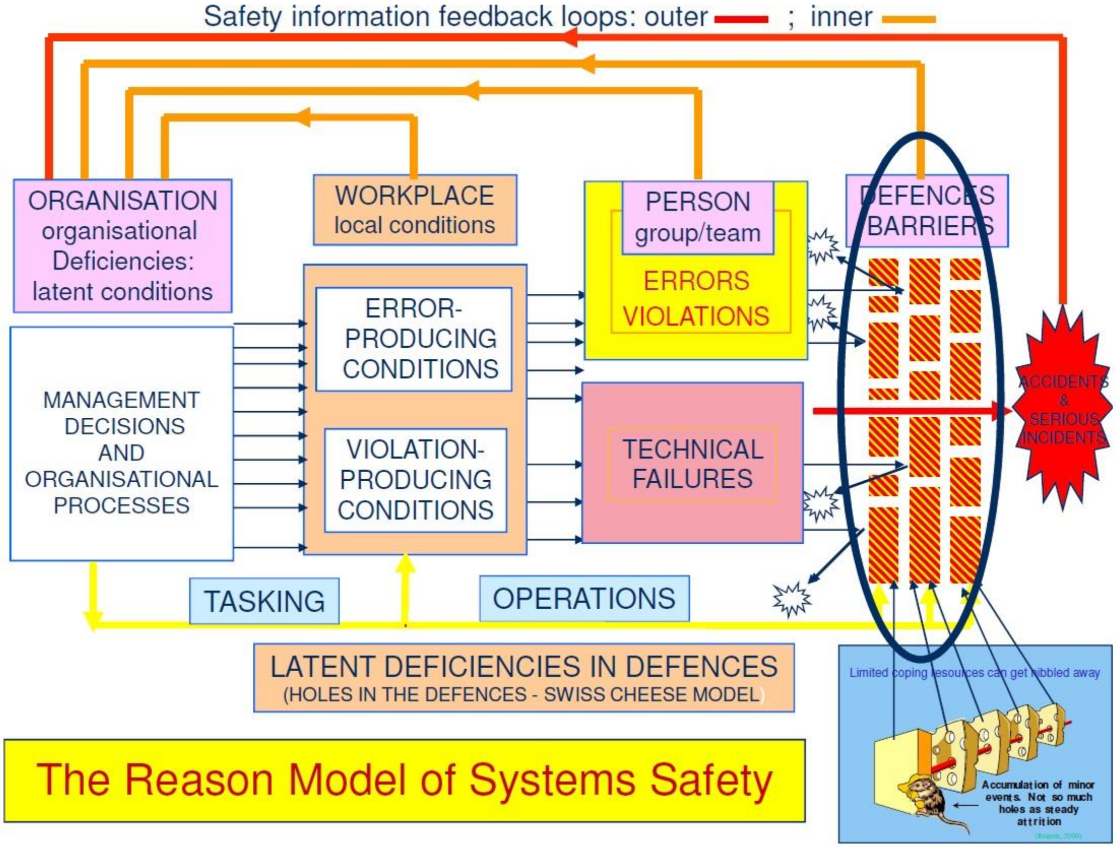

Figure 7: The Reason Model of System Safety (Reason, 1997)

Reason had a major impact on OHS thinking and accident causation in that he moved the focus of investigations from blaming the individual to a no-blame investigation approach; from a person approach to a systems approach; from active to latent errors; and he focused on hazards, defences and losses. Reasonôs Swiss Cheese and Systems Safety models were an attempt to reflect these changes.

To understand the role of James Reason in changing the thinking about accidents it is important to see his work in the historical context that his work followed closely the accepted work of Rasmussen on human error (see Rasmussen, 1982) and Reasonôs 1987 work in this area gave him initial credibility in the safety arena. However, by 1997 he wanted accident investigation to move away from blaming the individual at the sharp end of the system towards a no-blame approach, as had been an underpinning tenet of professional air safety investigators for many years (ICAO 1970 & USNSC 1973).[4] In focusing on hazards, defences and losses Reason (1997) wanted to convey the message that organisational accidents were a result of a failure to recognise the hazards in the system and the need to establish a variety of defences to prevent their adverse effects. The holes in the Swiss cheese represented a lack of strong, air-tight defences which ultimately let the accident sequence happen. Reason continued to discuss human error, but from an error management perspective, requiring organisations to again put in place barriers for errors rather than trying to eradicate them as he recognised total eradication as an impossible task.

