University of Alberta

The Ethos of Error: Analyzing Investigations of Industrial Events

by

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And finally, and by no means least, I dedicate this work to the memory of:

Donna Purser
1942 – 2002

Who knew what it was I was here to do long before I had the wisdom to ask.

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Chapter 1: Introduction

Accidents are phenomena that most people choose not to think about, yet as an occurrence they are widely recognized as events that are entirely preventable, if not predictable. Accidents are common – one need only consider the automobile sector in terms of frequency and severity. Similarly, industrial accidents at the workplace are all too frequent and exact a heavy toll in terms of operational efficiency and costs. On average in Canada, in the last three decades, Canadians experienced 985,000 lost time accidents in the workplace annually, costing in excess of 2.6 billion dollars per annum in compensation, as reported by Human Resources and Development Canada (1999).

Increasing environmental awareness has similarly brought environmental excursions under scrutiny, as the public and governments alike consider environmental damage as unacceptable and worthy of strong regulatory control and sanctions. The costs on the environmental side are much harder to measure and track, but there is little doubt that in the longer term the insidious nature of environmental degradation has the potential for huge economic impacts. In terms of environmental abatements alone the Canadian federal government spent on average 3.8 billion dollars per annum, for the years 1995 through 1999, as reported by Statistics Canada (2002).

Add to this the much less frequent but higher profile accidents within the aviation and aerospace sectors of the economy, and one wonders if we as a society are making any progress in terms of really understanding the etiology of accidents. To this end, incident/accident investigation is the method of choice, as a process of discovery that has stood the test of time, and is the focus of this project.

Problem Definition

The investigation of industrial incidents/accidents (hereon referred to as *events*) is generally considered an important element or sub-system of environmental, health and safety management systems typically in place at workplaces throughout the western world. As a process of inquiry, investigations are conducted within the framework of the EH&S programs and are very much shaped by the ideology if not the language of these programs or systems. That is to say, that a behavior-based model can be biased towards unsafe acts of workers; a risk management approach leans toward the physical workplace; and the loss control model tends to focus on unsafe conditions. The investigators are typically front line personnel with intimate understanding of the operational side of the equation, but often wanting in terms of investigation techniques or experience. In the latter decades, Environment, Health and Safety (EH&S) professionals have taken on the role of investigators, a role they are well suited too, but all too frequently under resourced for. Still, the need has been established, by organizations genuinely wishing to demonstrate their due diligence to those that are compelled to do so by regulatory statute.

The problem is this: the investigation of industrial events, be they health, safety or environmental in nature is being conducted in a vacuum from the point of view of a formalized theoretical basis or standardized methodology. In the presence of increased regulatory attention and public outcry, investigations are being carried out expeditiously to determine cause, put forward recommendations and bring closure to these tragic events. Often times, the outcomes of these investigations are laudable and for the most part satisfy the requirements of the stakeholder, the regulatory community and the public at large. Just as often however, the outcomes are less than satisfying due largely to the emotional volatility of the events; due to human nature; and due to lack of confidence in the investigation process if not integrity therein.

Over the years, industrial event investigation has experienced a plethora of analytical techniques and event causation models. These vary from the most basic, single causation model (Greenwood and Woods, 1919), to the complex, multi-linear sequencing model (Hendrick and Benner, 1987) popularized in their textbook on the subject. In between these two extremes, however lay many theories and models that are often incomplete, contradictory, and frankly lacking in critical review. Further, all too often these same models attempt to proselytize practitioners without the benefit of a substantiated theoretical basis or a formalized methodology. To their credit, the industrial community has recognized this shortfall in part, and has responded by collaborating with the fire investigation fraternity, their colleagues in transportation, as well as the police for techniques and training. It still remains however that there has been no formal process of evaluation of investigation as regards to quality, efficacy or standards. Practitioners are left to their own devices as to what approaches or models are appropriate for the investigation of industrial events – so much so that the very premise of what constitutes a cause and effect relationship is very much in argument.

That this is the case is understandable given the relatively early stages of evolution in the field of industrial investigation; yet in the absence of any process of evaluation or critical review, the status quo does present considerable concern and dismay to the author, as well as others (Benner and Hendrick, 1987, p. vii):

> Compelling evidence indicates that current accident investigation efforts are inadequate and that most investigation programs require fundamental rethinking. The continued demand for a "cause" attests to the continued demand to oversimplify the complex phenomena that we call "accidents". The continuation of accident litigation attests to investigative inadequacies and processes for coping with them and the inequities that these inadequacies generate. The continued attribution of so many accidents to human error (an opinion usually based on outcomes) attests to the ambiguity of the investigations and work products.

This paper will therefore, seek to address this problem, by proposing a theoretical basis for the analysis of investigation of industrial *events*, a viable methodology and a means (method), by which investigative processes can be evaluated in the form of an audit instrument.

Rationale

It is generally held that accident prevention is the cornerstone of operational integrity, operational integrity being a state of equanimity in an organization where all the risks are known, manageable and are acceptable in terms of outcomes. Any approach committed to this purpose must rely on the process of investigation as a diagnostic tool. It is self-evident then, that from a deterministic standpoint, investigation represents the *raison d'etre* of operational integrity. As an abstraction, it can be suggested that:

If A determines B and B determines C then implicitly A should determine C

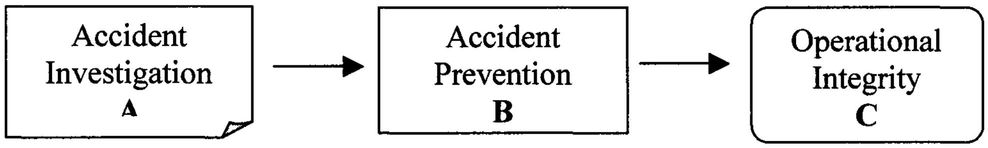


Figure 1.1: Abstraction illustrating the determinacy existing between accident investigation and operational integrity.

This logic flow should not be taken so literally however, as to assume accident investigation can, in and of itself contribute to operational integrity without some form of transformational and intermediary process – accident prevention. Accident investigation is by its nature a reactive exercise; accident prevention is very much a pro-active, and an iterative effort. Obvious perhaps, yet how often have we witnessed investigations failing to go further than the reports they generate; and expect that by virtue of this investment a change has been realized and that recurrence will be prevented? A more substantive abstraction is therefore offered:

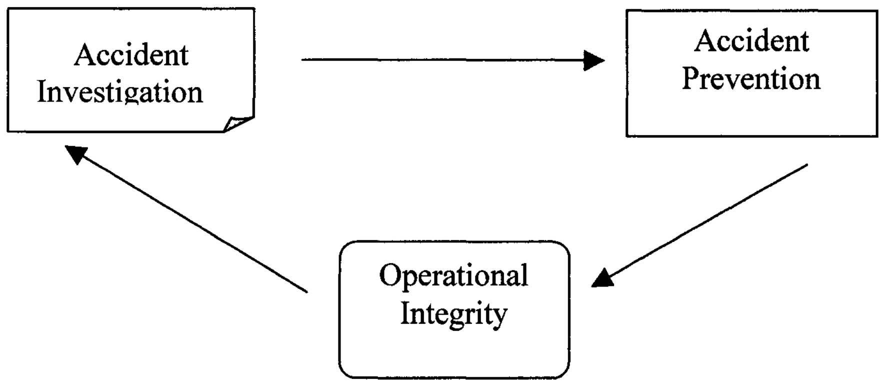


Figure 1.2: Abstraction illustrating a feedback mechanism existing between accident investigation and operational integrity.

The essence of this abstraction is that only through proactive accident prevention can operational integrity be achieved; further there is some measure of 'input' from operational integrity into the process of accident investigation. It is the position of this investigator that that 'input' should take the form of expectations: expectations in terms of time-lines and scope of the investigative process, as well as the expectation of veracity and objectivity. In the happy circumstance that these expectations are indeed met by the investigation process, the onus is then put upon the operators to respond appropriately and in a timely fashion to the investigative outcomes and engage the accident prevention systems of the organization. This being said, the quality and efficacy of the investigative process is of fundamental interest, if not essential to the bottom-line of any organization seriously wishing to expiate its industrial events.

Statement of Significance

The significance of this project will be the degree to which a valid tool can be established for the evaluation of investigative processes involving industrial events. Specifically, it is intended that such an analytical tool will foster veracity, efficacy and the quality of investigative processes. In general, any evaluation mechanism of a management system (such as investigations) is likely to encourage more formalized guidelines and methodologies. These in turn will have a dramatic impact on procedures, processes and formats within the investigation discipline, as indicated by Hanks et. Al (2003), (Figure 1.3).

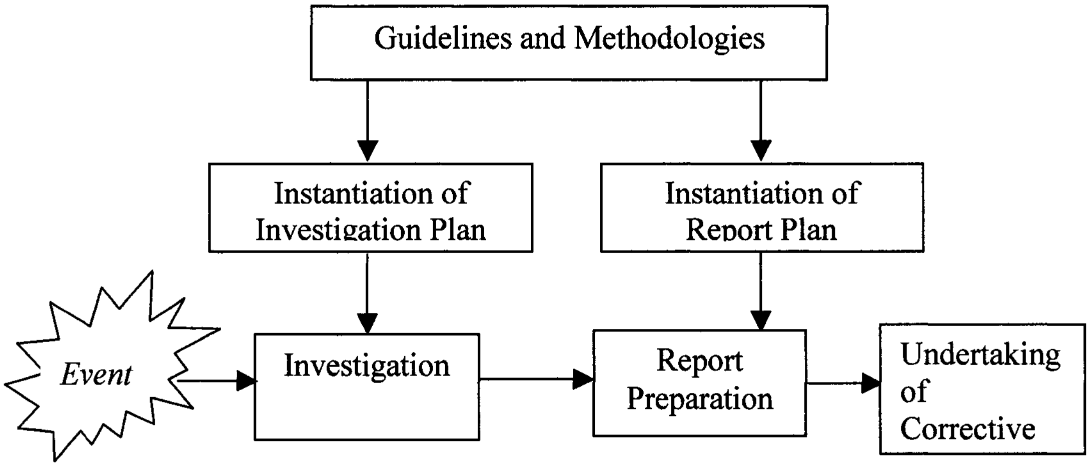


Figure 1.3: Schematic illustrating the role of methodology in promoting formalized approaches to accident investigation (Hanks et al., 2003)

Additionally, this thesis will be of merit by suggesting a means of characterizing an organization's safety culture through the analysis of its investigations. Finally, this thesis is significant by bringing a vital element of our environmental, health and safety management system under the scrutiny of critical review – the investigation of industrial *events*.

Chapter 2: Goals and Objectives

The goals of this paper are threefold:

i) Review the existing theoretical basis for the analysis of industrial event investigation, by;

   a. Establishing the distinctions between theory, methodology and models.
   b. Determining the existence of methodologies for the purpose of evaluating *event* investigations.
   c. Establishing a list(s) of criteria for the evaluation of *event* investigations.

ii) Design an audit process that can effectively evaluate investigations of industrial *events*, by;

   a. Proposing a design based upon the need to evaluate investigative process, veracity and efficacy.
   b. Providing a protocol (audit standard) by which the audit is carried out detailing the principles, rules and methodology.
   c. Providing an instrument or framework in which the audit is conducted, functioning as a front end to the investigation analysis.

iii) Propose a means by which the results of the audit above can be analyzed, by;

   a. Establishing a theoretical basis for an analytical model.
   b. Proposing a model upon which the methodology can be based.
   c. Developing a methodology to analyze *event* investigation data.

Scope

The scope of the proposed analytical process (audit) is focused on, but not limited to the disciplines of Environment and Health and Safety at the workplace. The author has a natural bias for the petroleum and mining industries but the utility of this process is considered equally valid irrespective of industrial sector. Indeed, due to the considerable accident models borrowed from the aerospace and aviation industries, the analytical process may well have merit within public sector investigations as well.

The audit protocol will be a stand-alone document that will enable an auditor to successfully apply the audit instrument, without the benefit of previous audit experience. It is expected however, that the auditors would benefit from considerable experience in investigative techniques and such technical knowledge as is appropriate to the client site. The audit instrument itself will also be a stand-alone tool that can function independently of any other documents. It is not the intention however, that the proposed analytical process replace any existing audit instruments or systems currently in use.

Methodology

The goals and objectives of this paper were arrived at in reverse order having established the need for some form of mechanism of evaluation for investigations of industrial events. Starting with an audit process as the premise, a search of contemporary literature was conducted to determine existing models or methods of evaluating the investigation of industrial events. There were surprisingly few. The search was therefore broadened to include the investigation of events within the civil aviation and public transportation sectors. This proved to be of great benefit due to the sheer volume of material as well as the revelation that they too were concerned with the lack of standards and methodology.

The next phase was to evaluate contemporary sources (industry associations, regulatory agencies and academic institutions) to determine what methodologies and methods there were for the evaluation of the investigative processes. This was fruitful on the part of methods, however this search was broadened to include the historical record over the last five decades in an effort to understand the lack of convergence of models and methods. Event investigation methodologies were conspicuous in their absence.

In the absence of methodologies, formal or otherwise, the search was broadened yet again for a theoretical basis for the investigative process. That is, what models exist concerning industrial events and how do they shape or determine investigative methodology? Discourses and opinions on the subject proved to be as wide and varying as the types of *events* themselves.

Finally, existing audit standards were evaluated for structure and format to determine what design would best suit an audit specifically tailored to investigative processes. In this regard, there is no lack of example as ISO Standards, the Loss Control model as well as regulatory agencies have much to contribute to the subject.

The following flow diagram summarizes the research methodology.

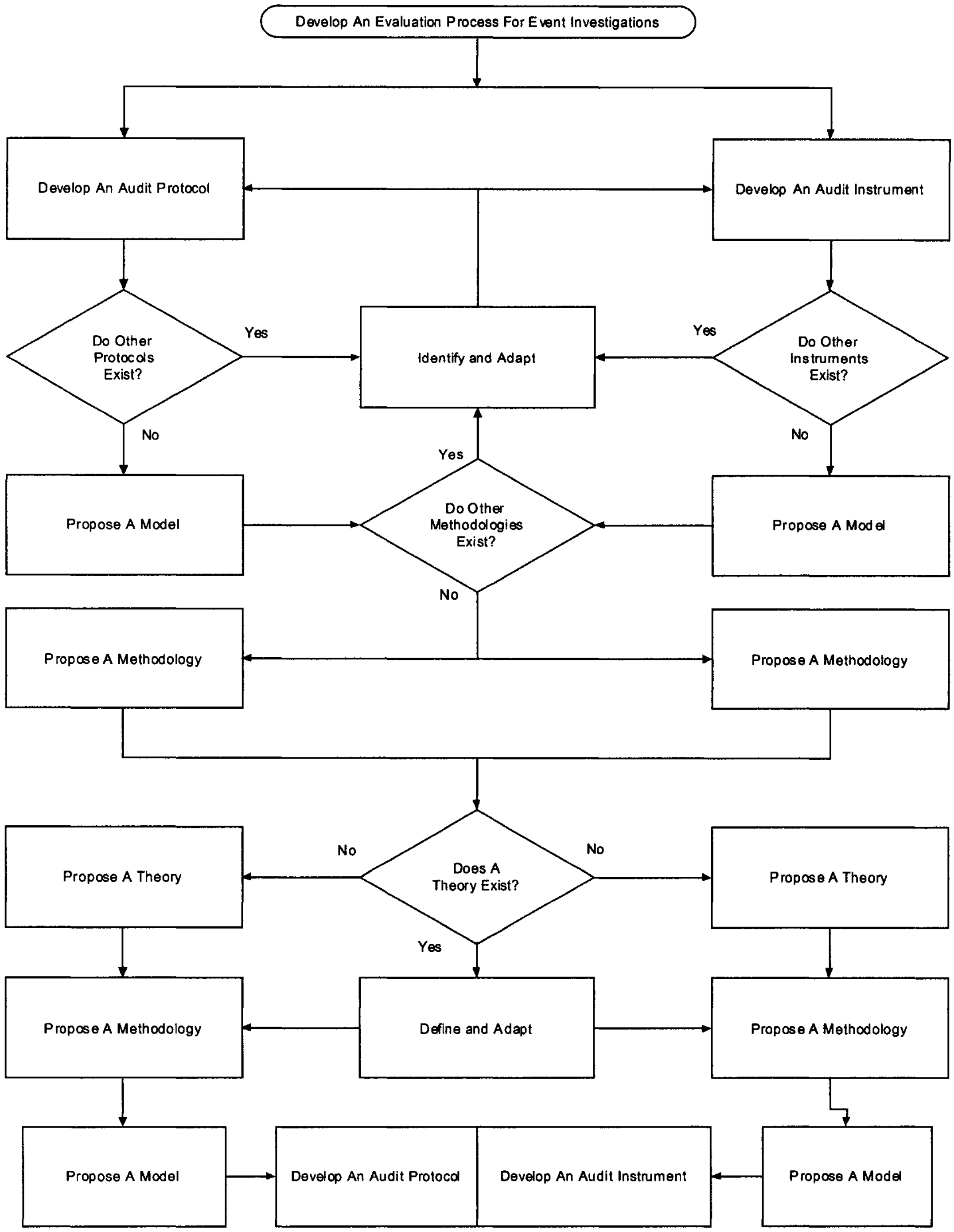


Figure 1.4: Flow chart illustrating the methodology of this thesis.

Chapter 3: Investigation Methodology

To be clear, it must be restated that this thesis is about the evaluation of the process of investigation, and not the investigation methods. It is necessary however, to be very precise in terms of the semantics of this endeavor. First, the investigation of an industrial event is a process, one that requires structure, logic and principles to be verifiable, credible and objective. Second, within this process are techniques – ways of accomplishing a task, securing of evidence, taking of statements and organizing the data. The latter are the methods or the *how to* of the investigation process. The former, are known as the methodologies, the *what* of the investigation process. The event itself is the *why*, and here and now address the *where* and the *when*, to complete this Kipling-like analogy. A dictionary definition (Gage Canadian Dictionary, 1983) of methodology reveals:

> **Meth-o-dol-ogy 1** a system or body of procedures, methods, and rules used in a particular field or discipline. **2** the branch of logic that deals with the analysis of such procedures or methods.

Similarly and for comparison, a dictionary definition of method reveals:

> **Meth-od 1** a way of doing something. **2** order or system of getting things done or in thinking.

It would appear that in the absence of any formalized methodology, an enterprise attempting to apply a method is at a singular disadvantage. No matter the skill; no matter the diligence; such an enterprise could run the risk of being lost in the doing, for lack of a plan. It is perhaps revealing to note that the noun method itself is subsumed within the definition of methodology; that the two compliment one another, both in terms of etymology and application.

The Loss Control System Model

Within the literature, there is a body of knowledge subscribing to the 'systems' approach to event investigation. These systems are firmly entrenched and do hold sway on investigative methods they incorporate. Some offer clear methodologies, many don't and a few have a solid foundation. The classic example of the latter is that of the Loss Causation model, (Bird and Germain, 1986), a system that popularizes the Systematic Causal Analysis Technique (SCAT); about which we shall learn more later. This system is both comprehensive in terms of providing a complete multi-element health and safety program, but also in terms of its *event* investigation methodology. The Loss Causation model is a prime example of an investigation method (SCAT) benefiting from a cogent and complete investigation methodology and theory.

The methodology incorporated by the Loss Causation model is an adaptation of chain-of–event (Heinrich, 1939) model and is characterized by the identification and *control* of antecedent factors, be they unsafe conditions, unsafe acts or management systems. Typically, the methodology identifies cause and effect relationships, as indicated by the proliferation of the word 'cause' throughout the model. Also typical for this methodology is the identification with *controls* as a means by which events can be mitigated, if not prevented. Thus, the methodology behind the SCAT model is heavily invested in the concept of cause and effect and that only through the imposition of *controls* can one suppress the causal chain of events. It is worth taking a look at what theoretical basis underpins this highly published and respected investigation methodology.

In this seminal of all system approaches to *event* prevention, the Loss Causation model has become an icon within the safety field. The theory upon which it is based is known as the 'domino theory' and is deceptively simple. The occurrence of loss (negative impact to people, property and production) has as a precursor, the *event* and then working backwards in time, antecedent causes. These causes flow from the specific (immediate cause) to the more general (lack of control) as one moves back in time, with the inference that they are management system in origin. Further, the theory holds that for each causation stage, there are *controls* that if in place, will prevent any given cause to be realized.

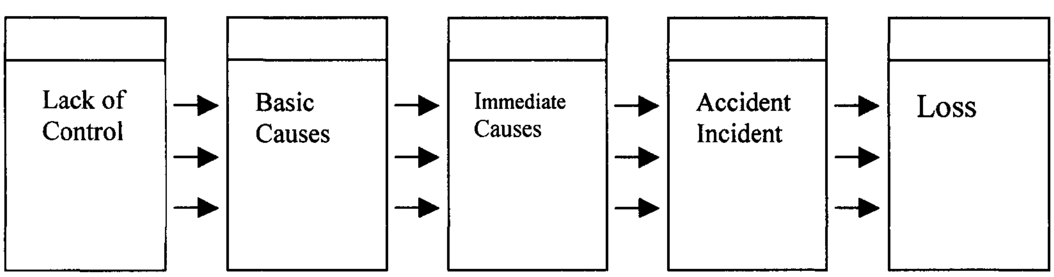


Figure 3.1: Simplification of the Loss Causation model (Bird and Germain, 1986)

Review of Contemporary Literature

Contemporary literature on the subject of analysis of event investigation in the industrial workplace is quite limited for health and safety, and extremely limited as regards to the environment. It is surmised by the author that there has been no particular reason to design investigative methods for the environmental discipline, as those models existing in the health and safety discipline suffice. The literature, in general falls into one the following categories:

1) First, there are the in-depth treatises on accident investigation, in the form of books which cover accidents from theory to practical application and are the bibles of any serious accident investigator (Surry, 1969; Hendrick and Benner, 1987; Ferry, 1988; Bird and Germain, 1986).
2) There are numerous technical articles published in journals and periodicals from conferences and symposia, such as *Industrial Accident Research* and the *Journal of Safety Research*; of which several are particularly insightful (Benner, 1985; Livingston, 2001; Surry, 1969).
3) There are the many safety associations and agencies that offer a wide selection of bulletins, papers and guidelines (HRDC Canada, 1997; DOE, 1997; Statistics Canada, 1998; NMESH, 2003)
4) There are the vendors of safety systems, programs and consulting services which offer training and software in the environment, health and safety (ILCI, 1986; TapRoot®, 1998; Dupont, http://stop.dupont.com/).
5) There is a growing number of internet web pages and sites that provide downloadable documents, links and databases relating to accident investigations. In particular, is that of the New Mexico

Environmental Safety and Health site which offers for sale a complete compendium of analytical techniques, investigative processes and procedures (NMESH, 2003).

6) Several academic research theses were selected for their relevance and insight (Munson, 1999; Leveson, 2002; Sklet, 2002).

The Work Of Livingston et al.:

One excellent resource is that of Livingston et al. (2001), and has proved to be veritable encyclopedia of investigation analytic techniques and models. Of particular use is a classification of the various analytical models, in which the models are characterized in terms of practical merit (Table 3.1).

System	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
MORT SRP TapRooT® HPIP HPES SCAT TOR SACA CAUSAL T												

Table 3.1: Conceptualized classification scheme tabulating analytical system against twelve attributes, from Livingston et al. (2001). Data intentionally omitted.

The twelve attributes of this classification scheme are:

1) Is the system publicly available?
2) What industries have used it?
3) How many years has the system been in existence?
4) Is it a structural methodology?
5) Is a schematic drawn first?
6) Is it a stand-alone technique?

7) Can the method be summarized?
8) Are there supporting documents?
9) Can the system be applied by one person?
10) Is the training less than 2 days?
11) Is the emphasis on organization?
12) Is the model developed in UK?

The Work Of Benner:

In a previous study by Benner (1985) goes a little further, in as much as the models and methodologies are classified and then rated. The first classification scheme tabulates various accident models against ten criteria (Table 3.2); the second scheme tabulates various methodologies against ten different criteria (Table 3.3). Here, we see an important distinction being drawn, between what constitutes a model and a methodology. Each scheme will be spoken to in turn. The Investigative Model classification scheme is conceptualized in Table 3.2, as follows:

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Epidemiological Chain-Of-Events All Cause Systems Violation Pentagon Explosion Fault Tree Event Process Stochastic Variables Haddon Matrix Mathematical Abnormality Levels										

Table 3.2: Conceptualized classification scheme tabulating investigative models against ten ranking criteria, from Benner (1985). Data intentionally omitted.

In this classification scheme, the ten ranking criteria are:

1)	Realistic	2)	Definitive	3)	Satisfying
4)	Comprehensive	5)	Disciplining	6)	Consistent
7)	Direct	8)	Functional	9)	Non-causal
10)	Visible				

Benner (1985) puts forward the notion that the language, if not the concept of causation is not a beneficial attribute; should in fact be avoided in favor of expressing interactions between parties and things. Additionally, Benner seeks to establish the extent to which the investigation demonstrates quality and validity in the criteria of *disciplining*, as well as transparency in the criteria of *visible*. The Accident Methodology classification scheme is conceptualized, as follows:

Methodology	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Epidemiological										
Chain Of Event										
Individual good Judgment										
Board Intra-organizational Groups										
Fact/Finding Legal Forms										
Kipling										
Fault Tree										
Gantt Charting										
Compliance Inspect										
Multidisciplinary group										
Events Analysis										
Statistical Data										
Closed End flowcharts										
NTSB Boards										
Baker Police										

Table 3.3: Conceptualized classification scheme tabulating investigative methodology against ten ranking criteria, from Benner (1985). Data intentionally omitted.

In this classification scheme, the twelve ranking criteria are:

1)	Encouragement	2)	Independence	3)	Initiatives
4)	Discovery	5)	Competence	6)	Standards
7)	Enforcement	8)	States	9)	Accuracy
10)	Closed Loop				

Benner (1985) produces a definitive description for each of his ten criteria (Appendix Ib), a number of which are worth taking a closer look at. The criteria *independence* speaks to the need for investigations to be inclusive in scope to the extent that all workplace parties are considered as to their roles in the event, without finding blame, fault or guilt. Similarly, the criteria *encouragement* speaks to the need for investigations to be inclusive of all workplace parties (labor, management, workers) in terms of participation, and through disclosure work toward harmony among the respective parties.

The fact that Benner advances the distinction between investigative models (methods) and methodologies to the extent of incorporating them into a classification scheme has not been lost on the author. Fundamentally, it is the methodologies that will shape the outcome of the investigation of industrial events, not the methods. The methods and models are tools; abstractions at best, incomprehensive at worst. The methodologies on the other hand offer some means of measurement and attachment of quality. Not surprising therefore, is the observation by Benner (1980).

> Of over 200 investigators queries informally, almost all had difficulty articulating the objectives for the investigation they

were conducting. Most replied in terms of reasons for investigative programs, rather than objectives for a specific case. General answers most frequently included "prevent accidents," "complete the forms," "save lives," and "find the cause".

The outcome of Benner's classification system is both revealing and confirmatory. The top three rated investigative models were (in descending order of rank): the Events Process model, the Energy Flow Process model and the Fault Tree model. In terms of investigative methodologies, the top three were (in descending order of rank): Events Analysis, the MORT System and Fault Tree Analysis. Each of these will be examined further in this paper.

The Work of Munson:

In his Master of Science thesis under the title of "Assessment Of Investigation Methods", Munson (1999) provides an in depth review of event investigation models within the context of the forestry service. In his research, Munson reviews many of the more familiar analytic methods in terms of their provenance, typology, strengths and weaknesses. Three methods in particular were selected for closer examination by means of 'reinvestigation', whereby Munson and five experienced investigators reinvestigated the South Canyon Fire. They were: Fault Tree Analysis (FTA), Sequential Timed Event Plotting (STEP) and Control/Barrier Analysis (CBA).