These models, whilst becoming highly recognisable and favoured, were criticised for a number of reasons including their lack of definition of what the holes in the barriers represented.

> [T]he Reason model, in its current form, fails to provide the detailed linkages from individual to task/environment to organization beyond a general framework of line management deficiencies and psychological precursors of unsafe actsò (Luxhøj & Maurino, 2001, p. 1).

Also, the model did not allow for the variation in organisational and individual working:

> Reasonôs model shows a static view of the organisation; whereas the defects are often transient, i.e. the holes in the Swiss cheese are continuously moving é the whole socio-technical system is more dynamic than the model suggests (Qureshi, 2007,"Epidemiological Accident Models" par.2)

While Reasonôs models achieved a change in thinking about accidents recognising the complexity of causation he was also part of the move away from the heavy human error emphasis (Reason, 1990) towards a no blame or ñjust cultureò approach (Reason, 1997). The ñjust cultureò approach recognised that human error was not only a normal operating mode but a normal occurrence allowing humans to learn as part of their natural path of development and function. Woods, Johannesen, Cook & Sarter (1994) describe this scenario as ñlatent failures [that] refer to problems in a system that produce a negative effect but whose consequences are not revealed or activated until some other enabling condition is metò (p. 19). By recognising that latent conditions require a trigger in the form of an interaction, usually with a human, it can be seen that the study of humans in the accident trajectory moves away from what the human did wrong to the study of normal

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[4] While this has now largely been accepted across industry, the recent emergence of the criminalisation of aircraft accidents has the real potential to undermine the effort and adversely impact the successful investigation of future accidents (Michaelidis and Mateou, 2010; Trogeler, 2010; Gates and Partners, 2011).

human behaviour and decision making based on the environment in which they are functioning and the knowledge and technology available for decision making at the time. The study of humans in the system moves from the individual to groups of individuals embedded in a larger system (Woods et al 1994). This is represented in Woods et al., depiction of the sharp and blunt end of large, complex systems (Figure 8.)

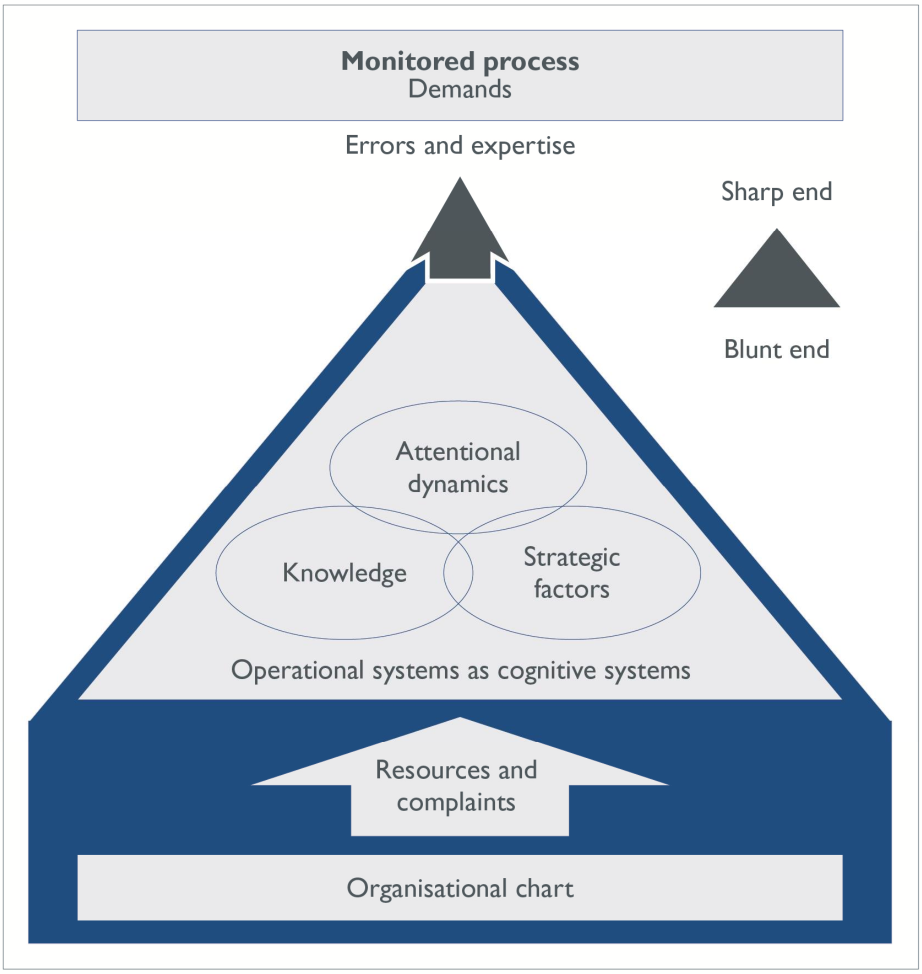

Figure 8: The sharp and blunt ends of a large complex system (Woods et al., 1994)

In 1984 Purswell and Rumar reviewed the progress of accident research in recent decades and in particular accident modelling. They noted the continuing discussion around the suitability of one accident model over another with the resolution that at this time ñno universally accepted approach which is unique to occupational accident researchò had yet emerged. They cautioned against the apparent dangers of trying to obtain uniformity in the methodology of accident investigation with the dilemma being ñthe prospect of the model driving the problem definition, rather than the problem generating the appropriate model to be usedò (p. 224). This observation and concern was still appropriate a decade later.

3.3 Complex non linear accident models

As shown in Figure 1 there has been considerable overlap in the development of the various conceptual approaches to accident causation. In parallel with the development of thinking around epidemiological models and systemic models the thinking around the complexity of accident causation led to non complex linear models. Key researchers in this approach have been Perrow, Leveson and Holnagel. The implications of recent discussions on complexity and ódriftô are briefly considered.

In the early 1980s Perrow began to argue that technological advances had made systems not only tightly coupled but inheritably complex, so much so that he termed accidents in these systems as being ñnormalò. Perrowôs normal accident theory postulated that tightly coupled systems had little tolerance for even the slightest disturbance which would result in unfavourable outcomes. Thus tightly coupled systems were so inherently unsafe that operator error was unavoidable due the way the system parts were tightly coupled. (Perrow, 1984) Components in the system were linked through multiple channels, which would affect each other unexpectedly, and with the complexity of the system meaning that it was almost impossible to understand it (Perrow, 1984; Tenner, 1996).

Two new major accident models were introduced in the early 2000s with the intention of addressing problems with linear accident models (Hovden, et al., 2009):

- The Systems-Theoretic Accident Model and Process (STAMP) (see Leveson, 2004).
- The Functional Resonance Accident Model (FRAM) (see Hollnagel, 2004)

3.3.1 Systems-Theoretic Accident Model and Process (STAMP)

Levesonôs model considered systems as ñinterrelated components that are kept in a state of dynamic equilibrium by feedback loops of information and controlò (2004, p. 250). It emphasised that safety management systems were required to continuously control tasks and impose constraints to ensure system safety. This model of accident investigation focused on why the controls that were in place failed to detect or prevent changes that ultimately lead to an accident. Leveson developed a classification of flaws method to assist in identifying the factors which contributed to the event, and which pointed to their place within a looped and linked system. Levesonôs model expands on the barriers and defences approach to accident prevention and is tailored to proactive and leading safety performance indicators (Hovden, et al., 2009). However this model has had little up take in the safety community and is not widely recognised as having a major impact on accident modelling or safety management generally. Roelen, Lin and Hale (2010, p.6) suggest that this may be because Levesonôs model does ñnot connect to the current practice of safety data collection and analysisò making it less favourable than event chain models such as Reasonôs.