Investigative Method	1	2	3	4	5	6
Fault Tree Analysis STEP Control/Barrier Analysis						

Table 3.4: Conceptualized classification scheme tabulating investigative methods against six distinguishing characteristics. Data intentionally omitted.

The six evaluation criteria were:

1)	Realistic	2)	Comprehensive	3)	Systematic
4)	Consistent	5)	Visible	6)	Easy to learn

Munson reported that STEP received the highest overall rating of 87%, FTA receiving 85%, and CBA a rating of 70%. STEP received particularly high marks for *comprehensive*, FTA particularly high marks for easy to learn, and CBA for *realistic*. Both STEP and FTA were reported to be of equal rank in this study.

The Work of Sklet:

Sklet (2002) takes a slightly different approach in his graduate thesis under the title of 'Methods for Accident Investigation' concerning the analysis of accident investigation. In his research, Sklet identifies fourteen different accident investigation models popularized in Europe and offers a classification scheme based upon six characteristics (Table 3.5):

Analytic Method	1	2	3	4	5	6
Events and Causal Factors Charting						
Energy and Barrier Analysis						
Change Analysis						
Events and Causal Factors Analysis						
Root Cause Analysis						
Fault Tree Analysis						
Event Tree Analysis						
Management Oversight Risk Tree						
Systematic Causal Analysis Technique						
Sequential Timed Event Plotting						
Human, Technology and Organization Analysis						
Atomic Energy Board Method						
TRIPOD Method						

Table 3.5: Conceptualized classification scheme tabulating analytical methods against six distinguishing characteristics. Data intentionally omitted.

Each of the distinguishing characteristics will be spoken to in turn:

1. Accident Sequence

In the first column, the question is posed as to whether the identified analytic technique has a graphical description depicting event sequence. Sklet brings home the point that a graphical representation is as helpful to the investigators in organizing their observation as it is to the audiences in explaining them. The response is a simple yes or a no.

2. Levels Of Analysis

In the second column, the models are characterized by ascending levels of organizational management; starting with the operators and working upwards to the Federal Government level. The response is a number from one through six corresponding to:

1) The work and technological system
2) The staff level
3) The management level
4) The company level
5) The Regulators and industry associations level
6) The Government level

3. Primary/Secondary

In the third column, the models are characterized as being stand-alone analysis or adjunct analytic tools to other models. The responses are primary, secondary or both.

4. Analytical Approach

In the fourth column the models are characterized by being deductive, inductive, morphological or non-system oriented in methodology.

5. Accident Model

In the fifth column, the models are characterized by a typology of accident models. They are:

1) Causal sequence model
2) Process model
3) Energy model
4) Logical tree model

5) Safety, health and environment management models

6. Training Need

The sixth and last column characterizes each model by the learning curve required and proposes three levels of training requirements. The entry of the word 'novice' indicates that the models can be applied upon completion of some form of orientation. The entry of the word 'expert' suggests that some form of formalized training be acquired, including hands on experience. Entry of the word 'specialist' implies skills somewhere in the middle.

Chapter 4: Event Analysis Models

In the absence of any conceptualized model, investigations are given to narration; a descriptive effort that is wholly dependant upon the investigators powers of observation and point of view. Prone to subjective interpretations and experiential bias, these narrative investigations have been the learning grounds of those in the regulatory community whose natural inclinations in terms of methodology was compliance; for whom until recently, no challenge was given concerning investigative merit. Good investigations ostensibly, were the product of good investigators!

A comprehensive analysis and description of event analysis techniques exist in the literature (Ferry, 1988) and (Livingston et al., 2001) and will not be further scrutinized in this paper. The models do however offer some insight into the cognitive modeling that investigators find useful in framing the processes of event investigation. Regardless of the choice of model, they have proved to be the one element or method within the investigative process, that most investigators adopt as a standard operating procedure, if only informally. The models are necessarily empirical in nature; those that add value and have the most utility are adopted – and adapted; those that fail the tests of practicality and a reasonable cost-benefit on behalf of the investigators resources are relegated as benchmarks along the road of *event* causation.

Some attempt has been made to classify and evaluate these models, on the basis of assumed methodologies (Benner, 1985), positive attribution (Livingston et al, 2001) and panel review (Munson, 1999). Collectively, these researchers have identified the following investigation models as achieving top rank in their studies (in no particular order):

- Fault Tree Analysis
- Energy/Barrier Analysis
- Events Analysis
- Root Cause Analysis
- Sequential Timed Event Plotting
- TapRooT® System
- Management Oversight Risk Tree

Each will be examined in turn, to identify possible commonalities and strengths.

Event Causation Models

Fault Tree Analysis (FTA)

This model has been attributed to the Bell Laboratories, when as early as 1959, the United States government contracted them to design a predictive model whereby undesirable events could be avoided during the development of the Minuteman Missile project (Hammer, 1989). The model consists of a very graphical analysis of a presumed event (predictive mode) or a realized event (investigation mode), followed by all possible elements or factors that could have contributed to the event, in a tree like fashion (Figure 4.1). The analysis uses Boolean logic to branch the factors of causation and in the instance of quantitative FTA, probabilities are calculated. The process of analysis continues back through time until a base event is established for which no contributing factors are possible, or probabilities impossible to discern.

The model is quite elegant in concept and can be applied to just about any event or investigative scenario. The strength is in its structure, graphical nature and deductive logic. Its limitations are owing to the fact that only those factors of causation in connection to the specified event are possible candidates for consideration. Caution must therefore be given to the choice of events when used in its predictive mode.

The analysis has a low learning curve, however a high degree of operational awareness and technical knowledge of the subject matter is required. As a process, it is best lead by an experienced facilitator, someone familiar with group dynamics. The model is customizable, easy to use and available in numerous software applications.

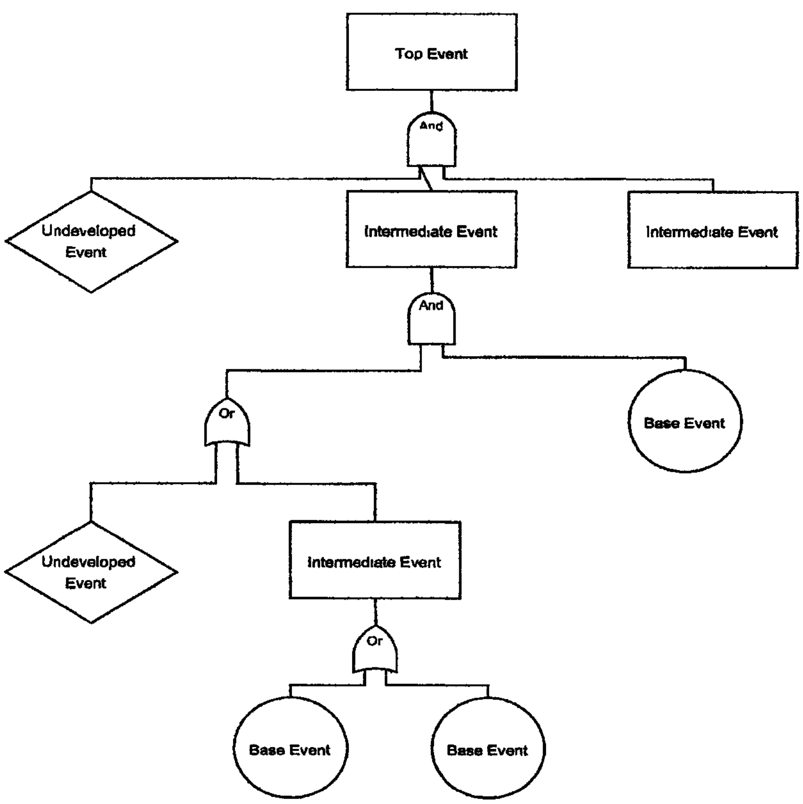


Figure 4.1: Conceptualized Fault Tree diagram (Livingston et al., 2001).

Sequential Timed Event Plotting (STEP)

Sequential Timed Event Plotting is the brainchild of Hendrick and Benner, and has been extensively presented in a textbook under the same name in 1987. Based to a large extent on the Multi-linear Event Sequencing model (Benner, 1975) and the Management Oversight Risk Tree (Johnson, 1980), STEP affords the investigator a comprehensive approach to investigation in a manner unparalleled in the past. The STEP worksheet consists of an event sequence diagram (Figure 4.2) moving from left to right with respect to time. The plot incorporates any number of *actors* that are characterized by their *actions* and *conditions* under which they occur. Events are confirmed in a multi-linear fashion and causal relationships established through a process of 'back-stepping'; a process of filling in vacancies of understanding within the evidentiary record.

STEP sets out a comprehensive methodology based upon a theory or model of accidents as processes. This novel theory puts forward the argument that accidents, like any process involve agents (*actors*; not necessarily people) engaged in some form of activity (*action*). One agent engaged in one activity defines one event. These events can then be cross-linked in a manner that comprises a dynamic model of the process for which the accident is an outcome.

Its strengths lay in its structure, methodology and graphical nature. It has a low to medium learning curve, but once experienced has immediate appeal to most investigators owing to its deductive and inductive logic, as well as versatility. The limitations are the extent to which participants must observe discipline and patience in carrying out what can be a lengthy endeavor. It is strongly supported by documentation and compliments Fault Tree Analysis and Change Analysis.

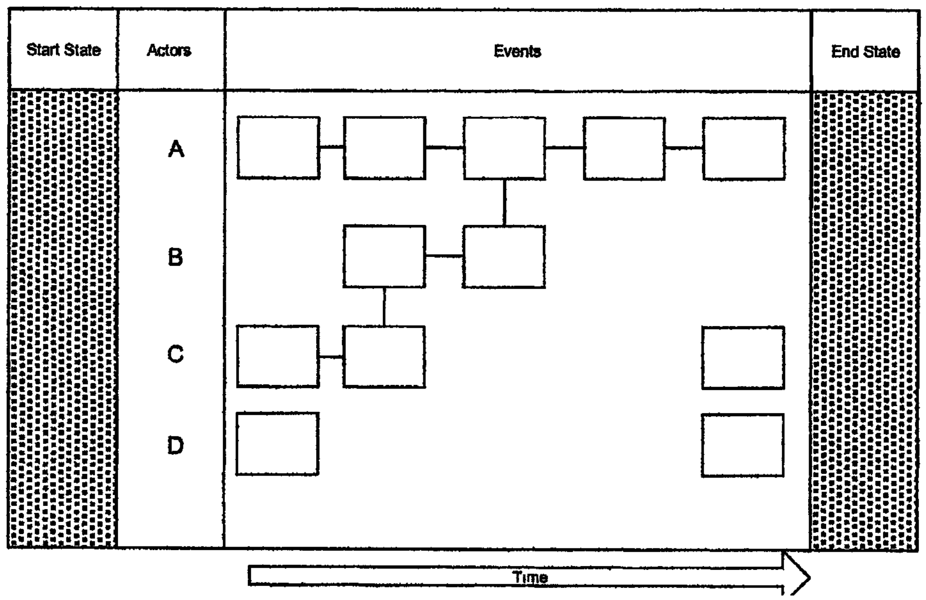


Figure 4.2: Conceptualized illustration of a Sequential Timed Event Plot diagram (Livingston et al. 2001).

TapRooT® System

TapRooT® (http://www.taproot.com/), incorporates Events and Causal Factors charting as a 'front end' to its integrated system that assists the investigator in identifying human performance problems. The model is computerized and is well documented with a paper-based guideline. Upon inputting the causal factors into TapRooT® Root Cause Tree, an algorithm incorporating Barrier analysis, Change analysis, and Critical Human Action Profile modeling generates a generic tree for each causal factor. The system has a checklist of fifteen human factor related questions (Figure 4.3) that assist the investigator in determining root causes to the scenario. A number of completed reports can be generated from the computerized version with some allowance for customization and explanatory comments.

Mastering the technique requires a moderate to high learning curve (3 to 5 days dedicated training) owing to the complexity and the computerized design of the system. The strength of TapRooT® lies in its structure, multiplicity of models and ability to guide the investigator through an inclusive list of considerations through its checklist query format. It has developed a number of back-end modules (e.g. trouble shooting) that provide further assistance to the user. There are also a steady number of training opportunities around North America for novices, practitioners and experts alike.

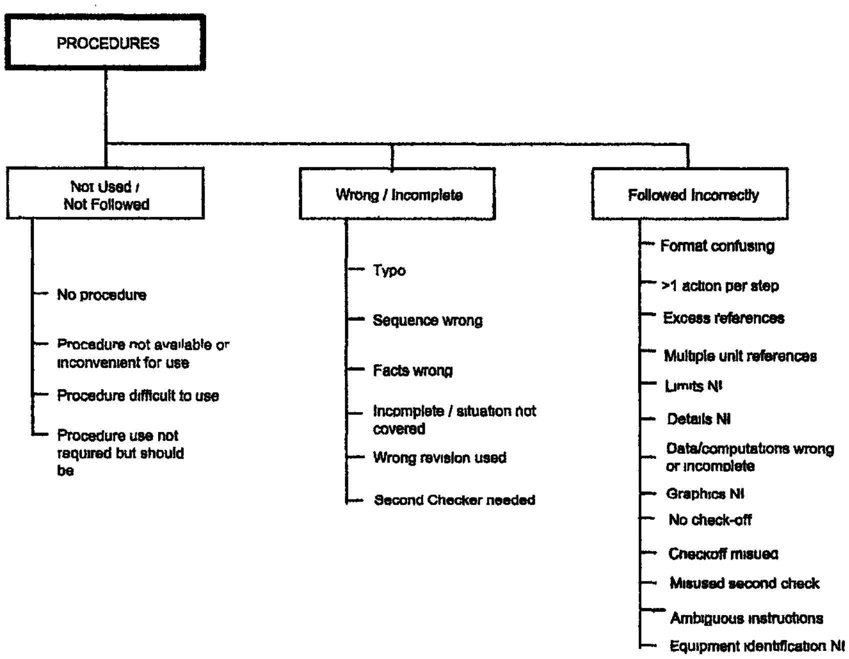


Figure 4.3: Typical checklist type query from the Procedures Basic Cause category of a TapRoot® analysis (System Improvements Inc., 2004).

Energy and Barrier Analysis

Barrier analysis (Gibson, 1961) and then Energy and Barrier Analysis (Haddon, 1966) are models with a great deal of appeal owing to its light learning curve and intuitive nature. It is unique insofar as it does not quite fit any of the contemporary models of the day; perhaps that is also part of its appeal. Starting with the theory that accidents are only likely to occur when a *target* (person, thing) gets between a *hazard* (energy) and the *barrier* (controls) the purpose of which is to function as a control against that energy. The energy sources can vary from potential, kinetic, thermal, acoustic ... nuclear, etc; and the barriers fall into one of two categories; physical and management.

The analysis is intuitive and graphical in nature, utilizing standard flow-charting symbols to construct a sequence diagram (Figure 4.4) of events and the conditions under which they operated. There are five basic steps:

1) Identify hazard and target
2) Identify each of the barriers
3) Evaluate the status and effectiveness of the barriers
4) Determine causes of failures of the barriers
5) Evaluate the effect of the failures of the barriers

The strength of this model is its simplicity, relevancy and flexibility. It is considered a companion tool to the Management Oversight Risk Tree (MORT) model, as well as others. Its weakness lies in its lack of structure and that the analysis would be required to be conducted iteratively, given the plurality of events associated with most accidents.

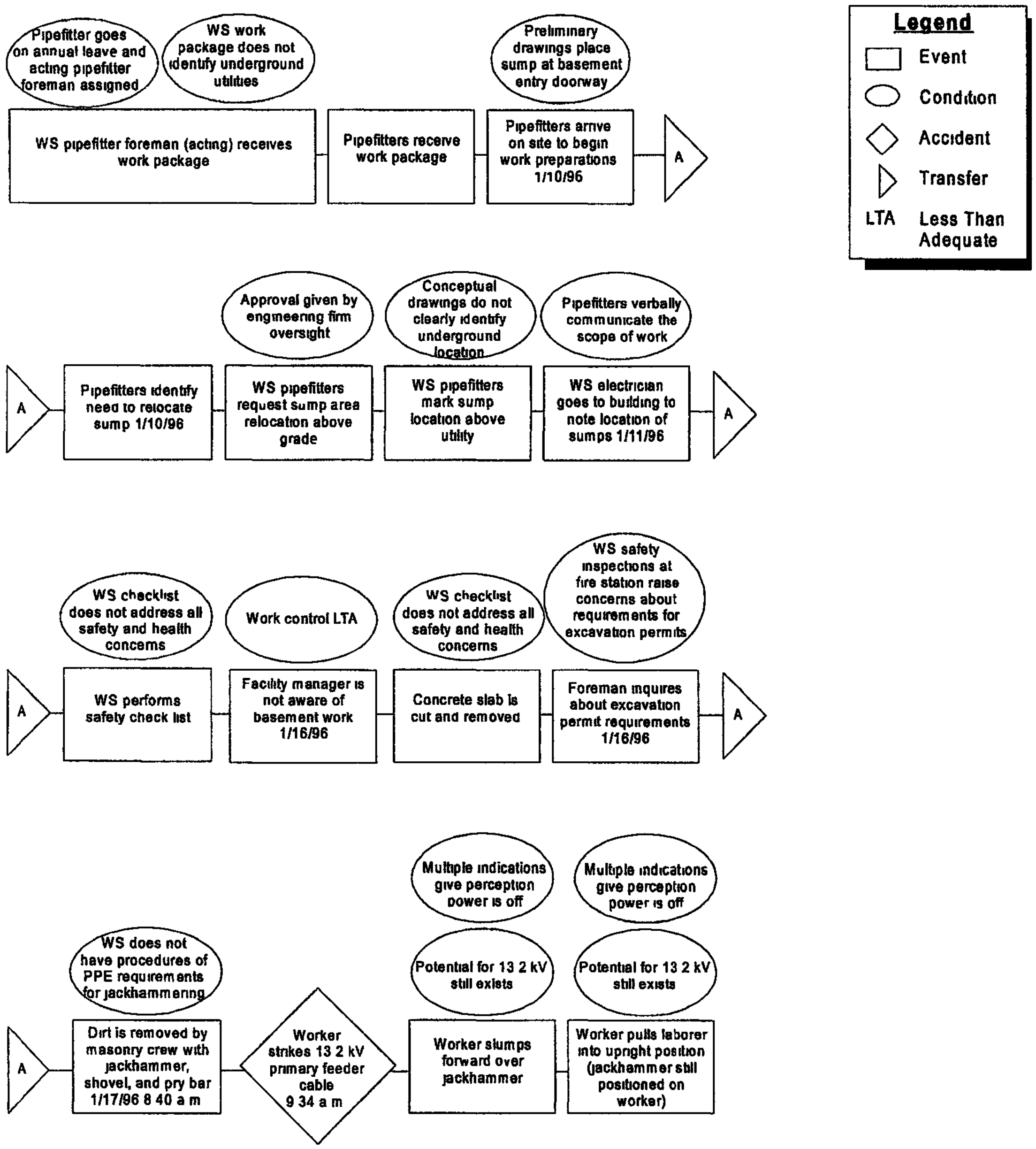


Figure 4.4: Example from Energy and Barriers Analysis worksheet (DOE 2003).

Management Oversight and Risk Tree (MORT)

No treatment of investigation of industrial events would be complete without acknowledgement of MORT (Johnson, 1973). Sponsored by the U.S. Atomic Energy Commission, MORT addresses the necessity within the nuclear industry of a more proactive analytical model for event causation than the 'fly-fix-fly' models to date. Incorporating similar symbols and logic of FTA, MORT goes beyond the event process (assumed risk) and seeks to relate the occurrence with more deeply rooted management systems (oversights and omissions).

MORT is comprised potentially, by as many as eight inter-linked 'trees', encompassing as many as 98 scenarios with between 200–1500 possible causal factors (Figure 4.5). The analysis is initiated with the identification of the loss event and then works down the possibilities along two logic streams; assumed risk or oversight and omissions. Next the analysis breaks down the factors further by separating the 'what' happened from the 'why'. The process continues to break down the causal factors into one of two groups, those considered adequate or less than adequate. MORT also relies frequently upon Change Analysis, Energy and Barrier Analysis as well as Event Causal Analysis as adjunct tools.

The strength of MORT lies in its proactive structure, encouraging the investigator to examine overlooked factors and to reduce bias. Further, it takes a system approach to event causation by bringing the management design and operating conditions under scrutiny. In doing so however, the model occasionally lacks specificity. The model is also not designed to be explicit with respect to time.

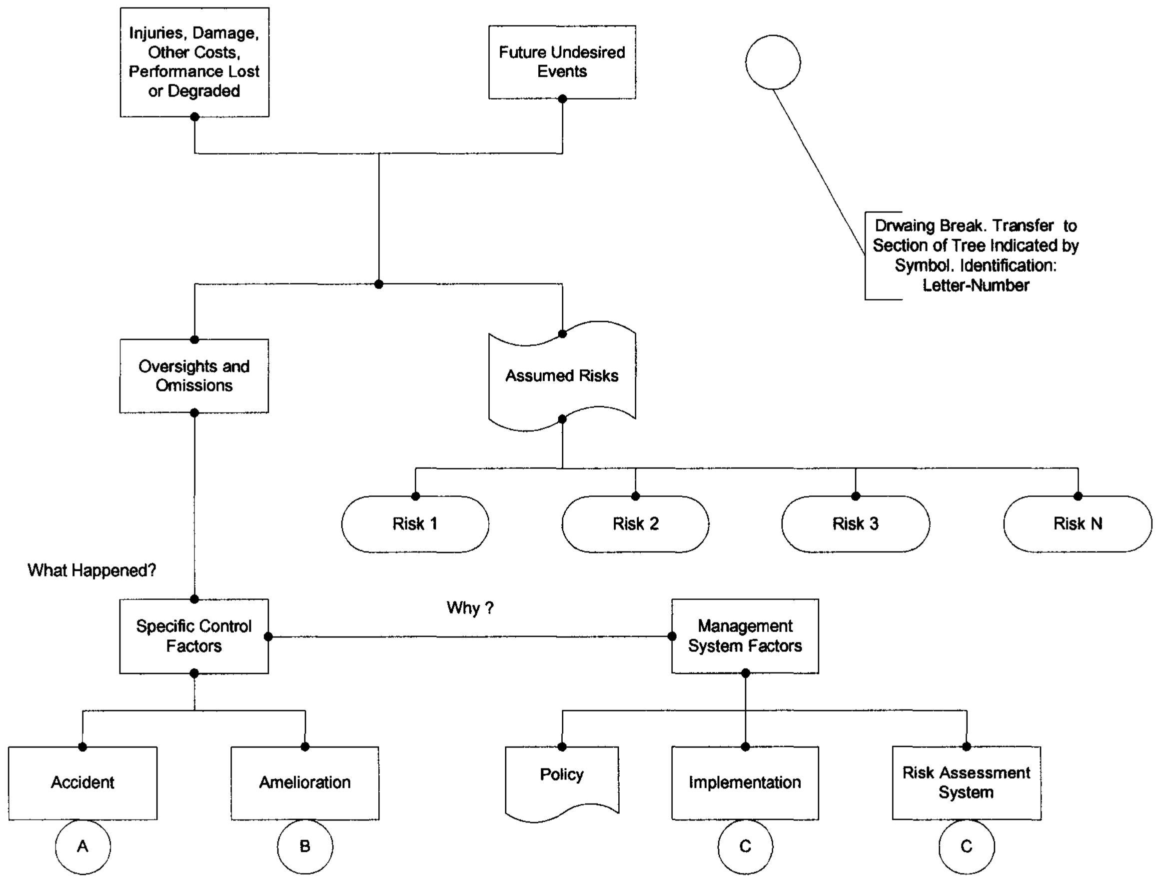


Figure 4.5: Conceptualized illustration of a Management Oversight Risk Tree diagram (DOE, 2003).

Root Cause Analysis

The Root Cause Analysis (Savannah River Plant) system (Paradies, 1988) was developed under sponsorship of the US Department of Energy. Similar to (indeed a component within) TapRooT® and building on MORT, Root Cause Analysis starts with an Event and Causal Factors Chart as input and proceeds to identify root causes with a user defined tree structure. Augmented by the companion analytic techniques of Events and Causal Factors Analysis, Energy and Barrier Analysis, and Change Analysis, the focus is determining the 'why' of an event resulting in a loss.

The tree structure consists of numerous sections or *nodes* that are sub-divided into six increasingly more detailed levels. Seven human performance categories are incorporated, namely:

1) Procedures
1) Training
2) Quality Control
3) Communications
4) Management Systems
5) Human Engineering
6) Immediate Supervision

Further, five equipment reliability categories are explicitly scrutinized, namely:

1) Preventative Maintenance
2) Repeat Failure
3) Unexpected Failure
4) Design
5) Defective Equipment/Parts

The investigator constructs the Events and Causal Factors chart and then determines what, if any factors were to be removed, would have prevented the event from occurring. For each of these causal factors, the investigator determines what *nodes* are applicable, and then works down through the tree to determine an underlying failure, such as lack of training or incorrect procedure.

The model is predicated on the theory that 80% of all events occurring within the nuclear industry have causal factors originating within the management systems. The strength of Root Cause Analysis is its structure and the extent to which it can identify these 'root' causes that the simpler models might miss. The limitations are in the language of the model; the preoccupation with cause and the risk of attaching blame to some of the human performance issues. As is the case for TapRooT®, the quality and efficacy of Root Cause Analysis, is largely determined by if not dependent upon Events and Causal Factors Analysis.

Event and Causal Factors Analysis

Events and Causal Factors Analysis (ECFA) is believed to have origins in the home safety sector (National Safety Council), during the mid '50's. Later, it was improved and updated (Johnson, 1973) to reflect the sequential nature of causes. Although, having merit in its own right, ECFA has become a standard 'front-end' for other models such as the Management Oversight and Risk Tree (MORT) and TapRoot®, in conjunction with Change Analysis, Energy and Barrier Analysis and Fault tree analysis .The Events and Causal Factors Analysis model produces a chart (Figure 4.6) which depicts the necessary and sufficient events and causal factors for an occurrence in a sequential manner. Although human factors and environmental factors are typically identified, but increasingly systemic factors are being incorporated to reflect organizational problems. ECFA serves three main purposes to investigators:

1) Assists the verification of causal chains and event sequences;
2) Provides a structure for integrating investigation findings; and
3) Identifies significant causal events for further analysis.

The strengths of ECFA are its structure and flexibility. While the structure requires the investigator to consider both necessary and sufficient conditions as criteria for causation, its flexibility allows the model to handle quantitative data, to operate as a training tool and to assist in system design. The limitations are few (hence its popularity), however its simplicity does hinder industrial events rooted in more complex organizational issues.

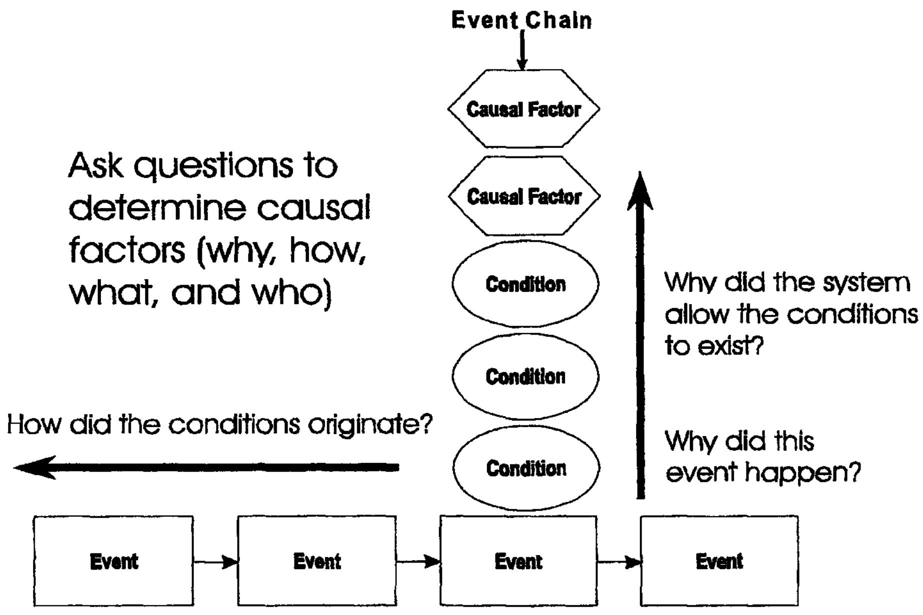


Figure 4.6: Conceptualized illustration of an Events and Causal Analysis chart (DOE, 2003).

Observations

It is worthy of note that the *event* analysis models identified by the researchers as being preeminent in their utility, turn out to be mutually dependent upon each other. There are in excess of 100 distinct investigative analysis models, yet the same dozen appear time after time in practical application. The more popular of these have been identified (Figure 4.7) with respect to time and grouped in terms of their defining characteristics. It is emphasized that these are characterizations or generalizations of improvements exhibited by the evolving models with respect to time, not a detailed historical retrospective.

Year	Analytical Method	Characterization
2000	Reason's® Root Cause Analysis	Epidemiological, System Based
	Event Root Cause Analysis Procedure	
	Human Performance Investigation Process	
	TapRoot® System	
1990	**Root Cause Analysis**	
	Technique for Human Error Prediction	
	Systematic Causal Analysis Technique	Sequential, Event Based
1980	Causal Tree Method	
	Multi-linear Events Sequencing	
	Technic of Operations Review	
	Management Oversight Risk Tree	
1970	**Energy and Barrier Analysis**	
	Haddon Matrix	
	Change Analysis	
1960	**Event and Causal Factors Analysis**	Hierarchical, Event Based
	Fault Tree Analysis	
1950		
1940		
	Chain of Events Theory	Multiple Factor, Cause Based
1930	Proneness Theory	Single Factor, Cause Based

Figure 4.7: Characterization of investigation analysis models with respect to time.

Discussion

Clearly, there is a trade off between the complex system type models of TapRooT®, RCA and STEP; the deeper and more sophisticated the analysis, the more dependent they are on the simpler models such as Fault Tree Analysis and Event and Causation Factors Analysis. Conversely, FTA and ECFA are simpler, quicker and more intuitive; but the results can be superficial and limiting. This is not necessarily a bad thing where the investigators intuition leads him/her to believe that a simpler analysis provides sufficient depth and scope; yet there is always the question of what lies beneath the stone yet unturned.

Reflection on the strengths and limitations of the proceeding analytic models offer the following revelations concerning optimizing investigation efficacy:

1) Formalized analytic techniques have become increasingly the norm, if not a requisite of professional *event* investigation.
2) The structure imposed by these models promotes completeness and objectivity within the discovery process.
3) Flexibility of the analysis is paramount to accommodate the diversity of *event* occurrences.
4) Investigators must be proficient at selecting the optimum analytic model and not be averse to conducting multiple analyses.
5) Each of the system type models have their own distinctive merit and advantages, however Fault Tree analysis, Event and Causal Factors Analysis and Energy and Barrier Analysis are precursory and essential in any investigators arsenal of tools.

Figure 4.8 illustrates the interdependency of the more complex analytical models and with the more established, precursory methods such as Event and Casual Factors Analysis, Fault Tree Analysis, Energy and Barrier Analysis and Change Analysis. The dotted lines indicate methods that are 'imbedded' within the model as algorithms.

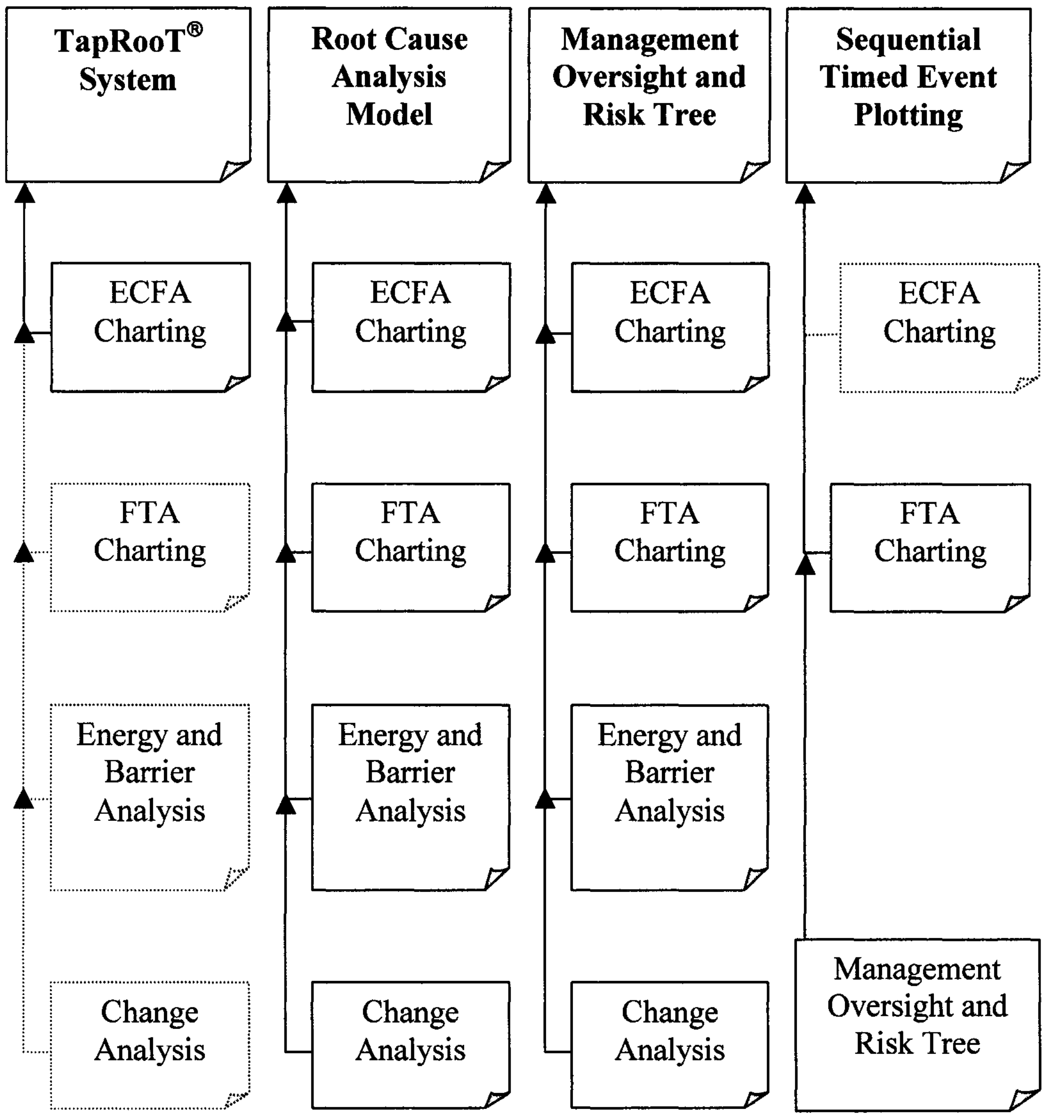


Figure 4.8: Schematic illustration of the interdependencies between the established 'system' analytic models and the more simplex methods.

Chapter 5: Event Causation

The Present Outlook

The proceeding retrospective into the present day tools of investigators is only half the story, a reactive one at that. For event causation models and techniques to make gains as regards to the capricious nature of industrial events, they will have to make further advancements, advancements in terms of predictive capacities and heuristic models. There is a distinction to be made here, because the typical notion of prediction implies some form of precognition or explicit ability to predict an event and in the forestalling, prevent it. This would be ideal, however a more realistic predictive capacity is along the lines of being able to read behavior aspects and reliability indicators to the extent of attributing or characterizing those scenarios (or organizations) that are set-up for failure.

It would appear that in this context, we have come full circle. It was not quite a century ago that the accident proneness theory was all the rage, as it related to individuals (Greenwood and Wood, 1919). History reveals that the amount of attention this rather presumptuous theory garnered was enormous. Over, the years it has been gradually supplanted by increasingly more inclusive theories as to the provenance of accidents; yet as theories go, proneness still has some life in it, albeit in the insurance industry sector.

Alternate theories of unsafe acts, unsafe conditions (Heinrich, 1936); homeostasis (Surry, 1969); loss causation (Bird and Germain, 1986); and accidents as processes (Hendrick and Benner, 1985) have served us well, to the extent that we have as a society been appropriately introspective as to our organizational conduct within the workplace.

In the intervening years, we have witnessed new hazards being introduced to the workplaces, new work structures and new information technologies. There is no doubt about it; safer systems have been designed, standards set and statutes written; all achieving in part, their intended results – injuries are on the decline. Still, industrial events resulting in losses are occurring in the workplaces. Apparently, our capacity to generate these events is nearly on par with our ability to prevent them. Perhaps along the way we may also have inadvertently introduced new and counter-intuitive organizational behaviors; the organizational context or culture in which accidents are permitted. It is time to examine a new approach to accident theory; one that brings under scrutiny the cognitive processes that govern **decisions** within an industrial *event* scenario.

The Propositional Calculus of Causation

In the studies of philosophy and pure logic, propositional calculus is a term that applies to relationships between propositions, that when applied correctly and fully, can easily be truth tested. Metaphorically, it is the tying of loose ends, the happy circumstance whereby the inferences and axioms employed are sufficient to win the argument and demonstrate a valid hypothesis or proposition. At first glance, one is tempted to say 'so what', but upon closer inspection the term reveals some insight and wisdom regarding the benefit of discipline and foundation as applied to accident theory. We start with the language of causation.

The Language of Causation

Much has been written over the last century as to the mechanics of event causation. This mechanistic aspect of industrial events reflects the very nature of industrial workplaces themselves; highly engineered, increasingly complex and somewhat appealing to the linear technocrat among us. In short, we hold dear the notion that all events are deterministic in nature. The chain-of-events theory (Heinrich, 1936), the Multi-linear Event Sequencing model (Benner, 1975) and to some extent, the later system approaches such as Loss Causation (ILCI, 1986) and TapRoot® (Paradies, 1988) are all predicated on some clockwork like mechanism linking events, conditions and agents within an accident scenario.

Within the last two decades, the emergence of the many models and systems has added to the confusion and contradiction in terms of both the language and syntax of terminology incorporated within causation theory. There has in general, been a gradual moving away from the word accident to incidents. Presently, much ambiguity exists as to what defines an *event*; or what exactly are the necessary or sufficient conditions to cause an *event*? At no time is this healthy debate more vigorous than when discussing the definition, merit and nature of causation.

If you were to ask twenty investigators what is the meaning of cause in the context of accident theory, you would probably get twenty different responses. The differences run deeper however; the very relevancy of cause and effect relationships has been brought into question (Benner, 1985) and here too, in recent years we see a movement away from its explicit use. Sklet (2002) comments that:

> Within the field of accident investigation, there is no common agreement of definitions of concepts, there tends to be little confusion of ideas. Especially the notion of cause has been discussed. While some investigators focus on causal factors (DOE, 1977), others focus on determining factors (Kjellen and Larsson, 1981), contributing factors (Hopkins, 2000), active failures and latent conditions (Reason, 1997) or safety problems (Hendrick and Benner, 1987). Kletz (Kletz, 2001) recommends avoiding cause in accident investigations and rather talks about what might have prevented the accident.

In the lexicon of investigations, the explicit statement of cause is being replaced with such implicit notions as causal factors, factors and contributing factors, the rationale being partly legal and partly sentimental. In the instance of the former, most investigators are more than aware as to the nature of the legal documents they produce, with the attendant possibility that they may be used for purpose of which they are not intended – in an increasingly litigious society. In the instance of the latter, investigators to their credit, are empathetic to those that might harbor feelings of remorse, resentment or guilt towards being party to the cause of an event resulting in tragedy.

Clearly, we must respect these sensitivities, both on the behalf of the participants in an industrial event and on the behalf of the investigators. Yet, there is a fundamental connection to be made with the *event* and those precursory or antecedent events, activities and conditions that lead up to it. It is to nobody's benefit to introduce unwanted vagueness or ambiguity into the analysis or narration of an investigation, therefore a balance must be struck between establishing clear and concise causal relationships and not tainting the assertions with judgment or aspersions.

With this in mind, and in deference to the nomenclature of the various authors previously cited in this thesis, the following terms are formally introduced as an encompassing and judgment free language in which to frame the occurrences of industrial events:

Event A significant real-time occurrence that happens; a single activity put in play by one or more agents (people or process). Events are defined by antecedent events, the conditions at the time of the event and the consequences or outcomes of the events. *Events* are characterized as having a subject or subjects, a noun and a verb in a non-complex assertion of occurrence.

An example would be beneficial here. Consider the simple statement, 'the bicyclist elected to leave the bike trail'. The single subject (actor: the bicyclist) chose to leave (action: made a decision to leave) the trail (noun: trail). The significance of **decisions** as events will become paramount later in this chapter.

Critical Event: The defining event resulting in a loss or for which a state of alert or preparedness exists; the event that represents the instability of, if not the collapse of control systems governing the workplace. Inclusive of those situations that do not result in a physical loss but under slightly different circumstances, may have.

Alpha Event: The first *event* under consideration within the investigation as having some causal connection or determinacy with the final *critical event*. This event may be arbitrary (first event of the day or shift) or procedural (first event as being identified in a process).

Omega Event: The last event, penultimate to the event resulting in loss or instability (*critical event*). The distinction here is an important one insofar as it separates the conditions previous to the *critical event* form those contemporaneous with the *critical event*.

An example here would be the scenario of a bicyclist electing to leave the bike path strikes a rock and then falls off of his bicycle, skinning his knee. The $_{\alpha}$*event* is the act of leaving the bike trail, the $_{\Omega}$*event* being striking the rock, and the *critical event* being falling to the ground; resulting in the injury. To continue:

Scenario: The sequence of events, conditions and decisions starting from the $_{\alpha}$*event* and concluding with the *critical event*.

Determinant: A general vernacular for the post posteriori establishment of cause and effect relationships between the events within a scenario and its ultimate conclusion -- the critical event; replaces the word cause as an assertion of cause and effect.

Necessary Determinant: A *determinant* asserted to be a requisite for the resulting *critical event* to be realized within the *scenario*, without which the *critical event* could not in fact occur.

Sufficient Determinant: A *determinant* asserted to be sufficient for the resulting *critical event* to be realized, but is not the only means by which this could be realized.

Proximate Determinant: A *determinant* (without intermediaries) asserted to be so immediate, direct, major or otherwise basic in terms of causation that the cause and effect relationship would be considered strongly established.

Remote Determinant: A *determinant* (with intermediaries) asserted to be somewhat distant in terms of the cause and effect relationships, but still within the context of balance of probabilities is reasonably established.

Balance of Probabilities: A framework for the weighing of known evidence as supportive or non-supportive for the establishment of determinacy (cause and effect).

Agent: The motive force or doer behind an action. The *agent* can be considered a person or persons, a process or equipment. If the *agent* is a person or persons (*actor*), then a special class exists for the event(s) to be identified as decisions.

Action The activity effected by the *agent* in which something is done (expressed as a verb).

Event Horizon: A hypothetical plane or horizon representing future events in terms of their risk and immanency. The larger the risk or more imminent the event, the more it dominates the horizon.

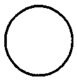
The utility of the preceding nomenclature is that it can be used regardless of the nature of investigation; clearly cause and effect knows no distinctions regarding industry, methodology or theory. The term of *events* is purposefully broad in scope and serves to defuse the arguments surrounding the reference to accidents, incidents and the like. *Critical event* is a term that captures the quintessence of an event for which most certainly emotions and adrenalin alike run high. In many cases, there are tragic consequences of *event scenarios*; perhaps it is time to recognize this in our investigation language as well. Finally, *critical events* are inclusive to states of un-equilibrium and high alert that sometimes exist and for which no physical loss may be incurred (upset conditions). An example is the conditions within metallurgical processes and chemical reactor vessels which may not result in failure or release, but come perilously close in terms of operating outside of their established operational limits.

The merit of this nomenclature is that *determinacy* appeals to our sense of dominion over accidents; that these are not divined events, nor are they subject to quantum like vicissitudes of uncertainty. The use of *determinants* in the place of cause will give some pause to the legal community and more importantly lighten the consciences of those unfortunate causalities of industrial events. *Determinants* also have a parallel, an accepted and established counterpart – of vectors from the epidemiological discipline.

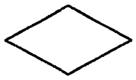
It is hoped that by the introduction of precise, coherent and judgment free language of causation will serve to focus the attention of investigators and accident theorists on what really matters – the development of more predictive and heuristic models. In a similar vein, it is important to introduce new theories and methodologies to challenge the weaker theories and build upon the stronger. With this in mind, the author proposes a theory that builds on the interrelations of events, actors and conditions; already established by others, but focuses on that special class of events known as **decisions**.

The Symbolism of Causation

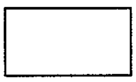
The symbols used in the depiction of event scenarios appear to be born out of necessity and intuition towards the complex interaction between man, machine and the environment. Heavily rooted in Boolean logic, the early causal theories of fault tree analysis and management oversight risk tree adopted the closest symbolism of the day – flowchart symbols from the computer industry, the key ones being:



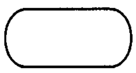
1) Primary Fault: An event with no subordinate causes.



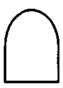
2) Secondary Fault: An event caused by and dependent upon a known extrinsic component or device.



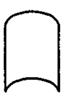
3) Basic Event: Typically a failure of material, process or equipment



4) Head Event: The event at the top of the chart and subject of the analysis (comparable to critical event).



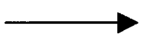
5) And Gate: Indicates the existence of two requisites.



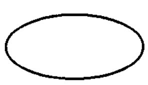
6) Or Gate: Indicates one of two possible options.

7) Off page connector: used to link multiple pages.

Building on this success, sequencing of events with respect to time have added the following conventions:

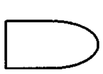


8) Arrow: Links events and actors indicating the forward passage of time from the earlier to the later time.



9) Condition: The physical state attributed to a person, thing or event.

Finally, for the purposes of this thesis the author proposes the following addition to the causation symbol convention; one that emphasizes the special importance of **decisions** as events.



10) Decision Event: A special class of events involving decisions believed to be determinants within the *event scenario*.

Typology of Decision Events

We start by the observation that, all decisions (with respect to *event* causation) fall into one of two categories or classes:

1) Those that have the capacity to be determinants of the critical event, and;
2) Those that do not have the capacity to be determinants of the critical event.

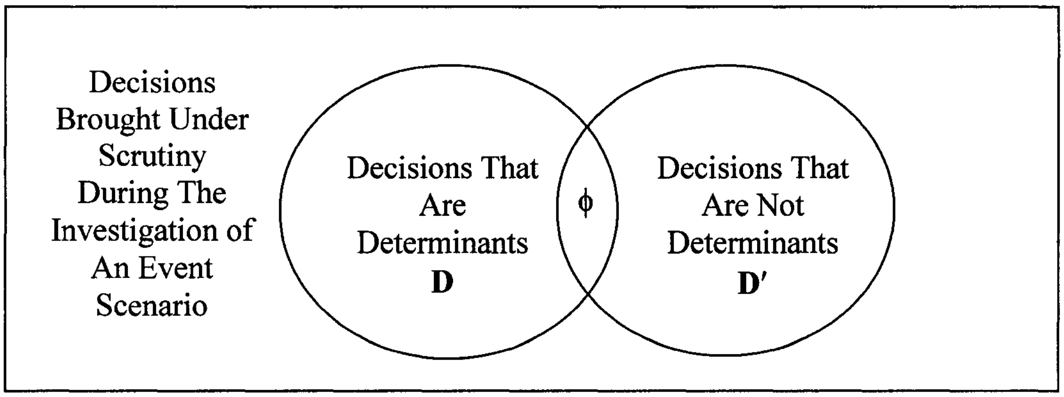


Figure 5.1: Venn diagram illustrating that, $D \cap D' = \phi$ and that, $D \cup D' = S$

We observe that there are no sub-sets as a product of intersection of the two classes; further their union comprises the entire universe of decisions. Now, the latter class **D′** does not have a deleterious effect to the scenario in which the critical event plays out. These decisions may have no affect on the event scenario or, may have in fact mitigated the actual event. They are of interest in terms of further studies in accident prevention, but are considered to be within the purview of this analysis. The former class however **D**, may be broken down into two further sub-classes:

1) Those decisions that exhibit affirmation of intent (D_1).

2) Those decisions that lack affirmation of intent (D_2)

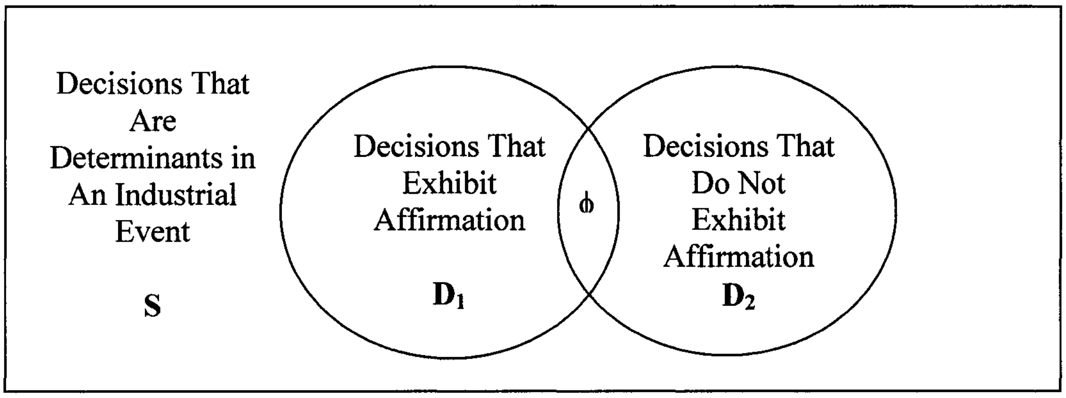


Figure 5.2: Venn diagram illustrating that, $D1 \cap D2 = \phi$ and that, $D1 \cup D2 = S$

By exhibiting affirmation it is meant those decisions where an actor consciously elects or chooses to act upon a particular option. The decisions that do not exhibit affirmation are those made by default and without the explicit knowledge of the actor (owing to the actor being present when a boundary condition was transgressed and having no awareness of that fact), and for which no account or recollection can be attributed on a conscious level (forgetfulness, fatigue, over-stimulation).

Finally, we can examine two additional sub-classes of D_1 that make a distinction as to whether the basis upon which the affirmative class decision was made, was valid or not. The validation in this instance is not a judgment to be made, rather recognition that the person may have had some reason or belief that had it been true, would have changed the outcome of the decision. The sub-class may D_1 may be further broken into:

1) Decisions that are based upon correct assumptions or beliefs.
2) Decisions that are based upon incorrect assumptions or beliefs.

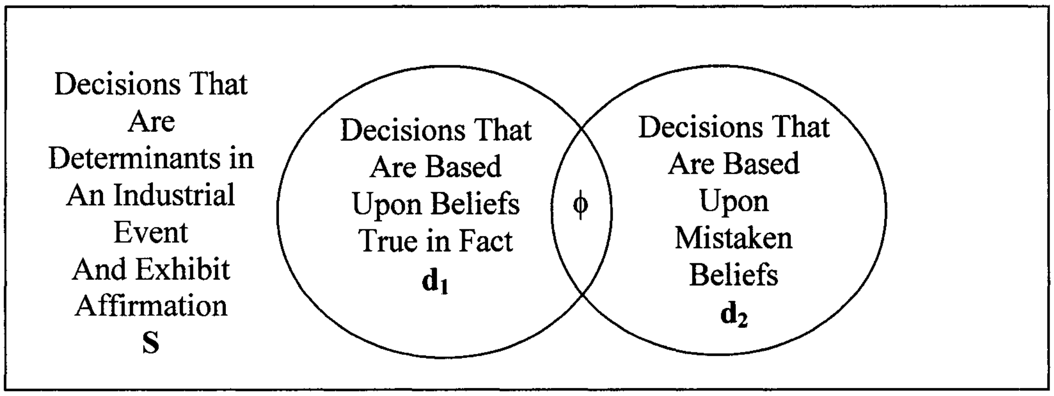


Figure 5.3: Venn diagram illustrating that, $d1 \cap d2 = \phi$ and that, $d1 \cup d2 = S$

The three preceding algebraic relations serve to establish a logical, theoretical basis on which to make the following fundamental assertion: Decisions revealed to have been *determinants* in a scenario leading to a *critical event*, fall into of three mutually exclusive classes:

1) Errors of Commission
2) Errors of Omission
3) Errors of Mistaken Belief

As this is of fundamental importance in linking the results of an *event* investigation to a typology of *event* experiencing cultures, it is important to be as clear and precise as possible in terms of the definitions of these decision classes. To this end, the following illustration will serve as a visual aid for the establishment of the distinctions between errors of commission, omission and mistaken belief. We observe a single chain of events on behalf of an *actor* (the driver) moving from the periphery of the concentric rings (*conditions*) to its focus (*critical event*). Each ring represents a different set of operating conditions. As the chain of events scenario progresses through each condition, it is incumbent on an *actor* to formulate a decision and respond accordingly.

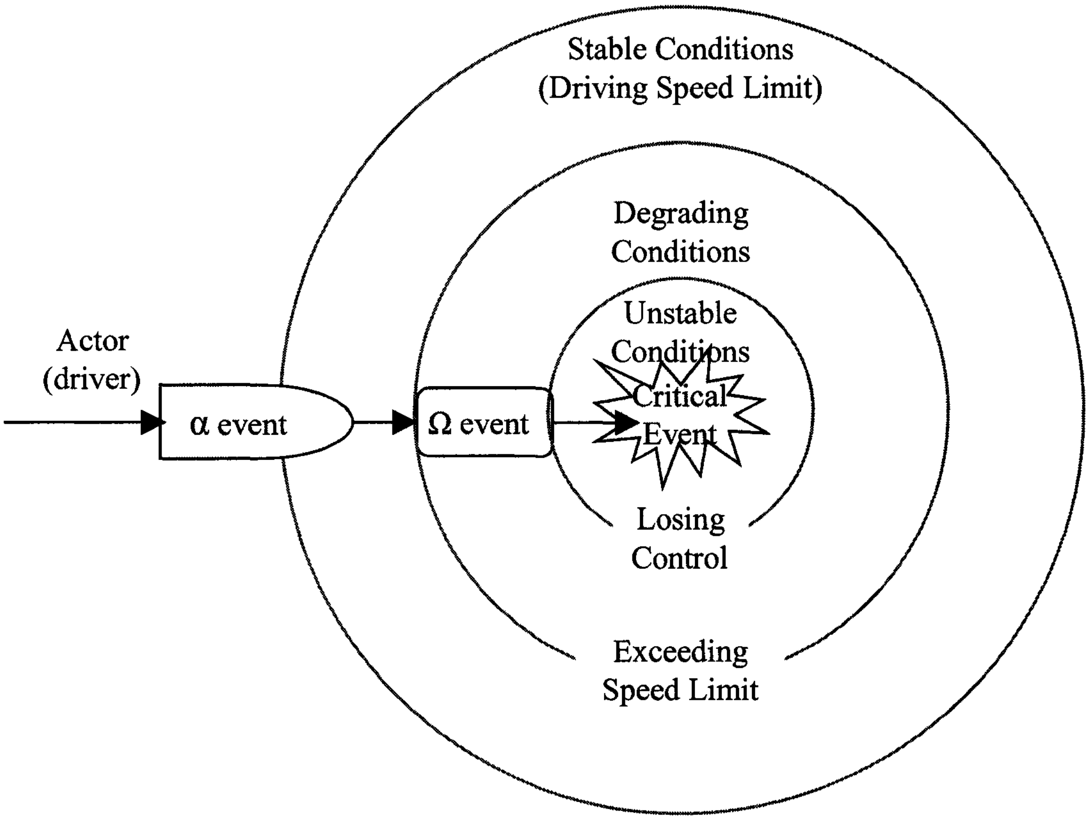


Figure 5.4: Schematic illustrating the nature of decision events on the part of a driver on the verge of exceeding the speed limit and an incipient critical event.