3.3.2 Functional Resonance Accident Model (FRAM)

Erik Holnagel is one of the more forward thinking researchers in the area of accident modelling and the understanding of causal factors. While Hollnagelôs early published work (Cacciabue & Hollnagel 1995; Hollnagel 1993; 1998) centred on human/cognitive reliability and human/machine interface his more recent work *Barriers and Accident Prevention* (2004) challenged current thinking about accident modelling. He introduced the concept of a three dimensional way of thinking about accidents in what is now known to be highly complex and tightly coupled socio-technical systems in which people work. He describes systemic models as tightly coupled and the goals of organisations as moving from putting in place barriers and defences to focusing on systems able to monitor and control any variances, and perhaps by allowing the systems to be (human) error tolerant.

Hollnagelôs Functional Resonance Accident Model (FRAM) (Figure 9), is the first attempt to place accident modelling in a three-dimensional picture, moving away from the linear sequential models, recognising that ñforces (being humans, technology, latent conditions, barriers) do not simply combine linearly thereby leading to an incident or accidentò (Hollnagel, 2004, p. 171).

FRAM is based on complex systemic accident theory but considers that system variances and tolerances result in an accident when the system is unable to tolerate such variances in its normal operating mode. Safety system variance is recognised as normal within most systems, and represents the necessary variable performance needed for complex systems to operate, including limitations of design, imperfections of technology, work conditions and combinations of inputs which generally allowed the system to work. Humans and the social systems in which they work also represent variability in the system with particular emphasis on the human having to adjust and manage demands on time and efficiency (p. 168).

Hollnagelôs (2005) theory of efficiency-thoroughness trade-off (ETTO) expanded on these demands on the humans, where efficiency was often given more priority to thoroughness and vice versa. Hollnagel recognised that complex systems comprise a large number of subsystems and components with performance variability usually being absorbed within the system with little negative effect on the whole. Four main sources of variability were identified as:

- Humans
- Technology
- Latent conditions

- Barriers (p. 171).

Holnagel proposed that when variables within the system became too great for the system to absorb them; possibly through a combination of these subsystem variables of humans, technology, latent conditions and barriers; the result will be undetectable and unwanted outcomes. That is a ófunctional resonanceô results, leading to the system being unable to cope in its normal functioning mode. (Figure 9)