Errors of Commission

Errors of commission are characterized as events within an *event* scenario in which a decision has been explicitly established on the part of an *actor* or *actors*. Such a decision would be subsequently established as a *determinant* within an investigation of an *event scenario* and would be contiguous with a boundary line between one condition and another (Figure 5.4). The *actor(s)* are fully cognizant as to the conditions prior to and subsequent to the decision and that some transgression of norm, rule or standard has taken place. The decision is one that the *actors(s)* carried out with affirmation and on an informed basis (no mistaken beliefs or invalid presumptions). It is understood that there is no intent on behalf of the *actor(s)* in the making of the decision to in any way cause harm, damages or a degradation of operational integrity.

An example of an Error of Commission in our vehicular scenario is the instance of a heavy-footed driver electing to exceed the speed limit. The *actor* assesses the driving conditions, frames the decision, implements it with the application pressure on the foot pedal and cognitively internalizes it by way of rationale. The likely rationale in this instance might be that his perceived need for expediency is greater than the assumed risk of incident (be that an accident or being caught by the police).

The *actor* (the driver) puts into play by his/her own devices, two *events*. The first *event* is a decision *event*, at or on the boundary between the condition of compliance with the stipulated speed; and non-compliance with that speed. The *actor* is fully aware of the conditions both before and after the decision and has a pretty good idea as to the potential outcomes should the conditions change for the worse. The *actor* arrives at the decision on the basis of the *balance of probabilities* that the conditions will remain stable with respect to time. The decision is an informed one, albeit ill advised. The second *event* is the more obvious one; the *actor* applying pressure on the foot pedal causing the vehicle to exceed the speed limit. A boundary is crossed, conditions change, and the *actor* (the driver) has now broadened the *event horizon* to include the possibility of being stopped by the police; an increased possibility of losing control of the vehicle with the attendant increase in severity of loss to people and property.

Errors of Omission

Errors of omission are characterized as events within an *event scenario* proceeding in the absence of decisions, as defined by affirmation. The decision (from the point of view of causation) has been made nonetheless, by default as some boundary line between conditions has been crossed. The *actor(s)* may not have registered a decision being made (or the need for one) as they are not fully cognizant of the conditions that prevail and that a transgression of a norm, rule or standard has been made. The *actor(s)* may be unable to recognize the boundary condition due to any number of factors such as: lack of attention, over stimulation, absent mindedness or fatigue.

As an aside, it is emphasized that the error is not in 'omitting' but rather, in the inability to recognize or acknowledge the existence of the boundary condition. Hence an error where a required procedure is omitted, but where the actor knows full well the requirements for that procedure, does

NOT constitute an error of omission, as the actor knows full well the conditions around them and is making an informed decision not to comply with the procedure. This would be another example of an error of commission.

Continuing the example of a vehicular scenario, let us presume the *actor* (the driver) was blissfully humming along with the tunes on the car radio and the vehicle steadily began to creep with respect to speed and eventually exceeded the speed limit; as did the driver in the previous scenario. Now, the *actor* did not form the intent that this should happen, had no awareness that a boundary condition had been passed and certainly no anticipation as to the possible outcomes of his/her new operating condition. The *actor* did not frame a decision but just the same, applied the same pressure to the foot pedal as in the first scenario, achieving the same increase of speed (and risk) as in the first scenario. The risk is the same [probably not as the 2^{nd} driver is unaware of the speed whereas the 1^{st} is and hence may be more alert while driving], the responsibilities are the same and the application of the Highway Traffic Act will be the same in both scenarios; yet in the latter case the *actor* (the driver) made an error of omission instead of error of commission.

Errors of Mistaken Belief

Errors of mistaken belief are characterized as events within an *event* scenario whereby a decision is made (or not), predicated on false or mistaken information. Typically, these mistaken beliefs are completely understandable, if not innocent in terms of competency of the individual involved. The *actor(s)* simply make a decision based upon assumptions or beliefs that had these assumptions been true, would have rendered a correct decision. Often characterized as an honest mistake, errors of mistaken belief are particularly difficult for *actor(s)* to come to terms with; owing to the often times perceived silliness or trivial nature of their assumptions. The decisions are affirmative ones, whereby the actors(s) may or may not be fully aware of the existence of a looming boundary condition (depending upon the nature of the assumptions). Interestingly, the *actor(s)* are of the belief that they are acting on the basis of informed decisions whereas in the clarity of hindsight investigation reveals serious inadequacies of situational awareness, cognition or both.

To complete the analogy of the vehicular scenario, our *actor* is now in the vehicle traveling down the road, exceeding the speed limit just as before, having formed the belief that they are not -- due to erroneous information. Typically, they assume an erroneous maximum speed limit or they have formed the belief that the 'real' speed limit is higher (as much as seven kilometers over the posted speed limit before an official intervention is likely). It could be that their odometer is under reporting the speed or they thought that the posted speed limit was only for night conditions. All the same, as the *actor* knows that a boundary condition exists but is under the mistaken belief or impression that they have not yet crossed it. The actor does not make the correct decision due to the fact that he/she is not in possession of all of the nascent facts or realities.

Contemporary Comparative Theories

Within recent years, considerable debate has been raging within the social sciences as to the social-political significance of some present day disasters. Be it the Space Shuttle Challenger, Kings Cross Rail Station or the Herald of Free Enterprise disaster, some first class theorists have taken on the challenge of establishing system, organizational and cognitive models, in examination of the etiology of disasters. One such researcher and expert in human factors; James Reason (1998), is a giant in his field and his influence is transcending boundaries of social sciences, the medical sciences and the industrial community alike. Reason (1998a) posits that accident causation can be modeled as a scenario in which safety 'defenses' or 'systems' are defeated by complex interactions between latent failures and more proximate triggering events. His 'Swiss Cheese' model as it has come to be known, handily establishes that there are psychological precursors (antecedents) to the unsafe act or condition, that define the accident trajectory (Figure 5.5). In reference to his model, Reason writes (1999b):

> It shows a trajectory of opportunity originating in the higher levels of the system, passing through the precondition and unsafe act planes and then on through three successive layers of defense. Each of these planes has windows of opportunity, but they are in continual flux due to largely the unpredictable influences of both intrinsic and extrinsic factors.

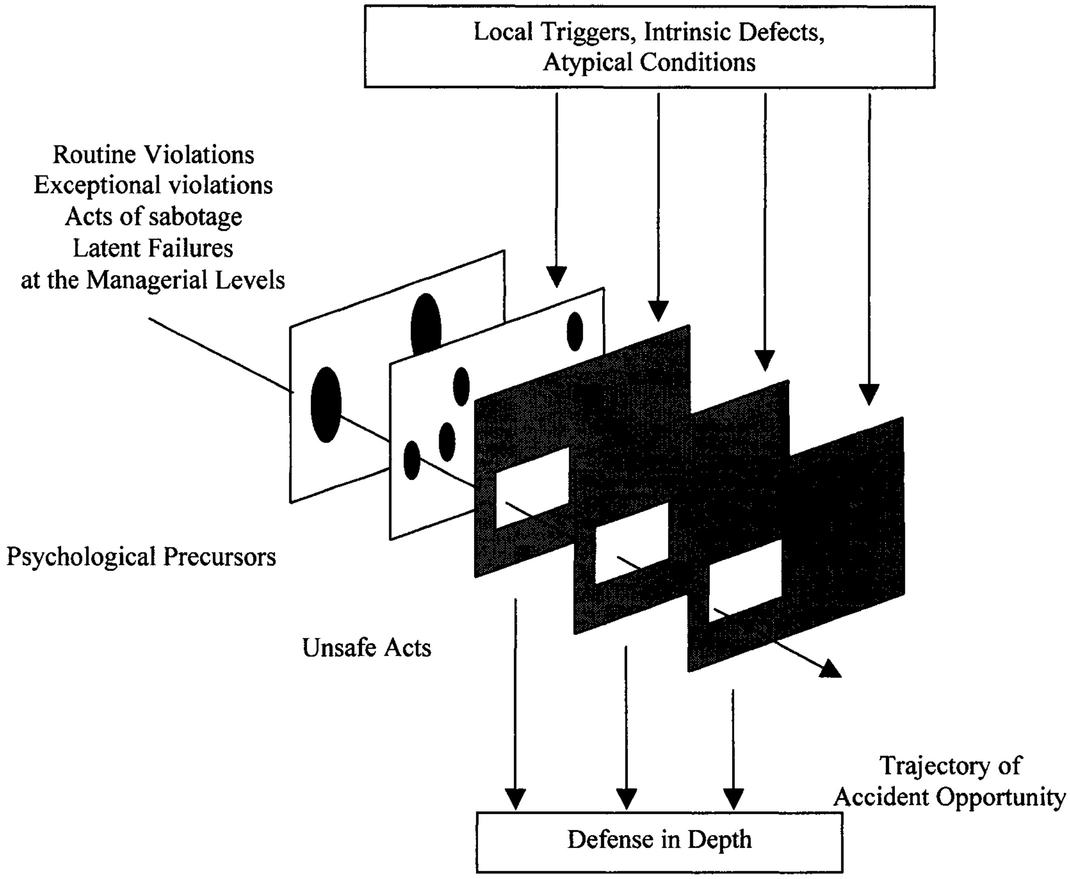


Figure 5.5: The Swiss Cheese accident causation model popularized by Reason (1999a).

Reason's model concisely provides a thumbnail of an *event* scenario, and establishes an explicit link between the *event* scenario and psychological precursors, precursors that in the opinion of this author are cognitive in origin. Reason (1999c) goes on to describe and classify such psychological precursors in terms of a model, which introduces error types (Figure 5.6). These 'basic' error types are: slips, lapses and mistakes and all fall under the descriptor of unintended action. These are similar to and supportive of the errors of omission, commission and mistaken belief introduced in this paper, although Reason does not predicate them on the existence or transgression of a known standard.

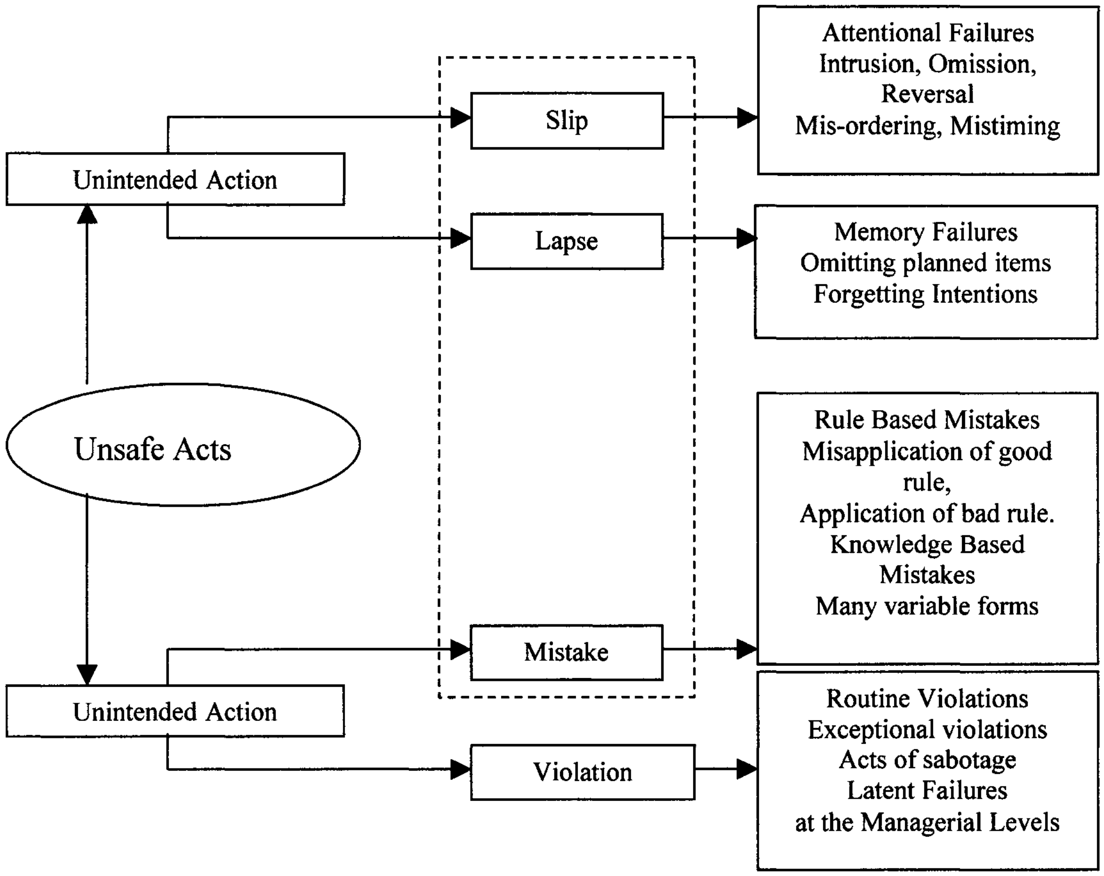


Figure 5.6: A summary of varieties of unsafe acts as posited by Reason (1999c)

Reason (1999d) offers the following counsel concerning management fallibility:

> As in the case of line management deficiencies, not all unsafe act precursors result from fallible decisions. Many of the pathogens at this level are introduced directly by the human condition. The capacities for being stressed, failing to perceive hazards, being imperfectly aware of the system and having less than ideal motivation is are brought by each person into the workplace. Thus, in casual terms, there is only loose coupling between line management and precursor 'planes'. The point to stress is that these predispositions can either be markedly exaggerated or considerable mitigated by the character of decisions made at the top levels of the system and communicated to the individual via line departments.

Analysis of Investigations – Decision Errors Theory

All decisions established as determinants within an event scenario can be classified as either errors of commission, omission or mistaken belief.

This simple, seemingly obvious statement of typology will form the theoretical basis for a methodology and method whereby accident investigations through a process of analysis, can provide some insight into the contributory effects of organizational culture on decisions made in error. The theory hereon shall be referred to as the Decision Errors theory in which the errors of: commission (EOC), omission (EOO) and mistaken belief (EMB) are central. The methodology; Cognitive Patterning model and the method; the Boundary Condition and Decision analysis (BCDA), will form the basis for the analysis of investigations, through a process of audit (the audit protocol and instrument).

Decision Error Class	Awareness That Boundary Condition Was Transgressed	Propensity For Repetition	Post Event Response To The Error
Errors of Commission	YES	Probable	Trivialization of Boundary Condition
Errors of Omission	NO	Possible	Contrition, willingness to correct
Errors of Mistaken Belief	SPECULATIVE	Probable	Defensive, likely to redirect accountability

Table 5.1: A summary of the three error types, and their defining characteristics.

Analysis of Investigations – A Methodology

Having established a theoretical basis for the typology of decisions identified as determinants within investigations of industrial events, it is time to put this theory to good work. It has been established (Benner, 1984) that the investigation as a process can be considered as consisting of three components:

1) The occurrence of the critical *event* as a source of input data
2) The method and methodology of investigation as a process
3) The investigative report as an output product, inclusive of the determinants of the critical *event*

It is therefore reasonable to suggest that the analysis of investigations may similarly be structured as consisting of three components:

1) The determinants of the critical *event* as a source of input data
2) A method and methodology for analyzing investigations as a process.
3) A heuristic model of the investigation as an output product, inclusive of the organizational cognitive context in which such a critical *event* can occur

Further, the critical *event* itself can be considered as a process (Benner, 1985) and in keeping with the structure above, consisting of three components:

1) The organizational cognitive context (how an organization internalizes risk) regarding hazards, loss and operational integrity as source of input.
2) Critical *event* scenario (events, decisions, actors and conditions) as a process.
3) The critical *event* as an output product.

Graphically, the relationships between the processes of event causation, causation investigation and investigation analysis can be illustrated as follows:

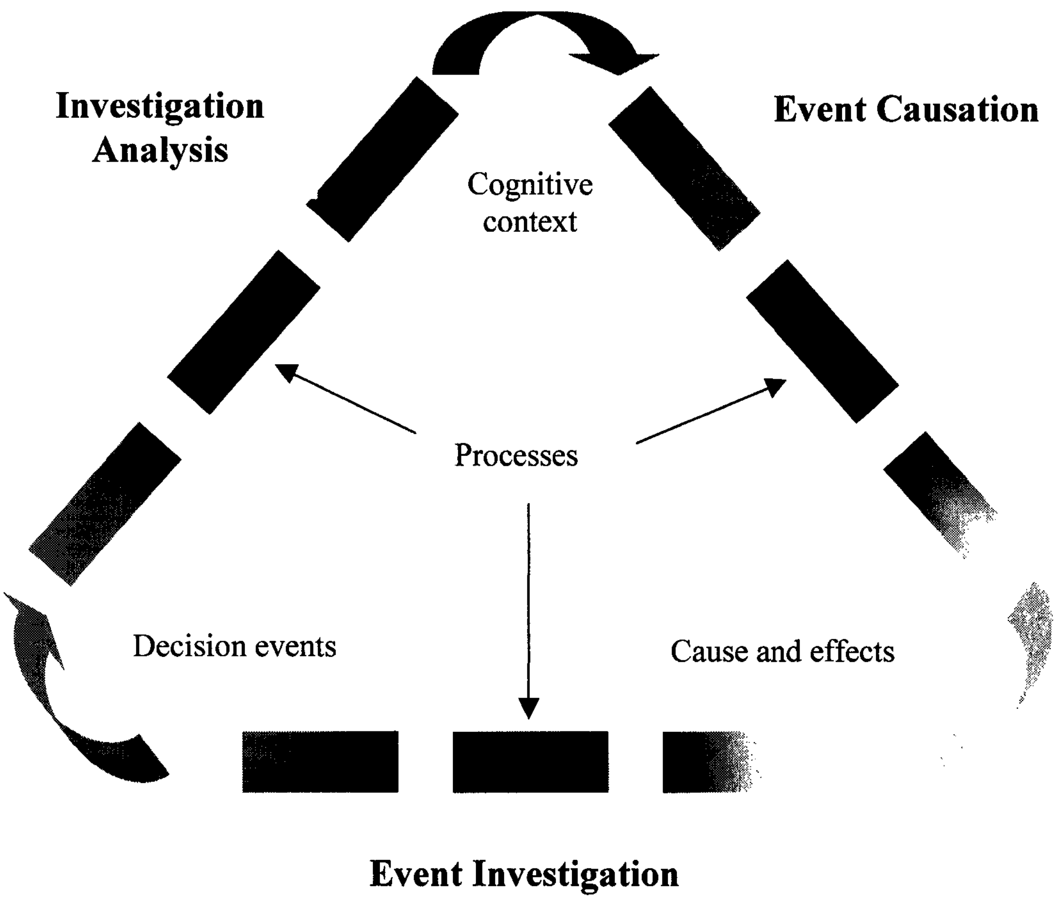


Figure 5.7: Cognitive Patterning Model illustrating the inter-relationships of events, their investigation and subsequent analysis.

Close inspection of this unique and compelling model reveals that a relationship exists between the inputs of *events causation* and the products of investigation analysis; specifically, that they are one and the same. Ostensibly, the objective now is self-evident, to learn as much about the organizational cognitive context as a precursor to *event* causation as possible. Central to this purpose is the method, to which we now direct our attention.

Investigation Analysis – Boundary Condition and Decision Analysis

We start with a backdrop in which all critical events must occur, the conditions. The conditions are hypothetically infinite in number and are depicted in this schema to surround the critical event in concentric circles (for purposes of simplicity only half of the condition horizon is depicted here).

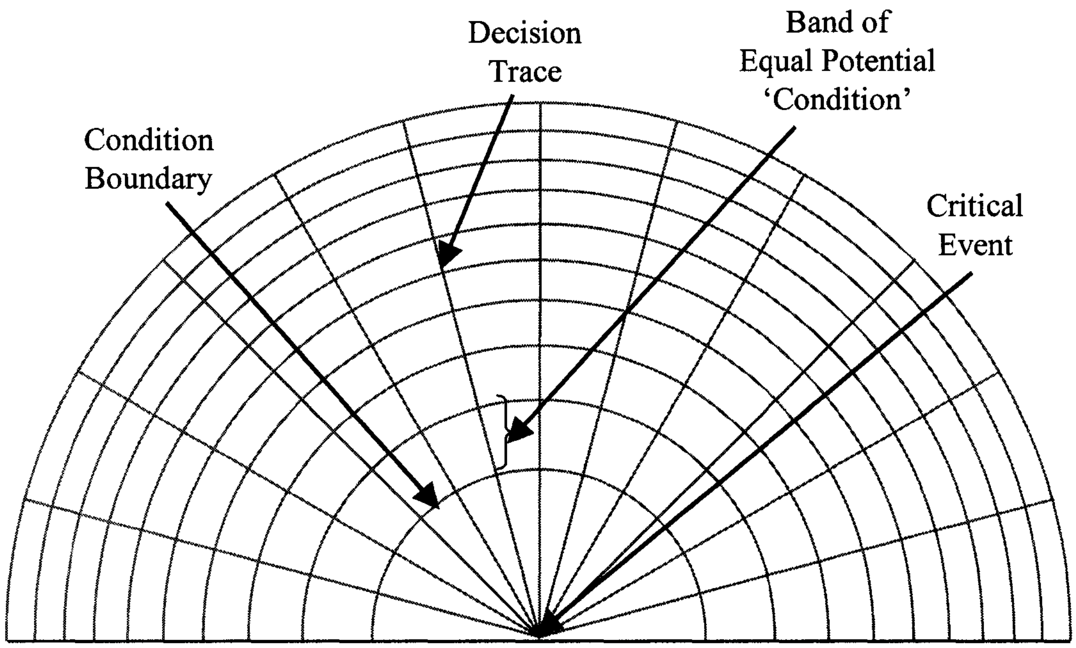


Figure 5.8: Boundary Condition and Decision analysis indicating condition equal potential rings, critical event epicenter, decision traces and condition boundaries.

Each equal potential band is distinguished by a boundary and it is understood that such a line of demarcation represents a boundary condition that must be satisfied to exist in one condition or the other (one side of the boundary or the other). An example here would be a condition of operating within a prescribed operating temperature is in excess of the designed limits. It is noted that the concentric equal potential conditions are larger as one approaches the epicenter, depicting an increase in influence, as one gets closer to the critical *event*.

The decision traces (of which there are thirteen in this schema) are radial lines emanating from the epicenter and represent a potential path upon which the decisions of an actor can be plotted. Potentially, the traces cut all of the condition boundaries and continue outward to infinity. There is also the possibility of an infinite number of decision traces (and therefore actors) emanating from the epicenter (critical *event*). We will now populate the schema with decisions:

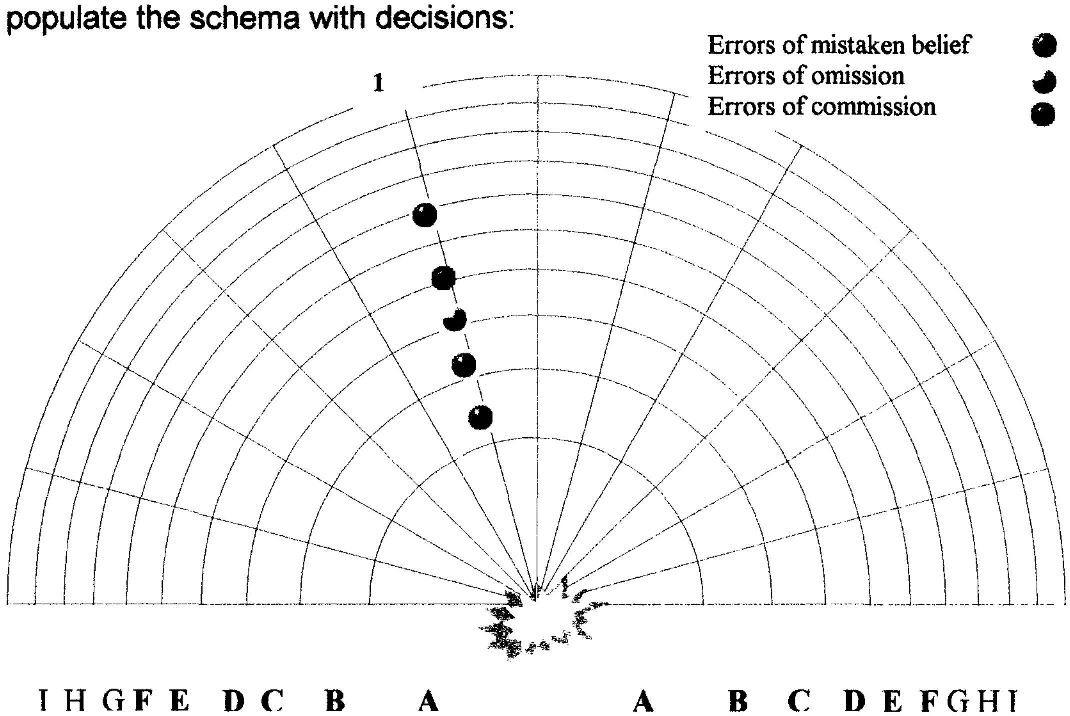


Figure 5.9: Boundary Condition and Decision analysis illustrating the decisions of one actor as having been determined by process of investigation.

For this particular hypothetical scenario resulting in an unspecified critical *event* (designated by the fireball symbol), one actor (designated as #1) was found to have discharged five separate decisions as determined to be contributory (determinants) in the investigation of this scenario. Three of these decisions were errors of mistaken belief; one was an error of commission, and one and error of omission. The first decision (mistaken belief) was established as an antecedent to condition **G**, the second decision (commission) an antecedent to condition **E**, the third decision an antecedent to condition **D**, and so on.

It is noted that the *actor* made no error regarding condition **F**; that is to say that he/she either made a decision that did not contribute to the degraded condition **F** or had no role to play in that decision. It is also noted that in this scenario, there were six conditions (A through F, in bold) that were found to be determinant to the critical event. There is no significance attributed to the location of the decision trace although the author prefers to work from left to right in a clockwork fashion.

Further populating the schema (Figure 5.10) will reveal some useful relationships in this *event* scenario:

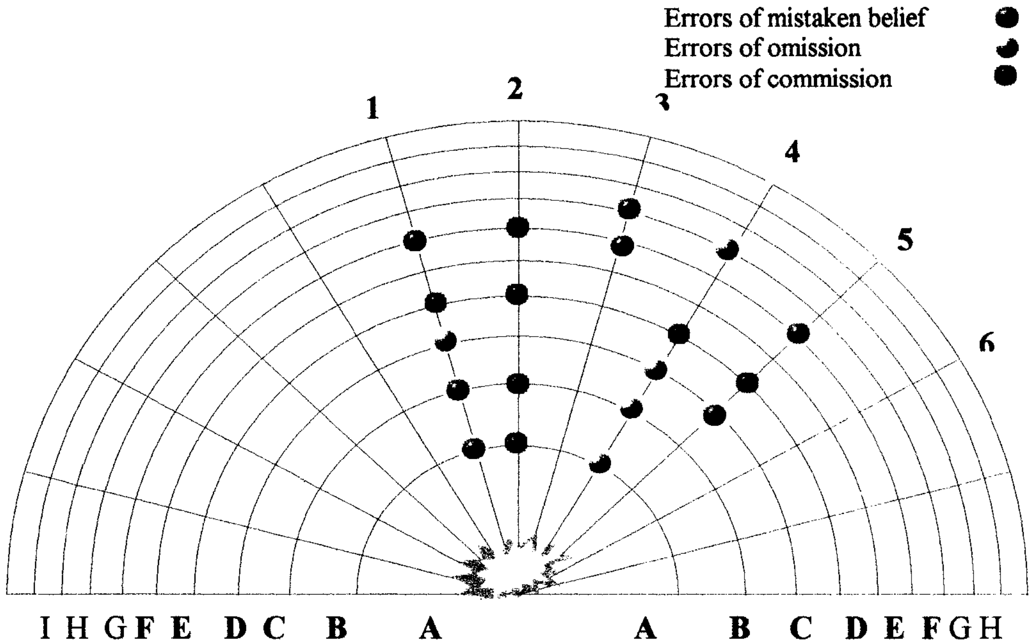


Figure 5.10: Boundary Conditions and Decision analysis illustrating a fully populated schema of decisions.

Once the radar diagram is fully populated, some observations, if not trends emerge. We observe that there are six actors involved in this critical event scenario. We observe that actor #6 made no decisions that could be considered as contributory to this critical *event*. Condition **D** appears to be a particular focus with respect to errors of commission. Actor #3 contributed to two errors of mistaken belief early in the scenario and then does not appear to contribute again. This is because of one or more of the following possibilities:

1) He/she is was absent during these decisions
2) He/she made decisions that were not considered being contributory to the accident.
3) He/she chose not to participate in these decisions

It is noted that condition **E** is problematic, in as much as there does not appear to be any decision that can be attributed to this condition by any of the actors. The fact that actor #2 made four errors of commission and that actor #4 made four errors of omission is probably a matter worth further looking into by the management of this hypothetical organization.

Rules,

1) One actor occupies one decision trace
2) Each decision entry must be substantiated as a decision having contributed (determinant) to the event scenario by investigation.
3) Conditions must be contiguous starting closest to the critical *event* and working outwards.
4) Each decision entry must represent an error of commission, omission or mistaken belief.

Advantages of this analytical method are:

1) Decisions are presented in a non-judging and non-threatening manner with only vague attribution (none if so desired).
2) The graphical presentation of decisions is clear and uncluttered; easily distinguishing errors of different type.
3) The analyst is (should be) separate and without affiliation from the process of event causation and investigation.
4) Errors of a given type are easily traced.
5) Conditions are very clearly delineated in accordance with decisions that may or may not have been made.
6) It is easy to discern conditions that were not given due consideration (decisions) or those where too many actors were involved, confusing the outcome.
7) Analysis of the types of decisions exhibited in a large enough population provides a cognitive 'glimpse' of how an organization collectively internalizes risks, rules and standards.

Next, we explore a means by which the latter point is carried out.

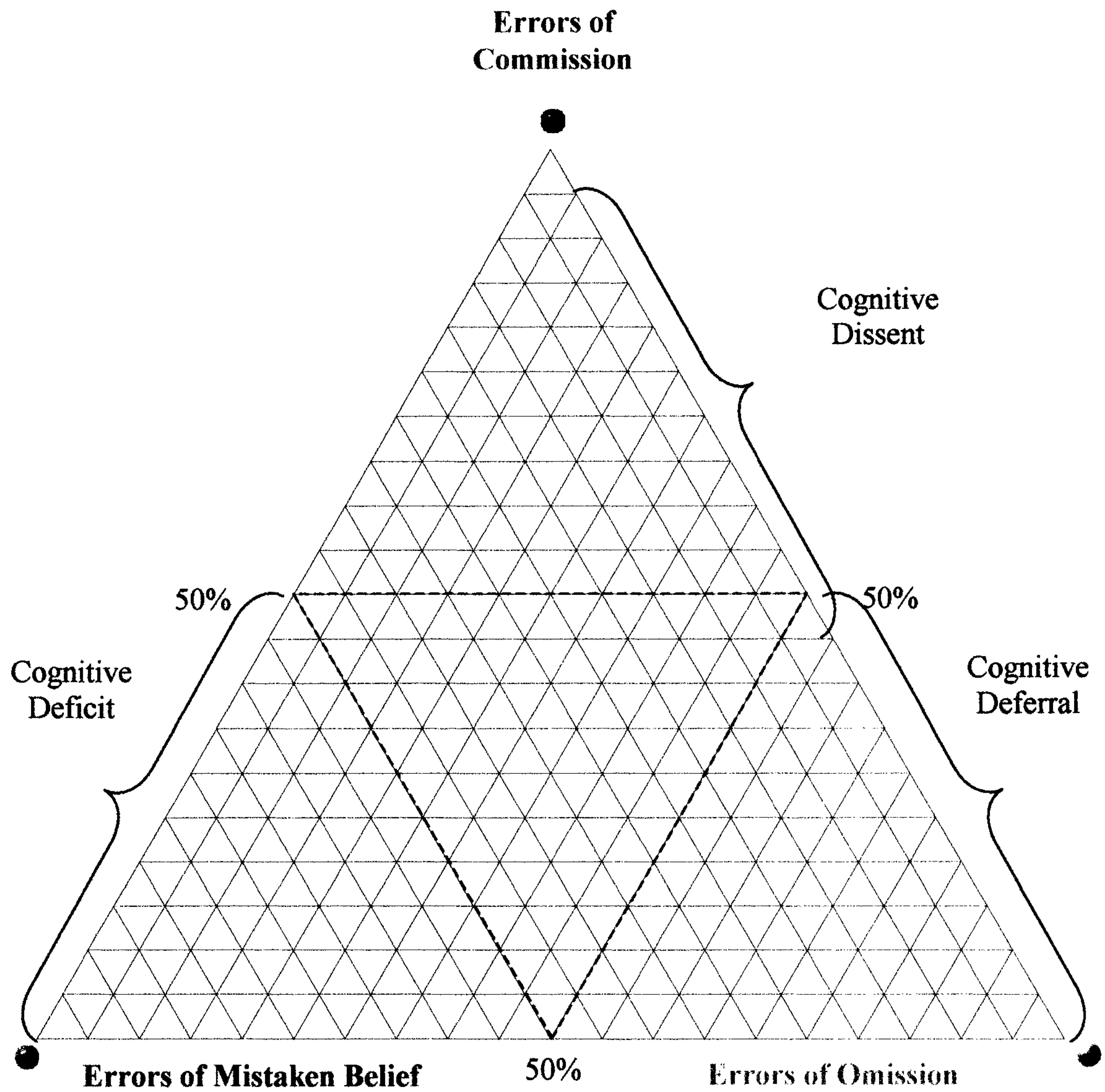


Figure 5.11: Ternary diagram illustrating cognitive dissent, deferral and deficit. The 'camps' are arbitrarily demarcated at 50%.

This standard ternary diagram allows us to conduct a quantitative evaluation of the three decision error classes, by collecting a population of observations (decisions established as determinants by process of investigation) and computing their respective percentages. It is advantageous to compute these entries out of as large a population as possible and it is worth considering running multiple investigations through the model to this end. The result is that decision errors within an organization report to one or the other 'camps' represented by the vertices of the ternary diagram and a profile or position is established within the diagram.

As a practicing safety engineer but certainly not an organizational psychologist, the author hesitates to overstate the significance of these results, but at the risk of anthropomorphizing the problem, offers a supposition. At the extreme top vertices, representing 100% error of commission (EOC, red bullets) an organization would be sufficiently extreme in its condoning, if not support for EOC as to characterize it as culturally conducive to Cognitive Dissent. Towards the lower right vertices, representing 100% error of omission (EOO, blue bullets) representing an organization culturally disposed to Cognitive Deferral. Finally, towards the lower left vertices, representing 100% errors of mistaken belief (EMB, green bullets), the organization can be characterized as harboring a culture of Cognitive Deficit.

In the case of the example analysis, a computation of the decision errors reveals: EOC=37%, EOO = 26%, EMB = 37%

Plotting these values on the ternary diagram results in the following profile:

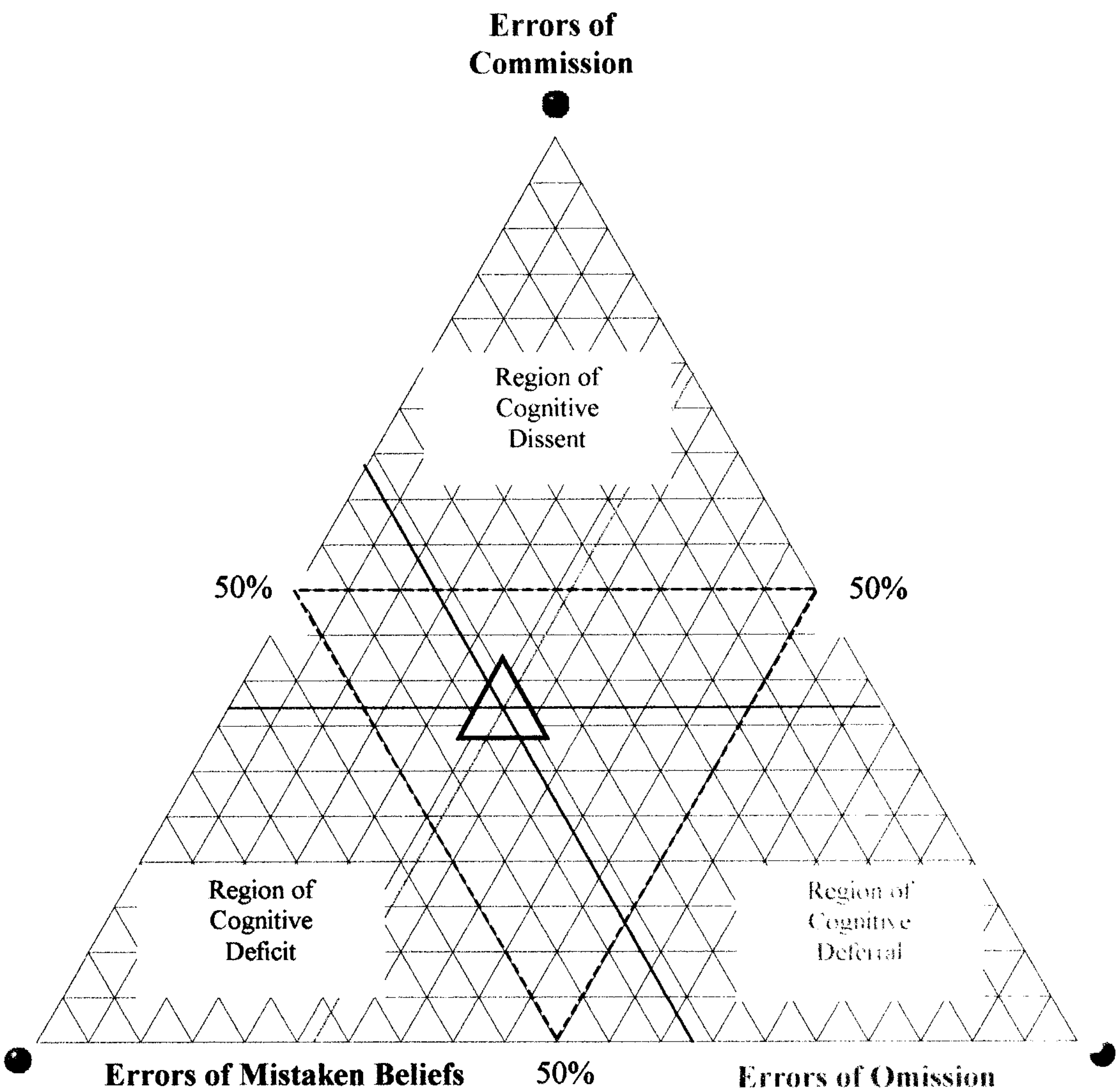


Figure 5.12: Ternary diagram illustrating an organization having a mixed characterization with respect to decision errors.

The decision error values plotted on the ternary diagram reveal a profile quite near the center of the diagram; certainly outside the region defined by the three cognition camps. It is a supposition of the author that such an organization exhibiting an even distribution of errors would represent the norm and not the exception. Exactly what this norm would be and where the transitions might lay with respect to aberrant or abnormal values is left open to speculation and the subject of further research.

Organizational Cognitive Context for Decision Errors

Cognitive Dissent

It is suggested that the Cognitive Dissent profile (greater than 50% EOC) reflects those organizations that afford discretion to their work force regarding the explicit or perceived 'right' to refuse compliance with a standard, rule or expectation. Workplace cultures challenging organizational change, having a militant culture or an aging workforce typically fall into these cognitive patterns.

Cognitive Deferral

The profile of Cognitive Deferral (greater than 50% EOO) is expressive of an organization that may be asking too much from its workforce respecting their decision forming acuity. Often, individuals are overwhelmed by external stimuli, have too many demands on their mental faculties or are given competing and conflicting expectations -- or all of the above. Workplace cultures experiencing downsizing, merger and acquisition stressors or overly aggressive management styles typically fall into these cognitive patterns.

Cognitive Deficit

The profile of Cognitive Deficit (greater than 50% EMB) are exhibited by organizations with workers who are at best are not understanding the operational 'rules of engagement' expected of them; at worst, may not be competent for the assigned tasks. Often in need of training and alignment, these workers are likely to do the best with the information, skills and understanding they possess, however occasionally to their detriment or the detriment of others.

Chapter 6: Audit Design

If the process of investigation is an exceedingly meticulous one, then the process of audit is even more so. Central to the process of investigation is the structure, a framework upon which the investigator plans and deploys his/her resources. Typically, the structure is as simple as Figure 6.1 whereupon the report is divided into three sections of the investigative process, reflecting three phases of the event causation process (Haddon, 1969; Bird and Germain, 1986).

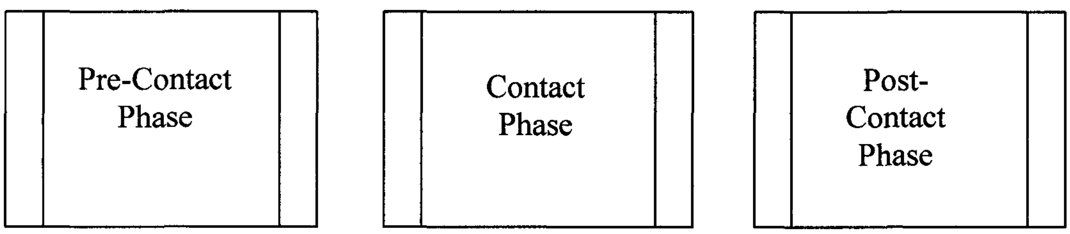


Figure 6.1: Tripartite model of the event causation phases.

Not surprisingly, many crafters of investigative process have designed the investigative process that reflects this simplicity, compartmentalizing the process into: chronicling the series of events, analysis of cause and effect and the recommendations portion of the investigation (Figure 6.2).

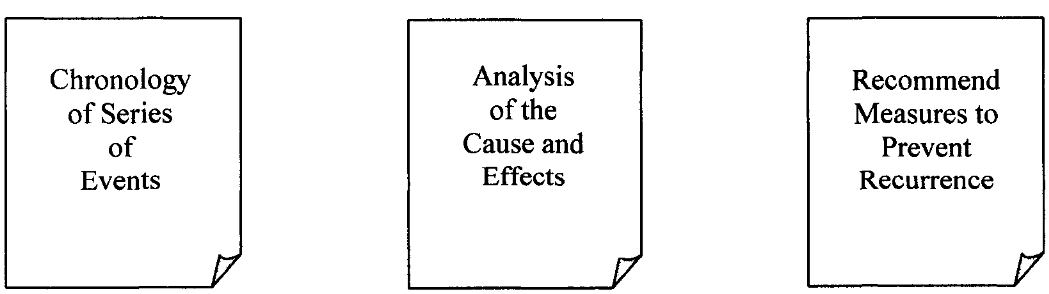


Figure 6.2: Minimum structure for investigation reports as required by many regulatory authorities and agencies.

Additionally, there is a tripartite model depicting the division of labor (Ferry, 1988), in which the investigative process is organized by type of activity: data gathering, analysis and report preparation (Figure 6.3).

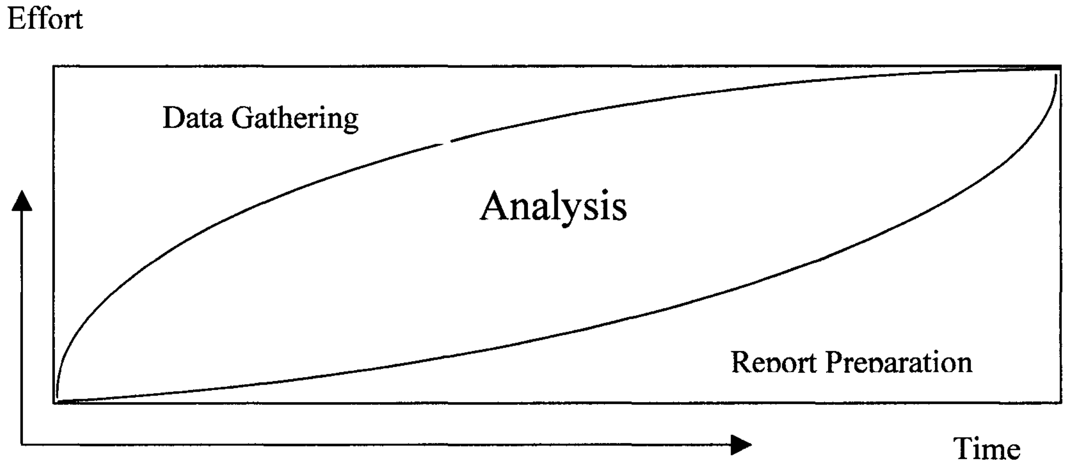


Figure 6.3: A model of effort presented against time for the three principle phases of the investigation process.

Whereas these models are useful, and the temptation is to organize an audit along these structural lines, it is considered of more merit to design the audit in terms of the objectives stated earlier in this paper: they being the promotion of quality, veracity and efficacy in the investigative process. To this end, this audit will be conducted within the following framework:

1) The existence of process tests (evaluation)
2) The veracity of investigation tests (evaluation)
3) The efficacy of analysis tests (evaluation)

Within this tripartite framework (Figure 6.4) are the blueprints for the essential elements of an investigation of an industrial *event*, and the theoretical basis for both the audit protocol and the audit instrument, to follow.

Audit Structure

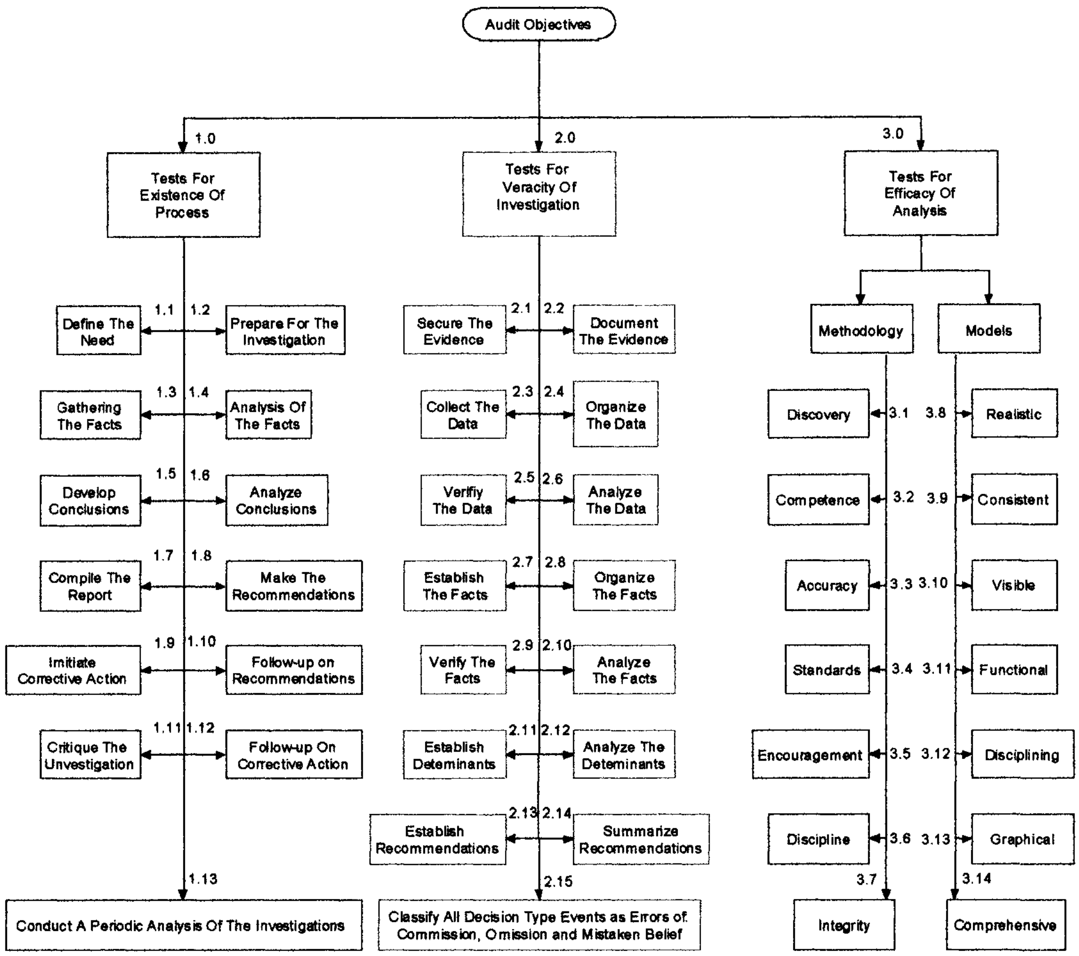


Figure 6.4: The blue print or framework for conducting an audit of industrial event investigations.

Chapter 7: Audit Protocol

Audit Principles

The auditing of the process of investigation is necessarily an analysis of an analysis and therein a departure from the conventional application of the audit process. The area of analysis is a ticklish one, given the nature of investigations but having said that, no less an exercise in methodical observation and reasoning. The process is the same; the principles are the same; and the value of the audit as a mechanism for evaluating management systems is the same, regardless of the nature of that management system.

Typically, an audit is a 'snapshot' in time of the management system, owing to the dynamic nature of the workplace and the ever-changing nature of management systems. For this reason, audits often have a limited context or value in direct proportion to the time between when the observations are made and when the findings are being considered. As applied to accident investigation however, the audit process is well suited, as the investigation and its follow-up are concluded and the subject area is static with respect to change. We arrive at the first principle for the audit of investigations of industrial events:

1) The subject of audit (the investigations) must be in a state of abeyance and conclusion.

The traditional method employed by auditors is to scrutinize the management system in a planned and formal way (audit protocol), applying a standardized audit methodology consisting of verification rules. Typically, these rules may include:

a) If the client site can't produce a document, then it does not exist.
b) A document must be provided within 72 hours of a request of an auditor, or it does not exist.
c) Observations of physical conditions by the auditor are not subject to debate or interpretation by the client site.
d) All reasonable effort must be made to locate and make available a witness or interviewee for the purposes of verification by the auditor.
e) All material, data and information obtained by the auditor is to be returned to the client site at the conclusion of the audit and is subject to non-disclosure (sometimes by written agreement).

In general, all of these rules apply as well to the auditing of event investigations and lead us to the next application principle:

2) All requirements of the audit instrument must be verified by document, investigative report reference, interview statement or observation by an auditor.

In most audit scenarios, the concept of intent or the cognitive processes of those that are being scrutinized by the auditors is not of much interest or value to the auditors. This is where the audit of *event* investigations must depart from tradition – the cognitive processes and intent of the investigators as they deliberate over evidence and establish *determinants* pertaining to the *event* is very much of interest, if not central to the objectives of the evaluation. Yes, we want to ascertain the processes;

certainly we want to document their methods; but the nature of investigative methodology is a nebulous one and must be afforded some latitude in its evaluation. Thus, a third audit principle, as applied to the investigation of industrial *events* is:

3) The investigative report and supporting documentation may not explicitly present a methodology of investigation; the investigators description of the logic and reasoning should be given due consideration and weight.

Discretion must be afforded to the auditor(s) in making the final call as to whether or not an audit element is credited; however the following principle must apply:

4) For the existence of a process to be established, verification must be made that the process was in fact in place *a priori* to the subject investigation(s) and further; that it was in fact applied and observed by the investigators.

The evaluation of management systems is not an exact science. The intricacies, complexities and diversity of management systems do not lend themselves to standardization, much less quantification. This is probably even more the case for *event* investigation given the intrinsic uncertainties and lack of formalized methodologies. Yet, it has become typical within the health, safety and environment auditing community to attempt quantification through scoring and grading, the client site. This has met with mixed results and reviews. At best, the scoring schemes offer the ability to compare 'apples with apples', all things being equal. At worst, scoring results in bruised egos and engenders resentment among competitive client groups, while obscuring the true benefit of the exercise.

Still, there is merit to scoring if applied and accepted within the correct context, and the audit of accident investigations, while not lending itself to scoring, would certainly benefit from it owing to the lack of any other standards or metrics. This leads us to the fifth principle of auditing, as applied to the investigation of industrial *events*:

5) The audit will include a quantification scheme sufficiently simple and robust as to be practicable to *event* investigations.

To achieve simplicity, the audit will incorporate Boolean responses whenever possible, with the discretion given to the auditor to strike those questions that are not appropriate to the client organization. An audit score of the subject investigation(s) can in this manner be achieved simply by computing the weighted percentage of those questions of the total (applicable questions) for which an affirmative answer (Yes/true) was reported.

<u>Audit Classification</u>

To achieve robustness, the audit will incorporate a classification system (Categories 1, 2 and 3) that will allow the auditor to apply a progressively onerous level of scrutiny to the investigative process, depending upon the level of investigative imperatives demonstrated by the client organization. The classification system is as follows:

Category 1: Investigations typically achieve due diligence on behalf of the stakeholders, insofar as representing a reasonable effort in establishing the cause, effect and preventative measures respecting an event. Documented attribution concerning each determinant is limited to recommendations and facts. Often, data and evidence are presented as facts with little or no truth testing, verification or substantiation. Category 1 events are typically minor in nature; examples being: material and equipment losses, production upsets, environmental excursions and minor injuries.

Category 2: Investigations typically achieve operational integrity on behalf of the stakeholders, insofar as the client organization has set high expectations on the investigators concerning the breadth and scope of the investigation. Additionally, the client organization will demand considerable validation from the investigators of their causation model; in return the client organization will achieve a high degree of certainty that the *event* in question will not be repeated. Category 2 investigations will arrive at determinants by application of a formalized method or model in which facts are documented as input and a ranked list of determinants is produced as output. Typically, there is an established and codified evidentiary record, although not necessarily inclusive or validated.

Category 3: Investigations typically achieve the high standard of legal defensibility insofar as there is a rigid adherence to such investigation procedures as: custody of evidence, data gathering and validation, corroboration of facts and expert analysis. These processes tend to rigidly documented and coded, with a clear reference system within the investigative report. The report is all-inclusive, independent of any other documents and is designed to stand on its own merits as a legal document. Category 3 investigations are serious if not tragic in nature involving fatalities, major loss of assets and production and environmental disaster.

Classification of the investigative reports is an important function within this audit protocol; clearly 'one size does not fit all' pertaining to industrial *events*. It is understood that different resources and skill sets will be brought to bear on an *event* resulting in the loss of life than that of a minor production upset. Further, in addition to the obvious objectives of an investigation, there are three organizational imperatives that must be met by investigations; depending upon the type of *event* and corresponding to the classification scheme (categories 1, 2 and 3). They are: the demonstration of Due Diligence, the achievement of Operational Integrity, and the existence of Legal Defensibility. They correspond to category 1, 2 and 3 investigation classifications respectively and for the purpose of clarification will be color coded in green, blue and red (Table 7.1).