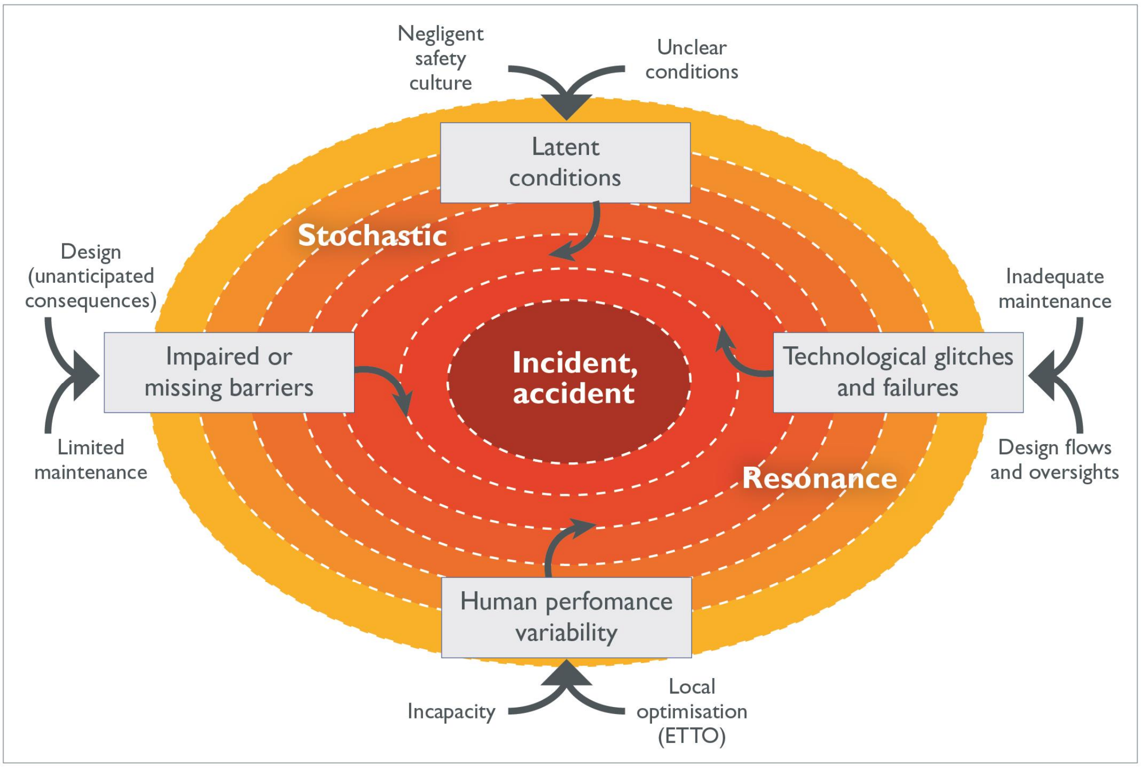

Figure 9: Functional Resonance as a System Accident Model (Holnagel, 2004)

Hollnagelôs FRAM model presents a view of how different functions within an organisation were linked or coupled to other functions with the objective of understanding the variability of each of the functions, and how that variability could be both understood and managed. The functions are categorised as inputs, outputs, preconditions, resources, time and control. Variability in one function can also affect the variability of other functions (p. 173). In 2010 Hollnagel launched a web site in support of the growing cohort of researchers and OHS professionals interested in using the model as a tool for understanding and managing accidents and incidents. While the Functional Resonance Accident Model provided a theoretical basis for thinking about accident causation Hollnagel clearly differentiated between models that aided thinking about accident causation and methods of analysing accidents as part of investigations. The Functional

Resonance Analysis Method evolved from the conceptual thinking embodied in the model which was highlighted by retaining the FRAM acronym. A detailed description of the method is given in Sundstrom & Hollnagel (2011). .

3.3.3 Complexity and accident modelling

While the FRAM model begins to address complexity of organisation and the relationship with accident causation Dekker (2011) takes the discussion of complexity further to challenge the notion of accident modelling and the predictive ability of accident models. In describing complexity of society and technology Dekker considers that:

> The growth of complexity in society has got ahead of our understanding of how complex systems work and fail. Our technologies have got ahead of our theories. Our theories are still fundamentally reductionist, componential and linear. Our technologies, however are increasingly complex emergent and non-linear. Or they get released into environments that make them complex, emergent and non-linear. (2011, p.169)

Accidents occur in these complex systems by a ñdrift into failureò which occurs through a slow but steady adaptive process where micro-level behaviours produce new patterns which become embedded and then in turn are subject to further change. Dekkerôs position is that as there are no well-developed theories for understanding how such complexity develops and the general response is to apply simple, linear ideas in the expectation that they will assist in understanding causation (p.6). He considers the search for the ñbroken and part or personò that underpins linear models where risk is considered in terms of energy-to-be-contained, barriers and layers of defence, or cause and effect are misleading because they assume rational decision-making (p.2).

Where does this leave the OHS professional wanting to understand accident causation and seeking a conceptual framework to inform prevention and investigation activities?