Classification	Category 1	Category 2	Category 3
Organizational Imperative	Due Diligence	Operational Integrity	Legal Defensibility
Typical Characteristics	Short, concise reports with little attribution and no formalized method or methodology.	Organized reports with cross-linked references and a formalized analytical method.	Highly structured investigative reports, rich in evidentiary record and a formalized methodology.
Event Examples	Minor injuries, production upsets, vehicle mishaps, near misses, environmental excursions.	Critical events, statutorily reportable incidents, major production outages and insurance claims.	Loss of life, large threat to public safety, possibility of negligence or the probability of legal challenges.
Key Result Areas	Introduction, event narration, discussion and recommendations	Chronologic series of events, statement of facts, causal analysis, referenced evidentiary record, internal review.	Transcribed witness statements, expert opinion, well developed methodology, corroborated facts, and external review.

Table 7.1: A classification scheme based upon varying organizational imperatives respecting accident investigation.

Section 1: Tests for Existence of Process

1.1 Define the Need

Intent: Often taken for granted, accident investigations must satisfy a very real, *a priori* need. Possibilities range from as a simple as the means by which compliance with regulatory statute is established to the examination of management systems and an eye directed towards quality control.

Seek: A program element of an environment, health and safety program that explicitly defines the role of investigation within the system context.

A statement or explanation within the preamble of the investigative report, that speaks to the issue of purpose, objective or need.

Verify: The investigators of the subject investigation(s) and determine as to whether a consensus existed in terms of their perceived understanding.

1.2 Prepare For The Investigation [format]

Intent: Industrial events are by their nature capricious and unpredictable. A prompt and effective response will be predicated on the extent to which the organization in general and the first responders, incident command and investigators in particular are prepared. In its simplest form, the plan details the provision of resources; in its' more complex form establishes policies, procedures and contingencies.

Seek: A program element of an environment, health and safety program that explicitly makes reference to emergency preparation plan.

A person designated as the emergency response coordinator or incident commander and determine as to the existence of one or more of the following:

i) Emergency call-down list
ii) Emergency notification protocol
iii) 'Go' kit

Verify: With the tour sheets, shift logs and security logs what notifications and procedures were engaged at the time of the critical event.

With security personnel, first responders and operators the extent to which a plan existed and was implemented respecting the critical event.

1.3 Gather The Facts

Intent: Considered one of the most essential if not the most essential activities within the process of investigation, the gathering of facts is the reiterative application of observation, preservation, documentation and organization of evidence.

Seek: A program element of an environment, health and safety program that explicitly makes reference to investigative procedures.

The EH&S coordinator and determine as to the existence of an adopted accident/incident investigation program or system.

Verify: By reviewing the investigation report to ascertain any documented reference to what or how evidence was collected.

By interviewing the investigators regarding their procedures used in the gathering of facts and evidence.

By examining the evidence log and such evidence that may have been archived during the process of investigation.

1.4 Analyze The Facts

Intent: From evidence to data and then data to facts, some process of selection and organization is necessarily applied to arrive at *event* determinants, significant findings and revelations. Based upon inference and deduction, this process should be substantiated and repeatable.

Seek: A program element of an environment, health and safety program that explicitly makes reference to investigative procedures to determine if a preferred process of analysis exists.

The EH&S coordinator and determine as to the existence of any techniques or methods that are part of training or procedure.

Verify: By examining the investigative records to determine if records, drafts or scratch sheets were retained indicating a systematic analysis of the data.

By reviewing the investigation report(s) to determine if there was any description of process of analysis or validation of evidence. With the investigators, the activities, processes or approaches they used to analyze the evidence and data for relevancy.

1.5 Develop Conclusions

Intent: Strongly dependant upon the preceding two elements, the existence of the process of developing of conclusions is probably not in doubt; the methodology behind it is. Conclusions should be arrived at with repeated reference to the established facts and analysis and in a systematic, formalized and reasoned way. Decision trees, fault trees, multi-linear sequencing charts, truth tests and logical constructs could be used and all should be documented.

Seek: The EH&S coordinator and determine as to the existence of any techniques and methodologies specifically designed for establishing cause and effect relationships.

Computer software, textbooks and investigation systems that is evident at the workplace or for which the investigators are trained in.

Verify: With training records of the investigators.

By interviewing the investigators to determine the process they employed to arrive at their conclusions.

By reviewing the analysis portion of investigative report to determine if any explicit reference was indicated as to how the *event* determinants were arrived at.

1.6 Analyze Conclusions

Intent: A process and an opportunity for validation of the conclusions (above) within the process of investigation. Having arrived at the conclusions by a factual, reasoned and methodical approach, the challenge is to corroborate the conclusions by independent means. Running a second analysis, a different methodology or introducing additional evidence are acceptable means of analysis.

Seek: Any records of additional or confirmatory tests of evidence.

Recollections from the investigators that counter proposals were entertained, any process that was used to weigh the conclusions on the basis of balance of probabilities, or hypothesis that were put forward to truth test a supposition.

Verify: By reviewing the investigative report to determine that all evidence was accounted for within the context of the conclusions arrived at and that no contradictions exist (reference).

By interviewing the investigators to establish if they had knowledge of any reports or documents that were prepared in parallel with the investigation that corroborated their conclusions or model (statements).

By establishing any minutes or meeting notes documenting the occasions where the investigators presented or defended their findings as a process of status update or information sharing (documents).

1.7 Make a Report

Intent: The instrument by which the event and most certainly the investigation will be recorded; a testament to the skills of the investigators; a legal document and often the means by which closure is achieved: the importance of this process can't be overstated.

Seek: The sponsor, EH&S coordinator or CEO of the organization to determine what if any scope, goals, expectations or objectives were given to the investigator(s) respecting the investigation and report to follow.

A program element of an environment, health and safety program that explicitly makes reference to the process of the investigative report, its format and requirements.

A template, process model, example or case study that the investigators are trained detailing the elements of an investigative report.

Verify: By reference to the report of an investigation that it physically exists and that it has been accepted as the definitive and complete report.

By interview with the investigator(s) that the report of an investigation fairly represents their efforts and deliberations that they and they alone participated in its compilation and that it has been concluded.

1.8 Make Recommendations

Intent: If the investigative report is the product of the process of investigation, the recommendations represent the means of going forward, the specifications for optimal use of that product. Contained within the investigation proper the recommendations are clear and attributable statements of initiatives that had they been in place, would have negated specific *necessary determinants* and prevented the *event*.

Seek: The sponsor, EH&S coordinator or CEO of the organization to determine what if any scope, goals, expectations or objectives were given to the investigator(s) respecting the investigation and report to follow.

Such documents, reports or status updates that reflect preliminary control measures or recommendations for remediation or mitigation.

Verify: By reviewing the investigative report that recommendations have been made and that they flow from the process of analysis and conclusions. Further, the recommendations should exist for all determinants considered necessary and proximate determinants.

With the investigator(s) that the recommendations presented within the report are complete and inclusive.

1.9 Implement Corrective Action

Intent: Not directly under the control or governance of the investigators; nonetheless the investigation should subsume and suborn the process of corrective action by establishing review date, reporting structures and dead lines.

Seek: The sponsor, EH&S coordinator or CEO of the organization to determine what if any scope, goals, expectations or objectives were given to the investigator(s) respecting the investigation and report to follow (statements).
Any expression of intent (on behalf of senior management or corporate directors) regarding policy or operational changes resulting from the *event,* the results of investigation or both.

Such preliminary findings, interim reports or workplace committee minutes that might exist express the need for action or remedial measures, even if a temporary measure.

Any corrective action addendum to the investigative report or process referenced within the investigative report.

Verify: By analyzing corrective action status update reports or meeting minutes substantiating corrective action follow-up or the signing off of accountabilities by those responsible.

By interviewing Joint Health and Safety Committee members to determine if there are any outstanding action items.

By physically observing that such corrective action has taken place.

By reviewing any correspondences, purchase orders or official notices to regulatory agencies attesting to the completion of correction action.

1.10 Follow-up of Recommendations

Intent: Any process independent of and clearly subsequent to the investigative report, the purpose of which is to revisit the recommendations made in the report and assess progress made, practicality of and further measures to be taken.

Seek: The recommendations section of the investigative report.

The updates to quarterly, semi annual or bi-annual operational reports identifying progress made or resource requirements of the recommendations contained within the investigation.

Verify: By interviewing members of the Joint Health and Safety Committee to establish their involvement or participation with follow-up.

By interviewing the EH&S coordinator to determine those program elements of the EH&S system that reflect changes in either the operating procedures or the EH&S policies.
By interviewing senior management staff to evaluate the extent to which the *event* or its investigation has galvanized follow-up.

1.11 Critique The Investigation

Intent: The event scenario and the subsequent investigation will have put to test the preparations, the plans, the intentions and the assumptions of all involved; it is extremely unlikely that any participants walk away without regrets, revelations and lessons learned. Debriefing is the tool of choice; the sooner the better upon completion of the investigation. In the instances of a serious *event*, the investigative report should also be subjected to independent and impartial review.

Seek: The program element of the environment, health and safety program that explicitly makes reference to investigative procedures and the quality control process that applies.

The EH&S coordinator and determine if there is any investigation protocol or policy specifying debriefing or critique by members of other operating units, by corporate professionals or independent consultants.

Verify: By interviewing the investigator(s) to establish that a timely and meaningful debrief of the investigation process was carried out and that some mechanism exists to move forward on recommendations and lessons learned.

By interviewing the EH&S coordinator to determine what improvements or changes are being made to the *event* investigation system and to what extent the organization is better prepared as a result.

By reviewing any: appraisal, review or formal report (by a consultant, colleague or corporate specialist) resulting from a critical review of the investigation.

1.12 Follow-up on Corrective Action

Intent: Post *event* weariness will have set in and by now the operators and management alike will want to 'get on with it' and perhaps observe less commitment to the items of corrective action. There is a tendency of losing focus on the efficacy of the corrective action (the substance) and instead to dwell on the number of meetings, requests made etc. (the appearance). At stake, is not just the prevention of the event but the legitimacy of the investigative process.

Seek: Any references within the investigation report to corrective action.

Any corrective action meeting minutes to review list of corrective action items.

Any EH&S audits that may have evaluate the EH&S management systems in terms of their performance respecting follow-up and change.

Verify: With the EH&S coordinator to determine if there are outstanding corrective action items.

By the Joint Health and Safety Committee meeting minutes to ascertain whether there are outstanding corrective action items.

1.13 Conduct A Periodic Analysis Of Investigations

Intent: Usually conducted on an annual basis, and required by most EH&S management systems (an audit question), the benefit ranges from the obvious; collection of accident statistics to the subtle; establishment of organizational behaviors and the cultural context for error.

Seek: Any policy, standard (ISO 14000, 18000) or audit protocol (ILCI) that requires the analysis of *event* investigation data.

Verify: By interview of the EH&S coordinator that the analysis has been conducted and establish what the salient results were.

The Causal Record

Discussion

The essence of any audit protocol is that it verifies that a stated management system, program or discipline not only exists; it meets a prescribed standard. The previous section (existence of process) tests the existence of widely held processes of investigation, but stops short of offering any insight as to the veracity of those processes in the context of the subject investigation.

In this section of the audit protocol, we will be examining and testing the veracity of that most crucial of all phases of the investigation: the discovery and cause determination phase. Appropriately, we are verifying the verification of evidence, data and information on behalf of the investigators. It cannot be overemphasized that the intent here is not to second-guess the reasoning or conclusions, just to verify that at each step of discovery, the facts were established and analyzed in a manner that is supportable in terms of process.

A model that in general speaks to the 'rhythm' of the discovery or fact-finding- phase, is as follows (Figure 7.1):

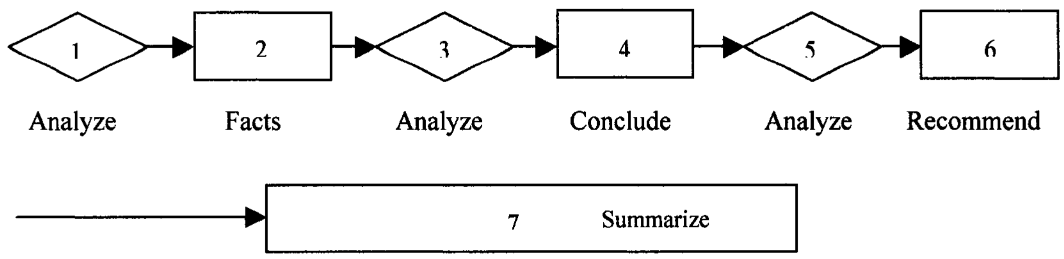


Figure 7.1: Sequence of fact-finding phase of the investigative process (Ferry, 1988).

It is implied and should be understood, that the noun 'fact' in the above model is inclusive (with respect to information in general) and that the nouns: evidence, data and determinants could be equally substituted.

There is no formalized methodology for transforming evidence and data into facts or data and facts into *determinants*. Knowledge, experience, intuition and group synergy all come together to make it happen, a process that does not lend itself to verification. What is verifiable however is the method by which information is collected, recorded, sorted and organized. If a formalized methodology such as STEP or MORT is present, so much the better; but it still remains that these models will be only as good as the information upon which they are based.

Methodology

The methodology behind this section of the audit is to work backwards from the recommendations and trace the extent to which the recommendations 'flow' from the causal determinants; the causal determinants flow from the facts; and the facts flow from the evidence and data. These informational elements are inter-related by one-to-one and one-to-many relations as we scrutinize the analysis. The report of investigation is an obvious place to start, but often times 'scratch notes', evidence logs and other lists employed by the investigators are archived and should not be overlooked.

In the more simple, less detailed investigations, the approach comes down to listing each recommendation and then one by one establish the precursory facts and information (or not). For larger investigations (> 10 recommendations), a sampling approach can be taken, bearing in mind that it must be a significant sample.

In a well-formatted investigation, each piece of evidence will be identified by a unique identifier, logged and eventually listed in the investigative report appendix. Other data (tests, weather reports, data dumps) will similarly be referenced by origin, time and significance and entered into a log prior to entry into the investigative report. Facts are usually listed by way of analysis and as they are introduced, should at least in the first instance refer to supportive evidence and data. Similarly, as conclusions are reached and the determinants of the *critical event* are established, they too must refer to the facts upon which they are based. Finally, the recommendations should not only be presented within the report, but offer some link to that *determinant*, aspect or condition of the *event scenario* for which they are designed to negate.

The auditor's job is made immeasurably easier in the instance of a well-formatted report, logically organized, codified and tabulated. The audit comes down to an exercise in 'plugging in' the codified informational elements into the audit instrument (Figure 7.2) and quickly evaluating the relationships as being valid or not. In the instance where the investigation is less structured; less formatted; less sequential, the task will broaden to require the investigator to list and codify the informational elements.

The proposed audit instrument, for this section of the audit is essentially a chart or diagram (Figure 7.2) that offers the auditor a framework for distilling the codified informational elements into a concise, inter-relational model.

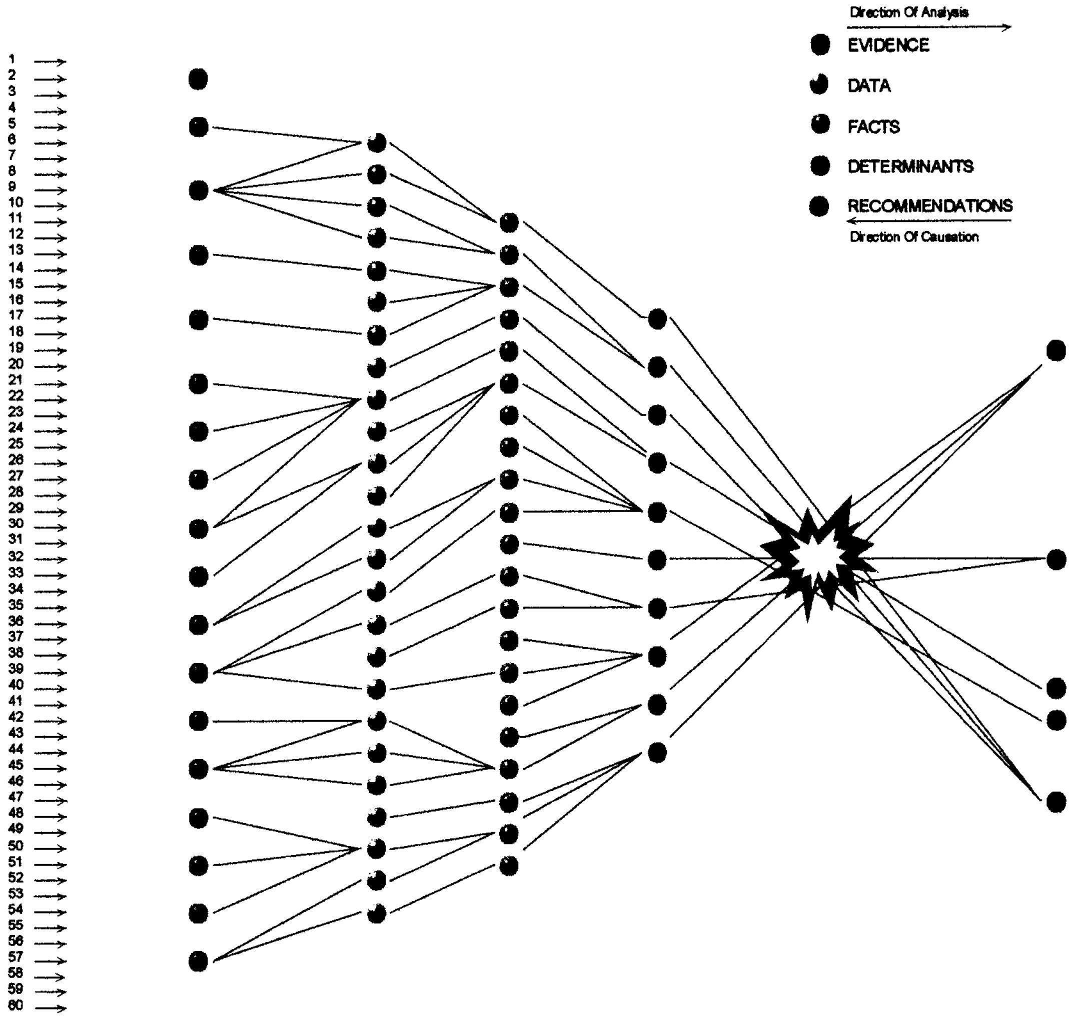


Figure 7.2: Bead diagram illustrating of the convergence patterns between evidence, data, facts, determinants and recommendations.

The utility of the bead diagram is as follows:

1) Clearly established one-to-one and one-to-many relationships within the event scenario.
2) Indicates where data, facts and recommendations are strongly supported by precursors, or not.
3) Indicates where facts or hypotheses are overly dependant upon one or more pieces of evidence.

As an example, we consider the populated bead diagram model (Figure 7.2) Observe the second recommendation (blue) identified in line 33. This recommendation was designed to negate the sixth determinant (maroon) identified also in line 33. This one-to-one relationship is supported by only one fact (green, line 32) that has no basis in data or evidence. A counter example to this is the observation of the first recommendation (blue, 19) that enjoys a one-to-many relationship with the bottom three *determinants* (maroon, 38-45) that in turn are based upon a one-to-many relationship with no less than ten facts (green, 36-51); ten data points (orange, 38-55); and seven pieces of evidence (red, 39-57). Note too that there are a total of six occurrences of facts having no basis in data or evidence, and six occurrences of data having no basis in terms of evidence. Additionally, there is one occurrence in which the evidence was apparently not linked or otherwise linked to data, facts or *determinants*.

Section 2a: Tests for Veracity of the Causal Record

We proceed in reverse order of the chronology of elements indicated in the audit structure (Figure 6.4), for reasons of efficiency and clarity.

2.14 Summarize Recommendations

Intent: The recommendations should be listed in order of priority, and be worded in concise, simple sentence structure. They should be codified and there should be some indication that they have undergone some form of analysis on the basis of feasibility, practicality or efficacy. The thinking here is on how these recommendations are to be carried out.

Seek: Copies (drafts) of the Investigative report, evidence and data logs and working documents.

Verify: By interviewing the investigators and determine as to the nature of the decision making process in determining the final recommendations (statements).

2.13 Establish Recommendations

Intent: These recommendations should make reference to the causal determinants they are believed to negate. These recommendations will usually be in no particular order and in many cases, established by one-to-one basis with *determinants* on a chart, table or working notes. These are the recommendations that reflect their origins in terms of causal analysis.

Verify: By interviews with the investigators and inquiring how many iterations of recommendations were conducted and the nature of the process and documentation.

2.12 Analyze Determinants

Intent: Otherwise referred to as causes, causal models, cause and effect relationships, factors of causation, major causes, immediate cause, root cause ... etc. The determinants will be identified as having some direct or contributory aspect to the *critical event* and should be organized chronologically, by influence or some other scheme relevant to the nature of the scenario.

Seek: Copies of the investigative report (drafts) and working notes.

The EH&S coordinator and ascertain what analytical models, protocols or training investigators have access to and the nature of any quality control.

Verify: By interviewing the investigators and inquiring as to what methods were used in organizing and validating the *determinants*.

2.11 Establish Determinants

Intent: The determinants should be clear statements of cause and effect making direct references to supporting evidence and facts.

Seek: Copies of the investigative report (drafts), charts, plots, software or technical reports (outside sources) that may be relevant.

Verify: By interviewing the investigators and ascertaining by what method or methodology the *determinants* were arrived at.

2.10 Analyze The Facts

Intent: The facts should be expressed as events, conditions, actions or decisions with direct reference to particulars within the event scenario. Often, a simple chronology of events that transpired immediately before, during and immediately after the *critical event* will identify the facts in a sequential manner. An ECFA or FTA chart or some other graphical model may be employed to present the facts.

Seek: The analysis portion of the investigative report and any technical reports that may have been submitted in support of the investigation.

The accident investigation component of the EH&S management system or program and determine if a set procedure, template or protocol exists for the analysis of facts.

The EH&S coordinator, inquire as to what expectations there were for the analysis of facts in terms of format, importance or outcome.

Verify: By examining the report drafts to observe an evolution as to the importance or relevance of facts and their inferences.

By interviewing the investigator(s) to determine what measures they took to analyze the facts for relevancy and significance; what truth tests were used.

2.9 Verify The Facts

Intent: A process of inclusion or exclusion of facts in terms of being corroborated by data and supported by evidence.

Seek: Copies of the investigative report (drafts), minutes from status update meetings and working notes.

Verify: By interviewing the investigator(s) and inquiring as to how many facts were eliminated by some process of validation, confirmation or weighting of evidence.

By interviewing the EH&S coordinator to inquire as to whether he/she had been consulted in terms of double-checking details concerning the facts.

By interviewing the key operators to inquire as to whether they had been approached by the investigators for the purpose of substantiating their facts

2.8 Organize The Facts

Intent: A process of taking the established facts and organizing them by 'rough cut'; to divide the work load among the investigators; to establish facts in need of corroboration; to rank in terms of probability or otherwise reduce from random occurrences. Should assist in following-up leads.

Seek: Working notes from the investigation and status update minutes.

Verify: Interviewing the investigator(s) and ascertain what documents, activities or techniques were used (brainstorming) to organize or winnow the facts.

2.7 Establish The Facts

Intent: To compile a list of events, actions, conditions and decisions which are potentially part of the *event scenario* and worthy of further investigation.

Seek: Working notes from the investigation and excerpts from any investigation diaries on the behalf of investigators.

Verify: By interviewing the investigator(s) the nature of the pool of facts at the outset and the extent that it can be substantiated.

2.6 Analyze The Data

Intent: To transform the data from data that is attributable and confirmed in terms of validity, to data that has some relevancy and potential to corroborate fact or theory.

Seek: Measurements, technical reports, computer downloads, instrument readings and surveillance material within the investigative archival record.

Verify: By interviewing technicians and experts that the material has some significance or relevance and why.

By interviewing the investigator(s) to establish what criteria or basis verified data was either included or excluded for further consideration.

2.5 Verify The Data

Intent: Data that can be validated in terms of time and origin; establishes some relationship with the actors, events, conditions or decisions transpiring during the event scenario.

Seek: Measurements, data logs, technical reports, computer downloads, instrument readings and surveillance material within the investigative archival record.

Verify: By interviewing the investigator(s) and inquiring what was the process or criteria used to validate and verify the authenticity and relevance of data.

2.4 Organize The Data

Intent: Data that is presented in some meaningful way; by list; by chronology; categorized by source or provenance.

Seek: Working papers, e-mail requests for data and spreadsheet files on behalf of the investigators.

The accident investigation component of the E&HS program to examine what forms or checklists exist for the collection and organization of data.

Verify: By interviewing the investigator(s) and inquiring what criteria or method they used to organize the data.

2.3 Collect The Data

Intent: Some means, method or methodology to identify all data that could be relevant to the investigation and then secure it for further consideration.

Seek: The investigative archival record and diary entries on behalf of the investigators to reveal efforts to identify and secure data.

The accident investigation component of the E&HS program to examine what forms or checklists exist for the collection and organization of data.

Verify: By interviewing the investigator(s) and inquiring as to what method or methodology was incorporated to collect data.

2.2 Analyze The Evidence

Intent: That evidence is expeditiously examined, documented, tested and considered for further analysis by persons objective and experienced in investigative procedures.

Seek: The investigative report and review the appendices respecting the physical evidence, technical reports, photographs and witness statements.

Verify: Evidence logs, diary or journal entries on behalf of the investigator(s), technical reports, invoices for expert opinion and professional service requests.

2.1 Securing Evidence

Intent: To fulfill all fiduciary, legal and procedural responsibilities in the provision of first aid, prevention of further degradation or escalation at the scene and to ensure that all evidence and materials pertaining to the event scenario are under the command and control of the investigators.

Seek: The accident investigation component of the E&HS program to examine procedures, instructions and checklists for the purpose of securing the scene.

Standing orders, policies and guidelines to be used by security, first aid or other first responders in the response to an emergency situation.

Seek: Any references within the investigative report to the first response chronology of events notification sequences or specifics respecting the securing of the scene, or the removal of evidence.

Verify: With the EH&S coordinator the sequence of events that occurred in the early minutes to hours of the event scenario.

With the facility security personnel the sequence of events that occurred in the early minutes to hours of the event scenario.

With the incident commander, emergency response coordinator or whomever took command and control of the scene, the sequence of events that occurred in the early minutes to hours of the event scenario.

Section 2b: Evaluating the Causal Record

The causal record can be considered to encompass all of the evidence, data and facts (information); collected; verified; organized; analyzed or otherwise subjected to scrutiny, during the process of investigation. For the most part, to complete this part of the audit, the auditor needs to determine that there is a complete chain of attribution with respect to all theories, conclusions, recommendations or assertions and the evidentiary record. A template is provided to assist the auditor in organizing the information (Chapter 8.5). The steps are as follows:

Step 1: Review the determinants section of the investigative report and identify all of the determinants, by list in point form (If there are greater than twenty five, then sample).

Step 2: For each of the determinants, establish those recommendations that can be attributed as preventative or mitigating measures to that specific determinant.

Step 3: For each of the determinants, trace back through the report to determine those facts that corroborate the determinant.

Step 4: In a likewise fashion, trace back the facts to the data and the data to the evidence to determine that there was at least one precursor to support the chain of attribution.

Step 5: For a maximum score, each determinant should generate two (2) recommendations; each determinant should be supported by at least two (2) established facts; each fact should be supported by two (2) documented 'elements' of data; each piece of data should be supported by at least one (1) established 'element' of evidence.

Step 6: Based upon a cursory examination of the scores, the auditor may exercise his/her discretion by characterizing the investigative methodology as category 1, 2 or 3; thus lowering the standard of attribution required to achieve maximum points.

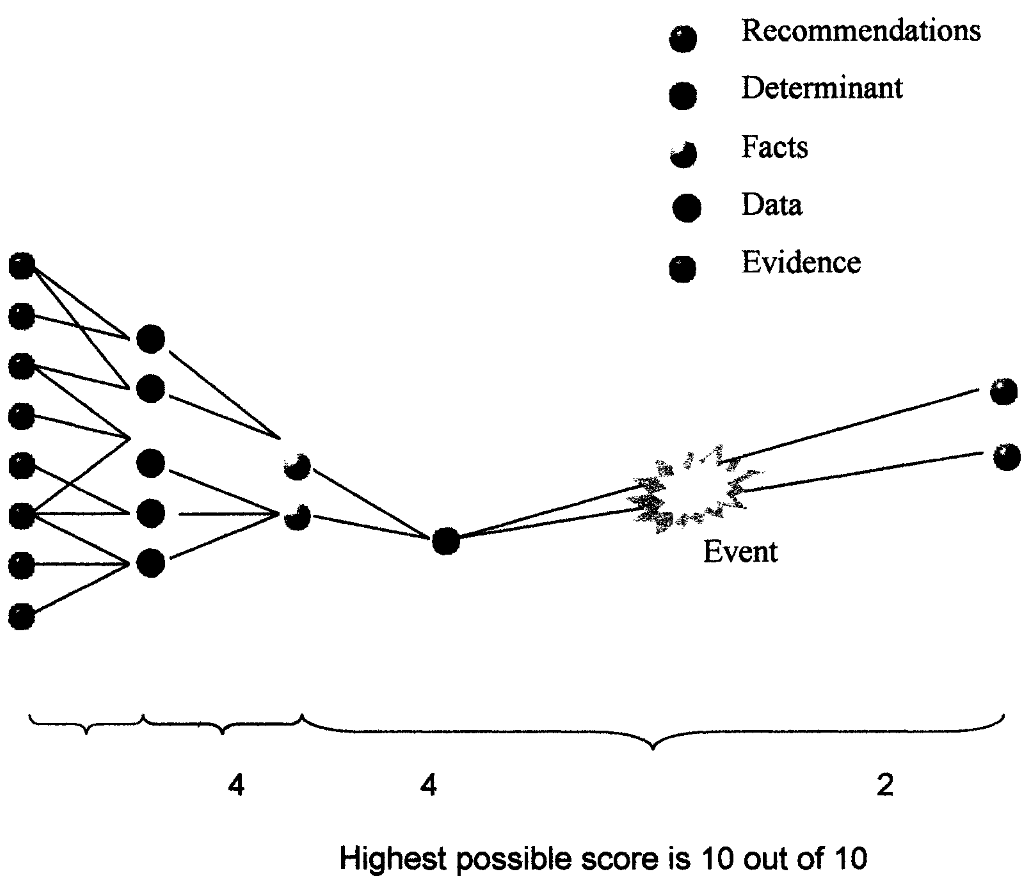


Figure 7.4: An example bead diagram illustrating the one to many relationships of the determinants to its precursors.

In the foregoing example (Figure 7.4), there is, as a minimum of a one to two attribution factor between the determinant and both its antecedent ‘elements’ (facts, data and evidence) and descendent ‘element’ (recommendations). However, it is not a requirement that each causal determinant have two descendent recommendations. It is often advisable, for purposes of ensuring negation of determinants.

Section 2c: Boundary Condition and Decision Analysis

In this section, we classify the decision *events* as errors of: commission, omission or mistaken belief. This section need only be completed if the auditor intends on applying Boundary Conditions and Decision Analysis. There is no quantitative evaluation associated with this section. The steps are as follows:

Step 1: Identify all events from the causation model in which one actor made one decision that was determined by investigation to have contributed in some way to the accident scenario.

Step 2: For each of the above decisions, identify the condition before and after the decision; that is establish the nature and chronology of the boundary condition in relation to other decisions and events.

Step 3: For each decision, classify the decision as errors of commission, omission or mistaken belief.

Step 4: List the conditions in order of chronology that were known to contribute in some way to the event scenario.

Step 5: List the actors (people in this analysis) known to have made at least one decision contributory to the event scenario.

Step 6: Identify in order of chronology each decision and its class beside each actor.

Step 7: Plot the conditions considered to have contributed to the event, working from immediately before the event outward from the epicenter of the radar diagram toward earlier events.

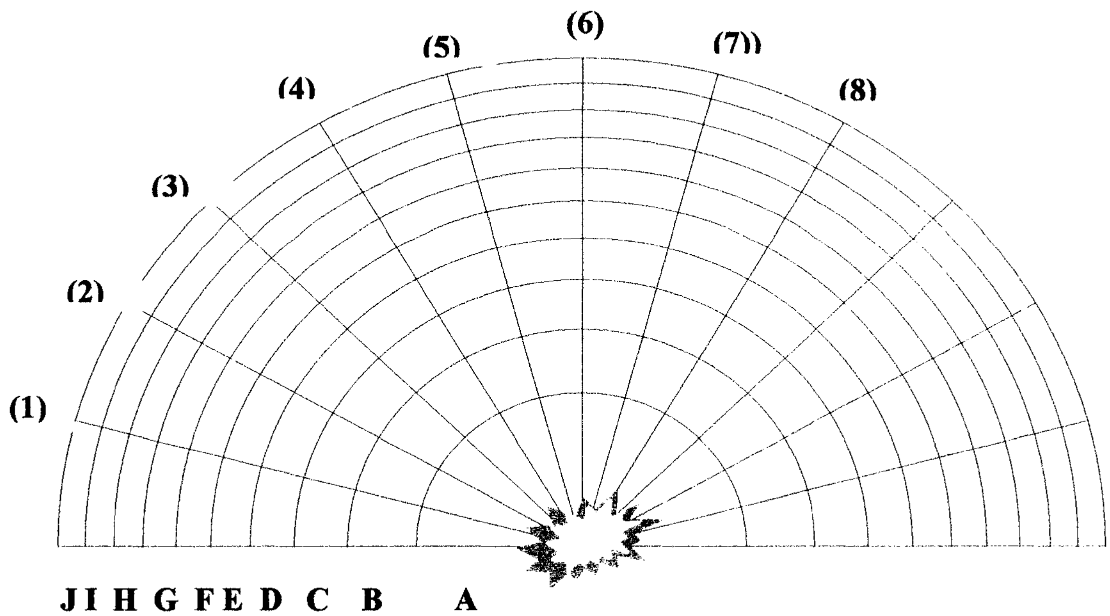


Figure 7.5: Unpopulated radar diagram illustrating an event in which eight actors or participants were present.

Step 8: Plot each actor's decisions as traces on the radar diagram at the appropriate condition boundaries, identifying the decision error class.

Step 9: Evaluate the radar diagram to determine:

a. Patterns of similar decision error class respecting a particular condition.
b. The absence of a decision at a condition boundary.
c. Patterns of similar decision error class respecting a given actor or group of actors.
d. Decision errors of a certain class where none should exist.

Step 10: Add all of the decision errors up for each class and in aggregate and calculate the percentage represented for each class.

Step 11: Plot the errors of commission, omission and mistaken belief on the ternary diagram and analyze for polarization towards one vertices or the other.

Step 12: Consider interviewing other operating staff not involved in the event but perhaps on different shifts, facilities or on leave as to their hypothetical decisions given the same circumstances to determine, how exceptional the decision errors are (as a control).

Section 3: Efficacy of the Investigation

In this third section of the audit, we look beyond the process; beyond the veracity of the exercise and evaluate some of the quality aspects of the investigation. Dividing our attention between the methodology and the methods (Hendrick and Benner, 1987) attributed to the investigation we are examining closely some of the characteristics that should be aspired to, if not practiced by every investigator.

Recall, that the methodology metaphorically speaking represents the 'what' of the investigation, the model the 'how'. In defining the methodology, it is necessary to consider the theoretical basis that is in turn predicated on the purposes of the investigation. In the Loss Control program as an example, the methodology (all-cause) of identifying event causes and imposing controls is predicated on the theory that if you break the chain-of–events represented by the Loss Control Model, the *event* will thereby be prevented. The purpose of the exercise is prevention; the terminology -loss control and prevention says it all.

Investigators need to understand then, exactly what is the purpose and thereby the theoretical basis is for what they are doing. The methodology will necessarily be designed to suit and the method will follow. The investigators need not be able to name the methodology, or theoretical basis for that matter; however they should have a good understanding as to the purpose, or need for the investigation as well as the strengths and limitations of any models used. The following list provides some insight as to the Formally recognized *event* investigation methodologies as identified by two leading theorists in event causation and investigation techniques (Table 7.2).

Benner	Ferry
Epidemiological	Event Sequencing
Clinical	Known Precedent
Trend Forecasting	All cause/Multiple cause
Statistical Inference	Codes, Standards, Regulations
Accident reconstruction	Man, machine, management, media
Simulation	Reenactment
Behavior Modeling	Hartford Approach
Systems Approach	Hazard Analysis Documentation
Heuristic	Inferential Conclusions
Adversary	Program Evaluation Review Technique
Scientific	Critical Path Method
Kipling (W5)	Failure Mode and Effect Analysis
Sherlock Holmes	Technique For Human Error Rate Prediction
Engineering	Fault Tree Analysis
Safety Traditional	Change Analysis
	Management Oversight and Risk Tree
	Multi-linear Events Sequencing
	Technic of Operations Review

Table 7.2: List of recognized methodologies used to date (Ferry, 1988).

The proposed process for this section of the audit is to bring together the investigating team and any persons affiliated with the subject investigation(s) such as the investigators, the EH&S coordinator, incident commander or JHSC co-chairs; and in a panel format, apply the audit instrument. The process is akin to a structured interview in which the auditor facilitates the completion of the instrument (each participant responding individually) and then subsequently evaluates the results. It should be noted that this particular exercise could conceivably be incorporated in a debriefing of an accident investigation independently of an audit, and provide interesting insight.

The auditor, having convened the meeting, explains the process and asks that the panel participants be sure of their understanding as to the distinction between method and methodology. Proceeding on this basis, the auditor(s) then prompts the panel to complete each audit element in turn, providing a clear description of intent of each element and pausing to allow such clarifications, as are deemed necessary.

Section 3a: Investigation Methodology Audit Elements:

The question put by each of these quality characteristics attributed to the accident investigation methodology is 'To what extent does your investigation methodology require, demonstrate, or promote

3.1 Discovery

Intent: Discovery is the noun that in the context of investigation methodology connotes the process of inquiry; the ability to identify problems and oversights; the capability of revealing evidence, data or information that would not have been otherwise evident. An investigation methodology that is 'open' to discovery typically embraces checklists and iterative approaches to evaluation and verification, is replete with opportunities to revisit fact finding and will explore holes or vacancies in the evidentiary record.

3.2 Competence

Intent: Competence speaks to that quality of the investigation methodology that adds to the participant's competence in the investigative sense but also in the operational sense, concerning the nature of risk: its evaluation, amelioration and control. Specifically, competence refers to a level of qualification, knowledge or experience that as a result of the methodology is added to, increased or otherwise improved.

3.3 Accuracy

Intent: This attribute refers to the both the findings (evidence, data and facts) as well as the recommendations as a source of output. In the case of the former (findings), the methodology must demonstrate a capacity to verify measurements, establish margins for error and qualify assertions of significance with expert opinion. In the case of the latter (recommendations) the methodology should incorporate some means of verification that the recommendations do flow from the causal analysis and that they are practical and likely to deliver on the desired effect. In other words, the recommendations are truth-tested as regards to efficacy; that had they been in place prior to the *event*; the *event* would have been averted.

3.4 Standards

Intent: A methodology that makes reference to standards as a means of qualifying the nature of the evidentiary record will intrinsically be defensible in terms of accuracy, significance and cause and effect. In the absence of standards, the investigators must make strong if not compelling supportive arguments concerning their assertions, all the while avoiding coloring their observations with bias or judgment. Standards are typically well defined in terms of metrics and testing and vary from the minimum statutory law (OH&S ACT) to management system protocols (ISO 14001).

3.5 Encouragement

Intent: The methodology is considered to demonstrate encouragement if it allows and promoted input from within the investigation as well as without. The investigators should feel that the investigation has offered ample opportunities for healthy discussion and deliberation concerning their views and ideas. In no sense should the methodology be so structured and regimented that innovation, intuition or initiative is suppressed. Similarly, those contributing to the investigation from the outside should be given ample opportunity to both have their views heard (particularly if they have evidence) and to be brought up to speed concerning the status and findings of the investigation.

3.6 Discipline

Intent: Discipline is the noun that applies both to the methodology practiced by the investigators during the course of the investigation as well as the methodology demonstrated within the written report, its ability to convey a continuous narrative of the *event* scenario without conjecture, speculation or informational gaps. The investigators should attest to the experience of having to corroborate all statements of fact with evidence and that the report reflects their diligence as regards to references both internally (codification of evidence, facts, causation) and externally (appendices or archived records) to the report.

3.7 Integrity

Intent: The integrity of the investigation is the most difficult to define -- the easiest to lose. Integrity speaks to that quality of the investigation when the process; the methodology is beyond reproach. No matter the outcomes of the investigation; its accuracy; its efficacy or its veracity, the investigation can and should achieve integrity. The investigators should feel that their deliberations were not tainted with questionable data or evidence; that they were not coerced into pursuing lines of inquiry while ignoring others; that their recommendations are their own and were not suppressed because of presumed cost, implication or difficulty. The investigative report should be complete and comprehensive; should be able to 'stand on its own feet' in terms of a document conveying the nature of and determinants to the *event* in question.

Section 3b: Investigation Method Audit Elements:

The question put by each of these quality characteristics attributed to the accident investigation methodology is 'To what extent is your investigation method:

3.8 Realistic

Intent: The quality of being realistic. The model or technique should fairly represent the nature of the event phenomena; the concurrency of conditions; the sequential aspects of events; and the inter-relationships between people, processes and their work environment. The model should neither understate nor overstate the existence of hazards, risks or the perception of danger. The model should state all assumptions and be particularly reflective respecting the passage of time.

3.9 Consistent

Intent: The need for consistency is understandable for any analytical technique; even more the case in the process of investigation. Given an *event* with significant and intricate dependencies with time, it would probably not be prudent to rely upon an event tree type model. Better to use an event sequencing model for the sake of consistency and realism. Similarly, if *event* reconstruction is the methodology of choice, then the method should be one that is strongly capable in terms of 'filling in the blanks' as regards to missing pieces of the evidentiary record. Further, the model should be consistent with the theoretical and system objectives of the existing environmental, health and safety management system.

A fault tree analysis often meets with considerable distrust and misunderstanding in an organizational culture that is blame-sensitive. Similarly, Systematic Causal Analysis Technique has an obvious fit with any organization practicing within the Loss Control Management framework, but as a method it would not be considered consistent with the precepts of a behavior based approach.

3.10 Visible

Intent: One of the greatest advantages or utilities of the application of formalized models and techniques is the extent to which they go beyond the problem solving aspect of analysis; they are equally useful in their capacity as teaching and learning tools, particularly those which are graphical. A technique or model is considered to be visible if it can be easily related to; is easy to comprehend; employs simple symbols and language; and produces relevant and organized output. The theory behind it should be known by the investigators and easily understood.

There should not be any elements of 'mysticism' associated with the process, computerized or otherwise.

3.11 Functional

Intent: The functionality of a model can be thought of in terms of how easily and with how much flexibility it conforms to the work processes and decisions made concerning the *event* scenario. Fault Tree Analysis is very functional in its application to *event* scenarios in which complex process or mechanical systems dominate; where decisions or options are Boolean in character and failures of equipment and materials are likely. Its functionality increases when the probability of failures of its constituent components is known or can be computed.

Similarly, STEP has great functionality and utility in those scenarios in which a large number of parallel and concurrent event streams are in existence. The epidemiological and system type methods are functional for workplaces dependant upon procedures and standards as the principle control measure (nuclear power plants). The choice of Change Analysis would be both consistent and functional for an *event* scenario in which a new design or process stream was being introduced; a recent reorganization has taken place; or in the instance of a maintenance shutdown or plant turn-around condition exists.

3.12 Disciplining

Intent: A model or technique is disciplining, to the extent that it imposes on the investigators the requirement for: validation, verification, pre-qualification or truth testing of the input information. Likewise, if the model offers opportunity if not the requirement for validation during the process phase of application, then it is demonstrating a disciplining quality. Finally, a model would be considered disciplining if it generates checklists, quality checks and further lines of inquiry on the part of the investigator as a by-product of output.

3.13 Comprehensive

Intent: Often, the application of a particular technique or model has to be deliberately narrow in scope, limited in complexity or sophistication and commensurately limited in output, for reason of effectiveness. This does not mean, however that we should not aspire through these same processes to be as inclusive, descriptive and definitive as possible; even if only by the reiteration of the model. Nature abhors a vacuum, the stock market moves away from uncertainty and investigators have an instinctive aversion to equivocation and ambiguity. Every effort should be made to optimize the process of analysis through inclusion, accuracy and attention to detail.

3.14 Graphical

Intent: The time dependency of event investigation; the sequential nature of an event scenario, lends itself to graphical representation. Plotting and conceptualizing the interrelationships of actors, actions and events is often the only way through what appears as clutter at the fact finding phase of investigation. Fault trees, sequence diagrams and evidence patterns are a boon to those among us who crave order, are highly linear in disposition and desire determinacy (most of us). In terms of a quick and easy way to communicate the cause and effect relationships, the things we do know and the things that we don't, models that incorporate graphical features have a strong following.

Chapter 8: The Audit Instrument

Overview

The audit instrument consists of the actual formalized printed documents, or templates, into which the audit observations will be recorded. The audit instrument for the purpose of this thesis, consists of the following record keeping forms or templates:

1) A template for the purpose of recording observations pertinent to investigative processes.
2) A template for the purpose of recording observations pertinent to investigative veracity.
3) A template for the purpose of recording observations pertinent to the efficacy of the method of investigation.
4) A template for the purpose of recording observations pertinent to the efficacy of the methodology of investigation.
5) A template for the purpose of recording observations pertinent to the evidentiary record.
6) A template for the purpose of recording observations pertinent to Boundary Condition and Decision analysis.
7) A template for the purpose of recording observations pertinent to Cognitive Patterning model.
8) A template for the purpose of computing a score for the audit.

The Existence of Investigative Process

The investigation demonstrates the existence of investigative processes in accordance with the following requirements:

Specific Requirement (see protocol)	Y/N	Evidence	Ref.
1.1 Have established or defined the 'Need' in terms of objectives, processes or policy regarding the investigation of industrial events.	Yes No	EVENT	
1.2 Have demonstrated the capability or capacity of being prepared for an event and the subsequent process of investigation.	Yes No	EVENT	
1.3 Have demonstrated a valid process for the gathering of evidence, data and information.	Yes No	EVENT	
1.4 Have demonstrated the ability to analyze the evidence, data and information in a meaningful, repeatable and verifiable way.	Yes No	EVENT	
1.5 Have developed and presented conclusions attributable to the evidentiary record and supportable in terms of reasoning.	Yes No	EVENT	
1.6 Have evaluated, organized, verified or otherwise analyzed the conclusions with an eye towards validity and certainty.	Yes No	EVENT	
1.7 Have prepared a comprehensive, complete and definitive investigative report.	Yes No	EVENT	
1.8 Have compiled recommendations that are ranked and codified and attribute determinacy.	Yes No	EVENT	
1.9 Have established corrective action that can immediately ameliorate conditions, prevent recurrence or mitigate an event.	Yes No	EVENT	
1.10 Have demonstrated the intent and the ability to follow up on the recommendations within the report.	Yes No	EVENT	
1.11 Have evaluated the investigation process internally (debriefing and soliciting feedback from the participants) and externally (professional colleague, consultant, objective reviewer).	Yes No	EVENT	
1.12 Have demonstrated the intent and the ability to follow up on corrective action within the report.	Yes No	EVENT	
1.13 Have demonstrated the intention and the capability to conduct an analysis of investigations, at least once per annum.	Yes No	EVENT	

The Veracity of Investigative Process

The investigation demonstrates accuracy, correctness and truth (veracity) in accordance with the following requirements:

	Specific Requirement (see protocol)	Y/N	Evidence	Ref.
2.14	Recommendations are summarized and codified in a manner that reflects consideration of how they will be carried out; in what order; in what time frame; expediency.	Yes No		
2.13	Recommendations have some connection or link to the determinants established within the causal analysis portion of the investigation and are limited to one-to-one linkages.	Yes No		
2.11	Determinants have been established on the merit of evidence and facts. Do the determinants reflect all of the evidence and facts with no unaccounted-for evidence.	Yes No		
2.10	Facts have been analyzed in terms of their relationship with each other; their sequential nature; their concurrency; their completeness or absence therein.	Yes No		
2.09	Facts have gone through a process of verification or validation in terms of their relevancy; their candidates for inclusion or exclusion or reliability.	Yes No		
2.08	Facts have been organized in such a way that makes sense either to the logistics of the investigative processes (division of labor) or for the purpose of following up leads.	Yes No		
2.07	Facts have been grouped or segregated from data or random information that may have no relevance to the determinacy of causation.	Yes No		
2.06	Data have been transformed from data thought to have promise in terms of relevancy to data that has some merit in supporting or corroborating a theory or fact.	Yes No		
2.05	Data has been validated as having some connection with the established events, actors, actions or decisions.	Yes No		
2.04	Data has been organized in some meaningful way; listed by chronology, source or provenance.	Yes No		
2.03	Data has been collected though some means or method that ensures completeness and chain of custody.	Yes No		
2.02	Evidence has been expeditiously examined, documented, tested and considered for further analysis by persons objective and experienced in investigative procedures.	Yes No		
2.01	Evidence and materials pertaining to the event scenario is under the command and control of the investigators and evidence has been secured in order of perish ability.	Yes No		

Evaluating the Efficacy of the Method

On a scale of one to five, five representing certainty and one the near absence of, how do you rank the investigation in terms of answering the following questions?

To what extent do you consider your method of investigation REALISTIC?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your method of investigation CONSISTENT?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your method of investigation VISIBLE?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your method of investigation FUNCTIONAL?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your method of investigation DISCIPLINING?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your investigative method COMPREHENSIVE?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider your method of investigation GRAPHICAL?
Circle the appropriate rating: 1 2 3 4 5

Evaluating the Efficacy of Methodology

On a scale of one to five, five representing certainty and one the near absence of, how do you rank the investigation in terms of the following:

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting DISCOVERY?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting COMPETENCE?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting ACCURACY?
Circle the appropriate rating: 1 2 3 4 5

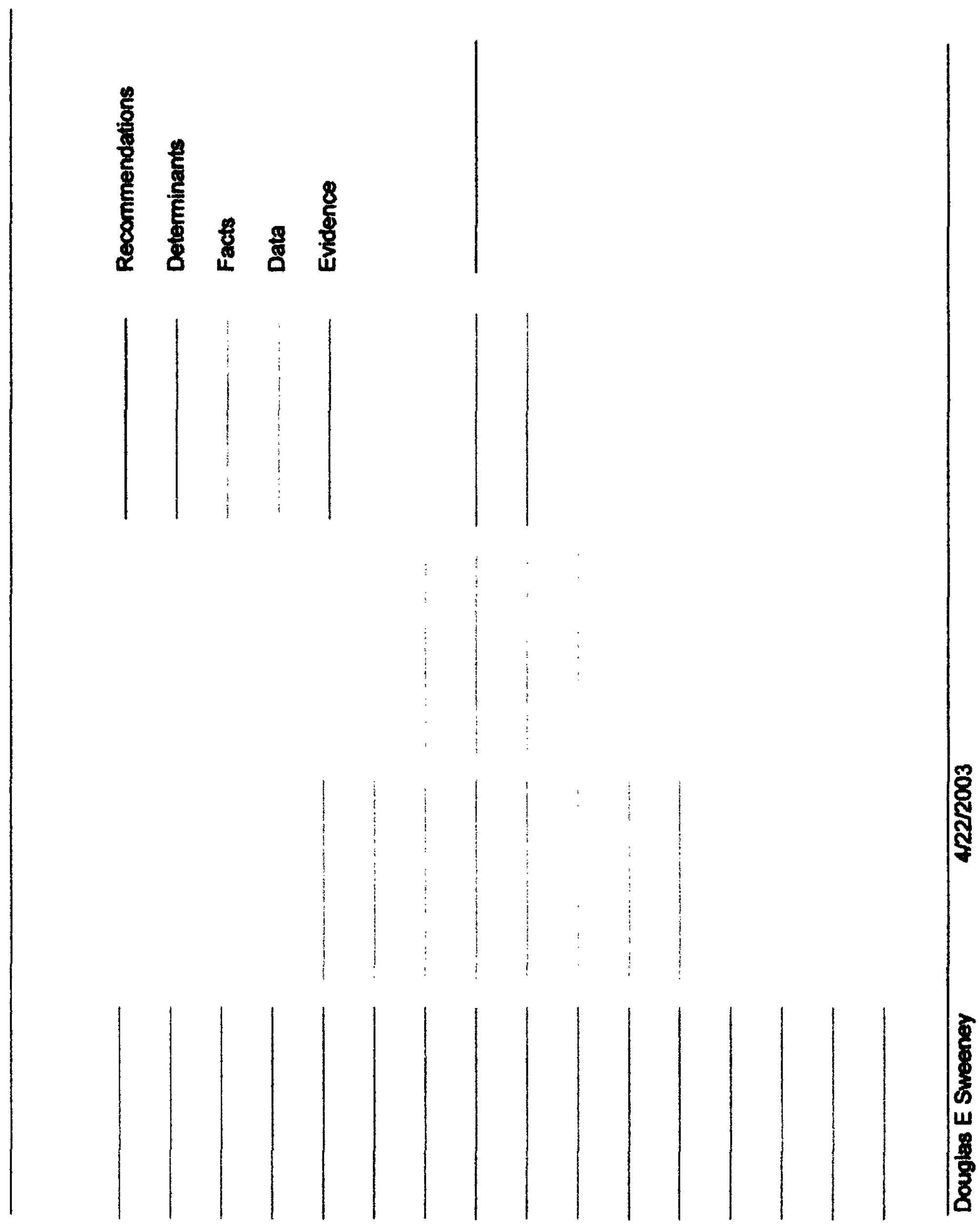
To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting STANDARDS?
Circle the appropriate rating: 1 2 3 4 5

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting ENCOURAGEMENT?
Circle the appropriate rating: 1 2 3 4 5