4 Implications for OHS practice

In 2010, Hovden, Albrechtsen & Herrera observed that:

> é technologies, knowledge, organisations, people, values, and so on are all subject to change in a changing society. Nonetheless, when it comes to occupational accident prevention most experts and practitioners still believe in the domino model and the iceberg metaphor. (p. 953)

If this is currently the case in Australia then a lack of awareness of the development of thinking about accident causation and the application of models of causation may be inhibiting the development of effective prevention strategies as:

> Merely identifying a proximate cause as the óôroot causeò may, however, lead to the elimination of symptoms without much impact on the prospect of reducing future accidents (Marais et al., 2004; Leveson, 2004). In order to identify systemic causes, one may need to supplement with models

> representing alternative mindsets in order to spark the imagination and creativity required to solve the accident risk problem. (Hovden et al., 2010, p. 954)

The Model of OHS Practice[5] highlights the role of a conceptual framework in underpinning professional practice. An understanding of the evolution of accident, or occurrence, modelling is vital grounding for the OHS professional in developing their conceptual framework or mental model of accident causation. This chapter has considered a number of models for causation of accidents but which on initial reading may leave the OHS professional asking ñAre models useful?ò and óSo which model?ô.

Hovden et al., (2010) put this discussion into perspective for the OHS professional. While recognising that todayôs organisations are dynamic socio-technical systems characterised by increased complexity, working life at the sharp end has, with some exceptions, largely remained unaltered. They argue that there is little need for new models for the sake of understanding the direct causes of accidents in daily work life but these basic models should be enriched by the theories and models developed for high-risk socio-technical systems. Thus, in developing their mental model the OHS professional should be aware of a range of models of causation and be able to critically evaluate the model for application to their practice. This evaluation should address the question of currency verses best practice. The more recent the model does not necessarily imply better practice. Section 3.3.1 noted that the STAMP model has not received broad acceptance while, in some industries, the Swiss Cheese model is still considered best practice 22 years after its introduction. The OHS professional investigating a workplace accident may be informed by discussions on complexity but may find that the energy damage model or the swiss cheese models is more informative for the particular situation. The OHS professional must also work within the environment of the organisation and the limitations that that brings. As noted by Roelen, Lin & Hale (2011) one of the problems with the advanced models of causation including complexity factors is that they do not connect with current practices in safety data collection and analysis (p.6). In applying a particular model the OHS professional also needs to be able to differentiate between what actually occurs in the workplace with that which should happen.

The OHS professional should differentiate between the model and methods that may or may not be underpinned by theoretical models. For example sequential models inform some of traditional forms of accident analysis such as events trees, fault trees and critical path models. The Incident Cause Analysis Method (ICAM) of investigation was developed from Reasonôs Swiss Cheese model. Holnagelôs Functional Resonance Analysis Method is clearly underpinned by the Functional Resonance Accident Model.

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[5] See *OHS BoK* Practice: Model of OHS Practice

5 Summary

Hovden et al., provide six uses for accident causation models:

- Create a common understanding of accident phenomena through a shared simplified representation of real-life accidents.
- Help structure and communicate risk problems.
- Give a basis for inter-subjectivity, thus preventing personal biases regarding accident causation and providing an opening for a wider range of preventive measures.
- Guide investigations regarding data collection and accident analyses.
- Help analyse interrelations between factors and conditions.
- Different accident models highlight different aspects of processes, conditions and causes. (p.955)

Accidents are complex events and that complexity has made understanding how accidents occur problematic. Beginning in the 1930s there has been an evolution in thinking about accident causation. While there has been significant overlap in the development phases, and a number of the models have enduring application in certain circumstances. The evolution has progressed from simplistic ódomino modelsô that focus on the behaviour of individuals through more complex linear models that consider the time sequence of event analysis, óepidemiologicalô models, to systemic models that consider barriers and defences. With greater recognition of the complexity of causation of accidents newer recent models became complex and non-linear.

While recent discussions on complexity and ódriftô have been interpreted by some as casting doubt on the usefulness of models of accident causation, the reality of OHS professional practice is that understanding accident causation is central to effective OHS practice. The learning and understanding about accident causation engendered by an awareness of the evolution in thinking about causation and with these models leads to the establishment of effective preventive methods and systemic defences and the ability to effectively respond to those which do occur. Failure to understand accident causation leads to degradation of preventive mechanisms and accident occurrence or recurrence.

References

Benner, L. (1975). Accident Investigations: Multilinear Events Sequencing Methods. *Journal of Safety Research*, 7(2), 67-73.

Benner, L. (1984). Accident models: How underlying differences affect workplace safety. Paper presented at the International Seminar on Occupational Accident Research, Saltjobaden: Sweden.

Bird, F. E. J., &Germain, G. L. (1985).*Practical Loss Control Leadership*. Loganville, Georgia: International Loss Control Institute, Inc.

Buzsáki, G. (2006). *Rhythms of the Brain*. New York: Oxford University Press.

Cacciabue, P. C., Holnagel, E. (1995). Simulation of Cognition: Applications. In J.M. Hoc, P.D. Cachiabue & E. Holnagel, (Eds.), *Expertise and Technology*, New Jersey: Lawrence Erlbaum and Associates.

DeBlois, L. A. (1915), *The Application of Safety Devices*, Hagley Museum and Library, Wilmington, DE

Dekker, S. (2011). Drift into Failure: From Hunting Broken Components to Understanding Complex Systems. Surry: Ashgate.

Gates and Partners (2011), Aviation and the Implications of Criminalisation, Gates and Partners Solicitors, http://alae.org/downloads/legal/accidents.pdf

Gibson, J.J. (1961). The contribution of experimental psychology to the formulation of the problem of safety ï a brief for basic research, in Jacobs, H.H. et al., *Behavioural Approaches to Accident Research*, New York Association for the aid of crippled children.

Gordon, J. E. (1949). The epidemiology of accidents. *American Journal of Public Health*, 39, 504-515.

Greenwood, M., Woods, H. M. (1919). *A report on the incidence of industrial accidents upon individuals with special reference to multiple accidents*. British Industrial Fatigue Research Board.

Heinrich, H. W. (1931). *Industrial Accident Prevention: A scientific approach*. New York: McGraw-Hill.

Hollnagel, E. (1993). *Human reliability analysis: Context and control*. London: Academic Press.

Hollnagel, E. (1998). *Cognitive reliability and error analysis method: CREAM*: Elsevier.

Hollnagel, E. (2004). *Barriers and Accident Prevention*: Aldershot:Ashgate,.

Hollnagel, E. (2005). The ETTO Principle - Efficiency-Thoroughness Trade Off. Retrieved from http://www.ida.liu.se/~eriho/ETTO_M.htm

Hollnagel, E. (2010). FRAM Background. Retrieved from http://sites.google.com/site/erikhollnagel2/coursematerials/FRAM_background.pdf

Hovden, J., Abrechtsen, E., & Herrera, I. A. (2010). Is there a need for new theories, models and approaches to occupational accident prevention? *Safety Science*, 48(8), 950-956.

Klein J (2009),*Two Centuries of Safety History at DuPont*, Process Safety Progress, Vol. 28 Issue 2 pp114 ï 122, Wiley Interscience.

Kletz, T. (1993). *Lessons from disasters: How organisations have no memory and accidents recur*. Warwickshire: Institution of Chemical Engineers l

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science,* 42, 237-270.

Luxhøj, J. T., Maurino, M. (2001). An aviation system risk model (ASRM) case study: Air Ontario 1363. *The Rutgers Scholar,* 3.

Michaelidis-Mateou S. and Mateou A. (2010), *Flying in the Face of Criminalisation,* Ashgate

Newbold, E. M. (1926). *A contribution to the study of the human factor in causation of accidents.* British Industrial Health Research Board.

Osborne, E. E., Vernon, H. M., &Muscio, B. (1922). *Two contributions to the study of accident causation.* British Industrial Fatigue Research Board.

Perrow, C. (1984). *Normal Accidents: Living with High-Risk Technologies*. New York: Basic Books Inc.

Purswell, J. J., &Rumar, K. (1984). Occupational accident research: Where have we been and where are we going? *Journal of Occupational Accidents,* 6, 219-228.

Qureshi, Z. H. (2007). A review of accident modelling approaches for complex socio-technical systems. Paper presented at the 12th Australian Workshop on Safety Related Programmable Systems (SCS'07). http://crpit.com/confpapers/CRPITV86Qureshi.pdf

Rasmussen, J. (1981). Models of mental strategies in process plant diagnosis. In J. Rasmussen & W. Rouse (Eds.), *Human Detection and Diagnosis of System Failures*. New York: Planum.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents,* 4(311-335).

Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction*. Amsterdam: North-Holland.

Rasmussen, J. (1990). Human error and the problem of causality in analaysis of accidents. Paper presented at the Human Factors in Hazardous Situations. *Proceedings of a Royal Society Discussion Meeting*.

Rasmussen, J., Jensen, A. (1974). Mental procedures in real-life tasks: A case study of electronic troubleshooting. *Ergonomics,* 17, 193-307.

Reason, J. T. (1975). How did I come to do that? *New Behaviour,* 24.

Reason, J. T. (1976).Absent minds.*New Society,* 4(November).

Reason, J. T. (1979). Actions not as planned: The price of automatization. In G. Underwood & R. Stevens (Eds.), *Aspects of Consciousness* (Vol. 1). London: Wiley.

Reason, J. T. (1984a).Lapses of attention.In R. Parasuraman& R. Davies (Eds.), *Varieties of Attention*. New York: Academic Press.

Reason, J. T. (1984b).Absent-mindedness and cognitive control.In J. Harris & P. Morris (Eds.), *Everyday Memory, Actions and Absent-Mindedness*. London: Academic Press.

Reason, J. T. (1984c).Order of output in category generation. Paper presented at the Cognitive Section, British Psychological Society, Oxford.

Reason, J. T. (1987).The Chernobyl Errors. *Bulletin of the British Psychological Society*, 40, 201-206.

Reason, J. T. (1990).*Human Error*. Aldershot: Ashgate.

Reason, J. T. (1997).*Managing the Risks of Organisational Accidents*. Aldershot: Ashgate.

Reason, J.T. (2008). *The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries.* Surrey: Ashgate.

Roelen, A. L. C., Lin, P. H., & Hale, A. R. (2011). Accident models and organisational factors in air transport: The need for multi-method models. *Safety Science*, 49, 5-10.

Rouse, W. B. (1981). Models of human problem solving: Detection, diagnosis and compensation for system failures. Paper presented at the Proceedings of IFAC Conference on Analysis, Design and Evaluation of Man-Machine Systems., Baden-Baden, FRG.

Sundstrom, G.H., Hollnagel, E. (2011). The Importance of Functional Interdependence in Financial Services Systems. In E. Hollnagel, J Pariés & D.D. Woods (Eds.), *Resilience Engineering in Practice: A Guide Book.* Ashgate.

Surry, J. (1969). *Industrial Accident Research: A Human Engineering Appraisal*. Toronto, Ontario: Labour Safety Council, Ontario Department of Labour.

Svenson, O. (1991). The accident evolution and barrier function (AEB) model applied to incident analysis in the processing industries. *Risk Analysis*, 11(3), 499-507.

Svenson, O. (2001). Accident and incident analysis based on accident evolution and barrier function (AEB) model. *Cognition, Technology & Work*, 3(1), 42-52.

Tenner, E. (1996). *Why things bite back*. London: Fourth Estate Limited.

Trogeler M. (2010), Criminalisation of air accidents and the creation of a Just Culture, European Air Law Association, http://www.eala.aero/library/Mildred%20Trgeler%20EALA%20prize.pdf

Vernon, H. M. (1919). *The influence of hours of work and of ventilation on output in tinplate manufacturing.* British Industrial Fatigue Research Board.

Vernon, H. M. (1920). *Fatigue and efficiency in the iron and steel industry.* British Industrial Fatigue Research Board.

Vernon, H. M., Bedford, T., & Warner, C. G. (1928). *A study of absenteeism in a group of 10 collieries.* British Industrial Fatigue Research Board.

Viner, D. (1991), *Accident analysis and risk control*, Derek Viner Pty Ltd, Melbourne.

Woods, D. D., Johannesen, L. J., Cook, R. I., &Sarter, N. B. (1994). Behind Human Error: Cognitive Systems, Computers, and Hindsight. Dayton, Ohio;Dayton University Research Institute.