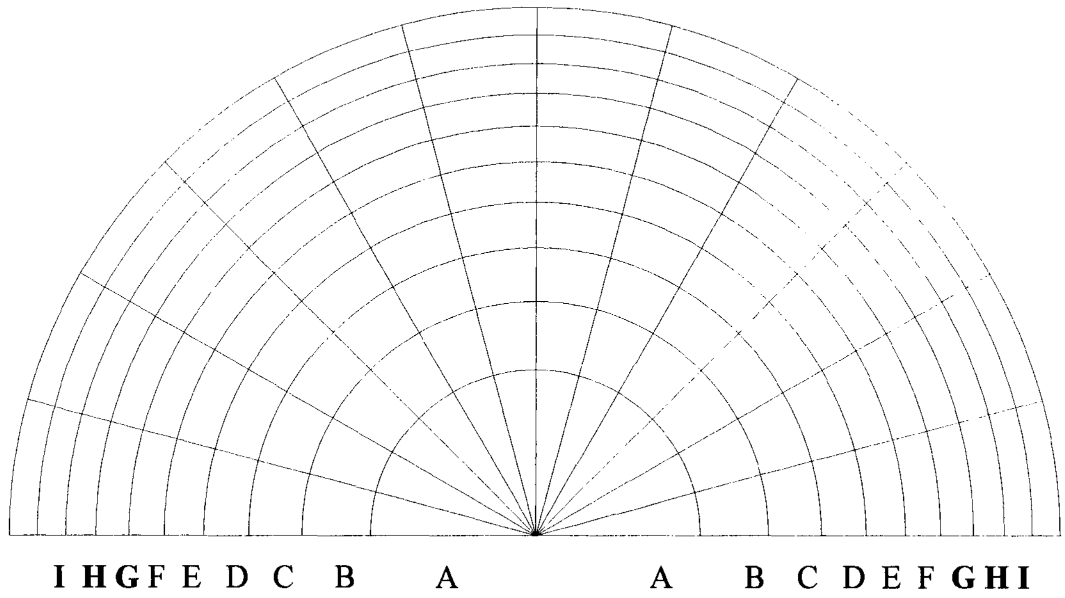
To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting DISCIPLINE?
Circle the appropriate rating: 1 2 3 4 5

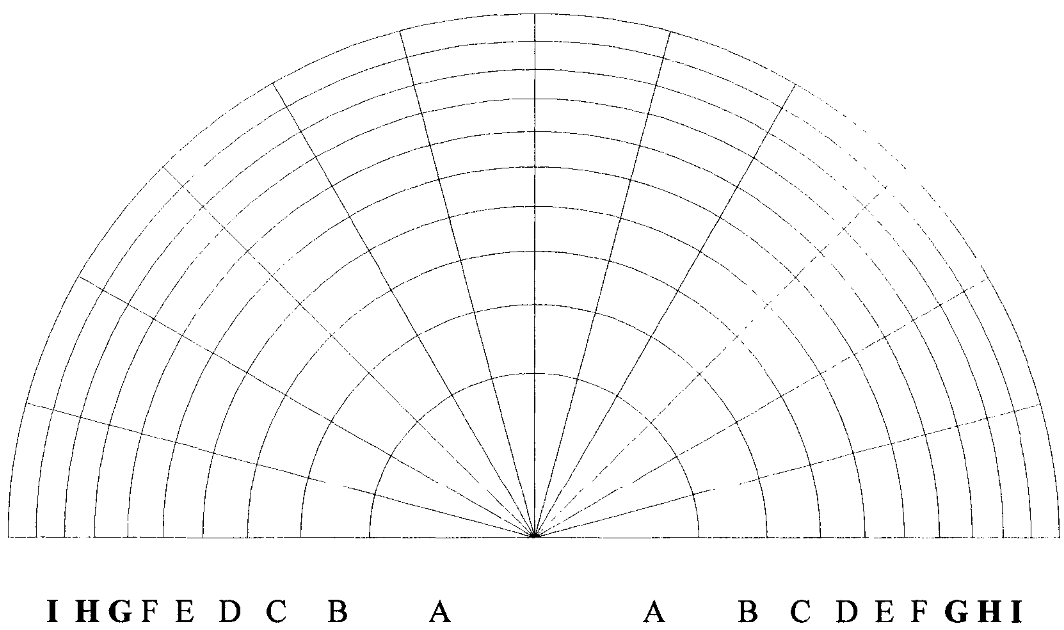
To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting INTEGRITY?
Circle the appropriate rating: 1 2 3 4 5

Graphical Aid for The Audit of Causal Records

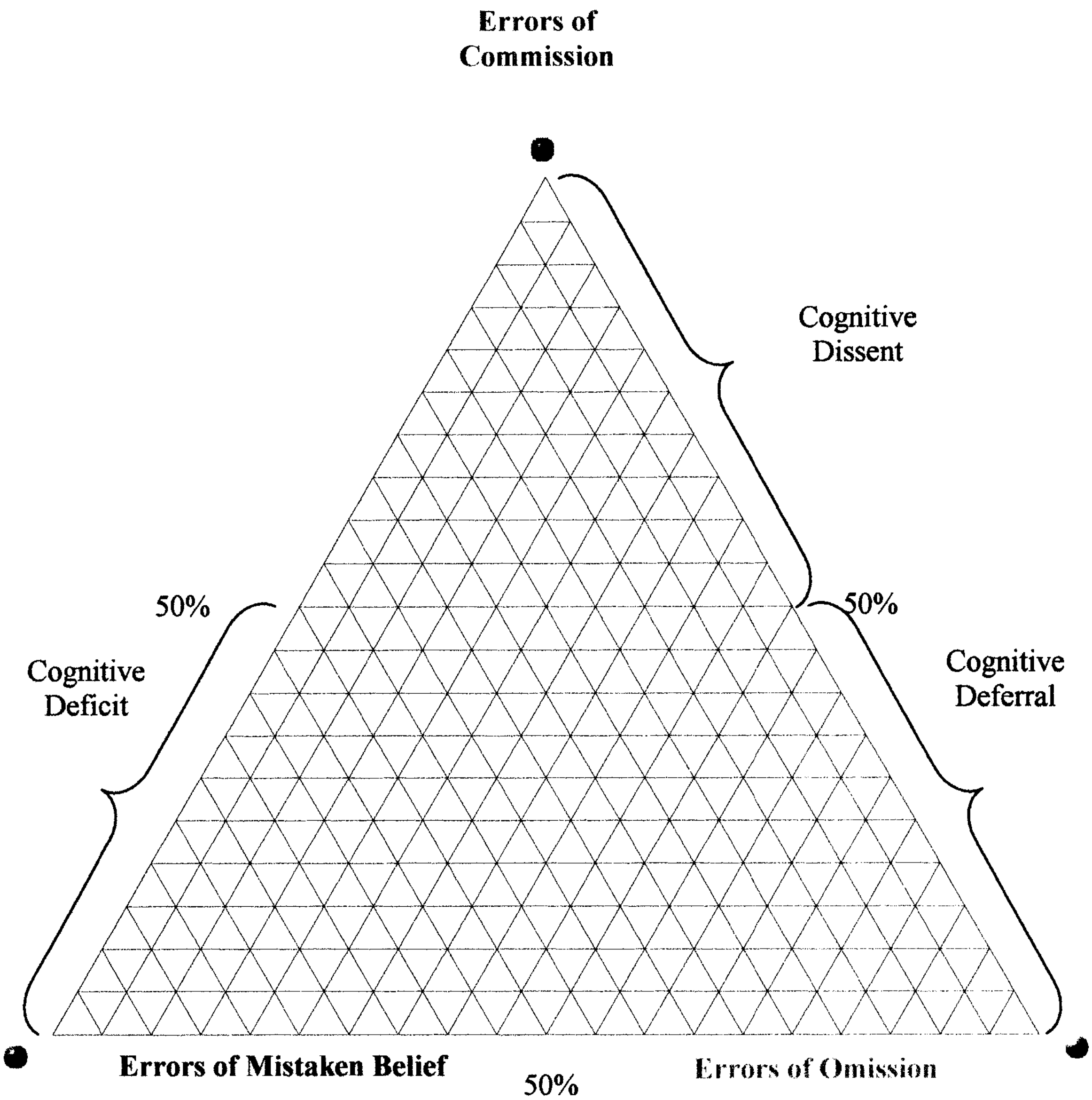


Charts for Boundary Condition and Decision Analysis





Ternary Charts for the Cognitive Patterning Model



Audit Scoring Scheme

Section 1: Possible Yes responses — Actual Yes responses

Box 1a ☐ Box 1b ☐

Percentile Score: ☐ Box 1c = (Box 1b / Box 1a) x 100

Section 2a: Possible Yes responses — Actual Yes responses

Box 2a ☐ Box 2b ☐

Percentile Score: ☐ Box 2c = (Box 2b / Box 2a) x 100

Section 2b: Add all of the scores for each recommendation and determine the average. The score for this section will thereby be between 0 and 30.

Average Score: Box 2d ☐

Percentile Score: ☐ Box 2e = Box 2d/30 x 100

Section 3: Add up all of the survey scores for each respondent (max: 140)

Calculate the average score for all respondents: Box 3a ☐

Percentile Score: ☐ Box 3b = Box 3a/1.4

Overall Audit Score = (Box 1c + Box 2c + 2 x (Box 2e) + Box 3b) / 5

Audit Score in % ☐

Chapter 9: Discussion

Event Boundary Condition and Decision Analysis: A Case Study

As an illustration of the proposed investigation analysis potential, it will be beneficial to apply the technique to a case study. The utility of this case study is that the accident is of the type to have sufficient complexity to reflect the organizational culture in which it occurs; yet not so complex as to require a great deal of description.

The event in question occurred within the mining industry, in an underground setting in which the miners were operating an air actuated drill known as a 'stoper', the purpose of which was to drill holes into the roof or 'back' of the mine and install rock bolts to secure the workplace from fall of ground. This is known as 'bolting and screening', one activity within the cycle of drilling, blasting and mucking of the ore. The crew in question consisted of two men, a lead hand and his assistant.

The crew had just arrived at their workplace and were in the process of installing their third rock bolt, when nearly five tones of rock fell onto the lead hand, killing him instantly. The assistance was unharmed and was able to initiate a response. Here are the salient factors of causation determined by the investigation:

i. The deceased, the lead hand had elected not to install a bolt immediately in the hole drilled (as was the rule), but was in the process of drilling a second of three holes when the fall of ground occurred.

ii. The deceased and his assistant had chosen not to scale (remove loose material with a long handled pick prior to working under, as was the rule) the roof as they considered the material to be too 'slabby' and 'rotten' (bad ground).

iii. The Lead Hand and his assistant were aware that in the adjacent *stope* (work area), a fall of ground had been reported by the previous shift of excess of one tonne but did not report it to the Shift Supervisor.

iv. The fall of ground had not been recorded (logged in the shift log) by the Cross-Shift Supervisor, on the basis that the occurrence was frequent for the location in the mine.

v. The workers who had drilled and blasted the *stope* in which the deceased was working had not drilled according to standard and left a 'belly' or stressed overhang in the roof. The crew (blasters) had not drilled to standard for reasons of expediency.

vi. The level in which the miners were working was approaching the extreme operating depth of the mine and ground instruments had recorded that the ground was 'working' and moving. The ground control technicians whose job it was to investigate such movements and recommend appropriate action had ignored the readings as being insignificant.

vii. Previous shifts within the last three weeks had noticed frequent fall of ground and heard many instances when the ground 'bumped' or exhibited audible sounds of strain and stress relief. On the few instances that the workers reported these occurrences, the shift Captain omitted recording them in a ground control log kept for this purpose.

viii. The mine manager had commissioned a ground control study of the level in which the event occurred and was advised of incipient ground control problems.

The decisions that were made pertaining to these boundary conditions were:

i. Error of commission (actors: blasters); did not drill sufficient holes in pattern prior to bolting and screening.

ii. Error of mistaken belief (Lead Hand and Assistant; Lead Hand and Assistant were under the wrong impression that scaling was left to their discretion.

iii. Error of commission (Lead Hand); elected not to bolt the recently drilled hole for reasons indeterminate.

iv. Error of omission (Cross-Shift Supervisor, Lead Hand, Assistant); failure to evaluate (or report) work place for unstable ground conditions as evidenced by 'slabbing' and frequent falls of ground.

v. Error of omission (Cross-Shift Supervisor); failure to log fall of ground occurrences greater than 500 kg.

vi. Error of omission (Ground Control Technician); failure to respond promptly and affirmatively to an elevated alert ground control state.

vii. Error of commission (Ground Control Technician, Shift Supervisors, Mine Captain); committed to continued mining (made a decision) within a level with known ground control problems and questionable mining methods.

viii. Error of commission (Mine Manager); committed to the mine method knowing from a previous ground control report of incipient loose hazards.

The plotting of these observations yield the following charts:

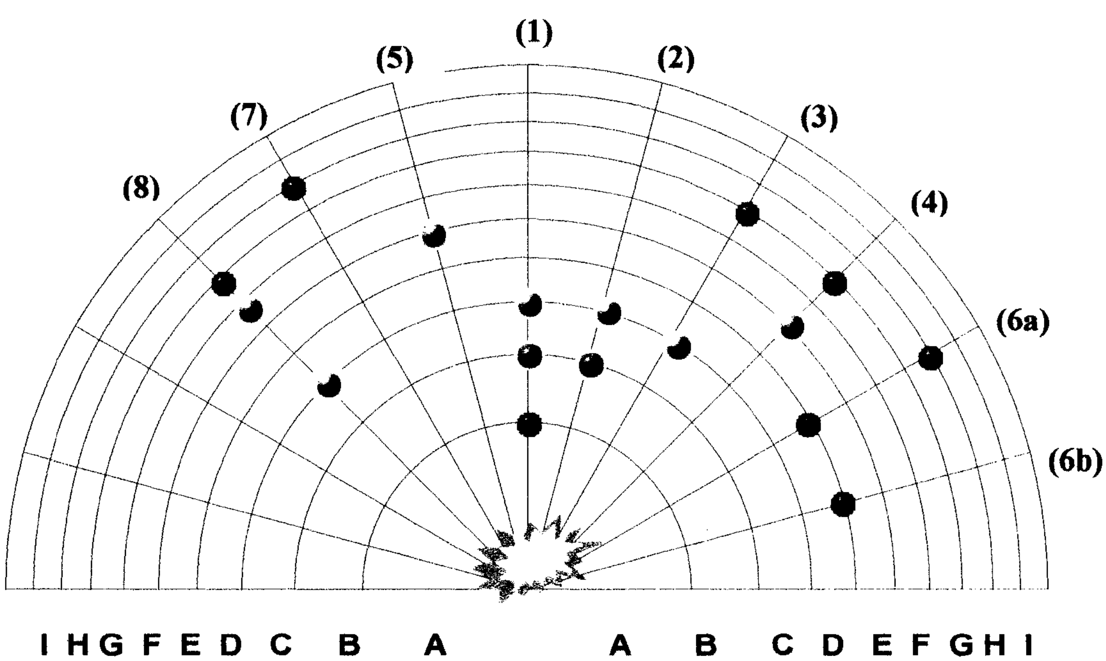


Figure 9.1: Populated radar diagram illustrating which the actors made decisions in error that contributed to the *event* scenario.

For the purpose of simplicity, the following 'actors' will be identified and the subjects of the Boundary Condition and Decision analysis:

1) Lead Hand (deceased)
2) Assistant (to deceased)
3) Supervisor (of the deceased)
4) Mine Captain
5) Ground Control Technician
6) Shift Blasters (2)
7) Mine Manager
8) Cross- Shift Supervisor

The boundary conditions were, from proximate to remote:

A. Work area risk of fall of ground increased by induced stress resulting from drilled hole without requisite rock bolt (actors: Lead Hand)

B. Work area improperly scaled and secured from loose ground (actors: Lead Hand, assistant).

C. Stope unstable with respect to fall of ground due to known slabbing actors: Cross-Shift Supervisor, Lead Hand, Assistant, Shift Supervisor)

D. Incipient risk of fall of ground immediately in the 'back' as a result of stressed induced by insufficient drilling and blasting (actors: blasters).

E. *Stope* was unsafe with respect to fall of ground as indicated by the frequent loose related falls and 'slabbing' (actors: Cross-Shift Supervisor and the Shift Supervisor).

F. Level was unstable with respect to fall of ground as indicated by ground control monitoring instruments (actors: Ground Control Technician)

G. Level unsafe with respect to fall of ground due to extreme depth and aggressive mining method (actors: Ground Control Technician, Shift Supervisor, Mine Captain)

H. Inappropriate mine method given the nature of the rock mechanics and the technology available (actors: Mine Captain, Mine Manager)

A Glimpse of Organizational Culture

A quick calculation of the three error types, in percent reveals:

Error Classification	Color	Count	Total	Percent
Error of Commission	Red	8	17	47
Error of Omission	Blue	7	17	41
Error of Mistaken Belief	Green	2	17	12

Table 9.1: A table indicating the distribution of error 'types' as produced by the Boundary Condition and Decision analysis.

Plotting these figures on the ternary diagram (Figure 9.2) reveals that for this particular sample population, the investigation falls within the middle quadrant (although marginally) and that decision makers were disposed to errors of commission and errors of omission. That is, in the majority of instances (88%), the decision makers were aware of the standards that applied. Thus, in terms of cognitive patterns, the analysis would suggest that both cognitive dissent and deferral could be influencing decision making, at some level.

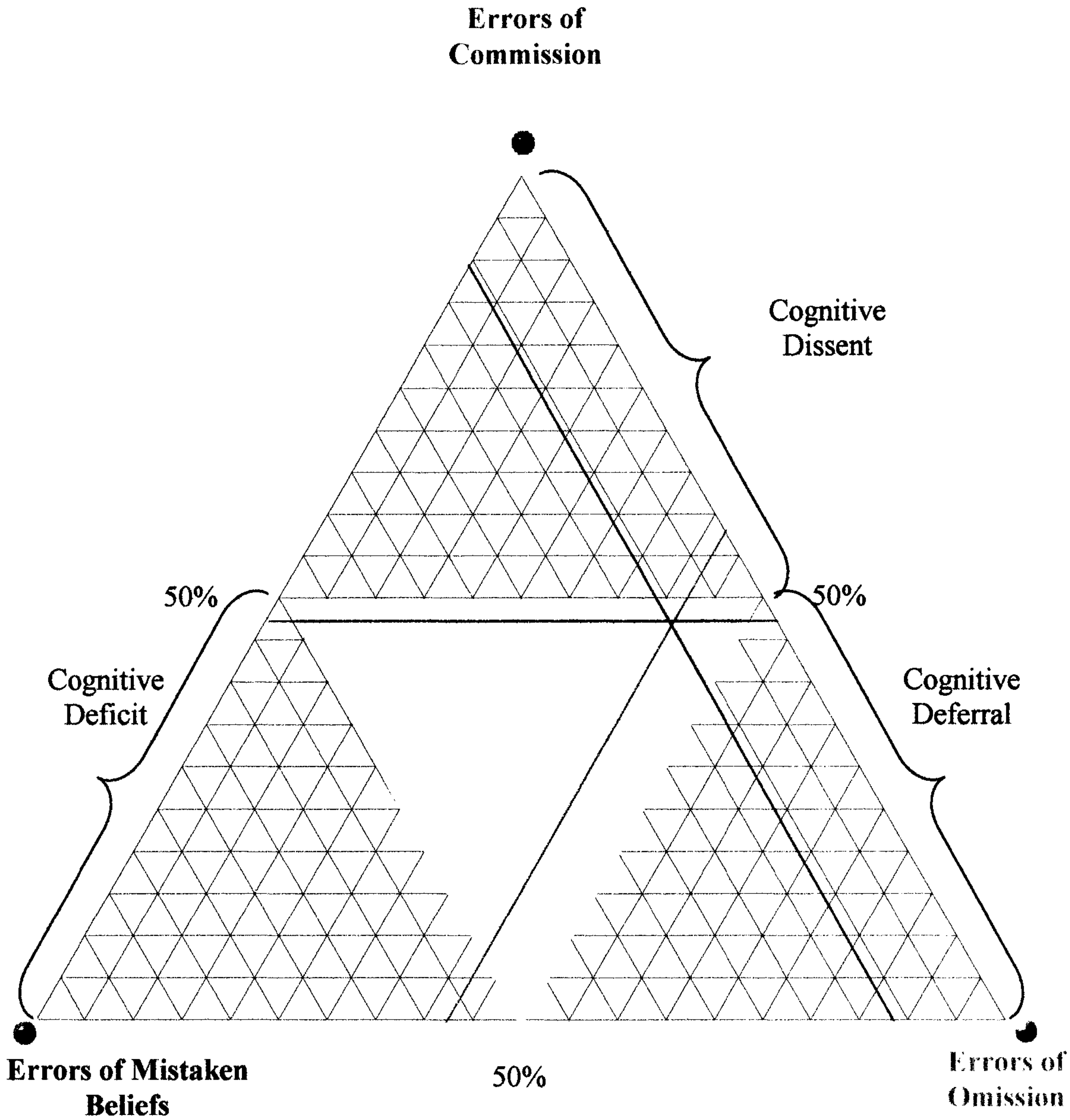


Figure 9.2: Ternary diagram illustrating the distribution of decision errors in the case study (Note that this particular workplace falls marginally within the norm).

Chapter 10: Field Trial of the Audit and Analysis

Executive Summary

On September 3rd through the 5th of 2003, an analysis of recent incident (*event*) investigations was conducted an operational mine/plant site. The analysis took the form of an audit of four (4) *events,* each of which had been investigated by mine investigators, utilizing mine systems, methods and methodologies. The objective of the audit was twofold. First, to evaluate the investigative capabilities of the mine investigators, respecting the following aspects of their investigations:

1) The existence of investigative processes
2) The veracity of the causal scenario
3) The efficacy of the methods and methodologies

Secondly, the audit was an opportunity to acquire data concerning decisions made by persons involved in *event* scenarios; to the extent that those decisions contribute to the occurrence of that *event*. This data was then put through an analytical model called Boundary Condition and Decision (BCD) analysis in which the cognitive context for these decisions, and therefore the *events* could be determined.

The audit results are as follows:

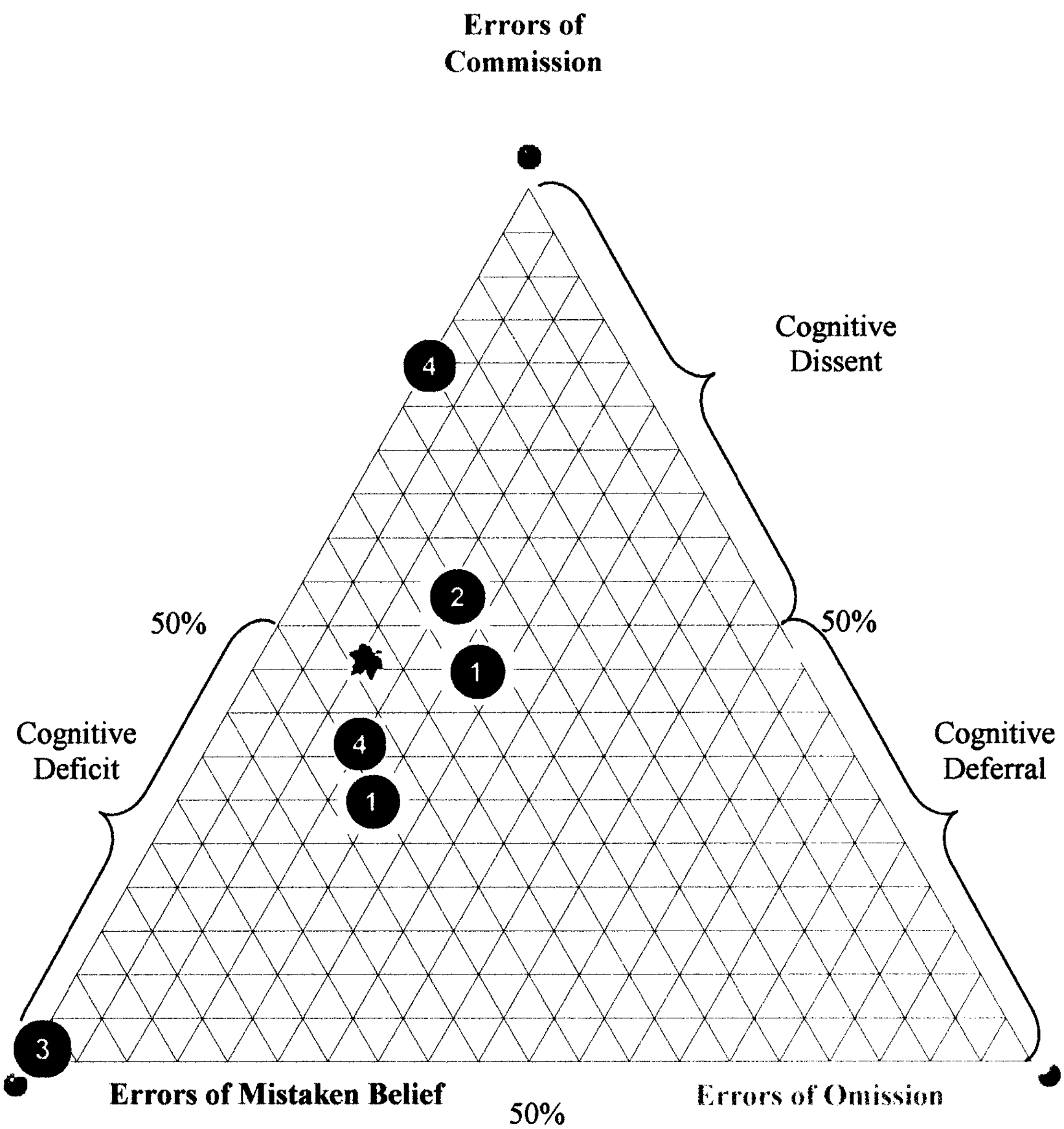
The existence of investigative process:	Score of 70%
The veracity of investigative process:	Score of 78%
The efficacy of methods and methodologies:	Score of 79%
Overall Score:	Score of **75%**
Classification:	**Category 1**

(Refer to the Audit Protocol (Table 7.1) for a detailed explanation of Category 1)

Boundary Condition and Decision analysis revealed that the *events* under scrutiny generated a total of 62 decision errors, of which 28 (46%) were errors of commission, 26 (43%) were errors of mistaken belief, and 8 (11%) were errors of omission. These results exhibit a signature that would suggest a bi-polar distribution between two 'camps' of cognitive patterning: they being cognitive dissent and cognitive deficit. Cognitive dissent is characterized by individuals who make decision errors that are based upon the individual having full awareness that a standard, rule or boundary condition exists, but chooses to transgress the boundary for reasons of their own choosing. It is suggested by the auditor, that organizations disposed to this type of cognitive patterning are those in which the decision makers are quite senior in experience/age or very technically competent; or both. Cognitive deficit is characterized by inadequate information; that had the information been true (or present) the transgression of the boundary condition would not have occurred. The existence of the boundary condition can in some instances be the information that is absent. It is suggested by the auditor, that organizations disposed of this type of cognitive patterning are those in which decision makers are quite junior in experience/age or recently assigned to the tasks presently assigned, or both.

Interestingly, the audit and subsequent analysis of the mine investigations would suggest that there are two cognitive patterns in existence at the mine/plant site, in some ways contradicting each other (Figure 10.1). On the one hand, there is a cultural disposition to unilaterally disregard a standard, rule or boundary by some, while others are unaware of the boundary being transgressed or have erroneous information respecting it. This brings to consideration several possibilities:

1) There is no correlation between the culture at the mine and the cognitive patterns which are observed.
2) The workforce is evenly divided between older, more experienced workers and younger, less confident workers.
3) The workforce, although highly technically competent, is being frequently called upon to work on tasks out of their comfort zones or for which their experiences and assumptions don't hold true.



= aggregate of all of the *event* analysis accidents

Figure 10.1: Ternary diagram illustrating bi-polar distribution of decision errors.

Discussion

Owing to the limited sample size (n=4) and the nature of those investigations, it is apparent that the types of *events* and the subsequent investigations at the mine/plant site fall into Category 1 classification. The audit of the mine/plant site investigations was a tripartite process. The first analysis concerned the investigative processes and systems. The score was 70% (Category 1) reflecting a strong performance in achieving the fundamentals in accident investigation. The investigators were trained; they had modern day equipment and computer technology at their disposal, in which they were proficient. They demonstrated a good understanding of the objectives of accident investigation and had some familiarity of various models such as Root Cause Analysis, Fault Tree Analysis and TapRoot. They were particularly proficient at integrating the cause and effects relationships of the *event* scenario and translating them into reasonable and practical recommendations.

The investigations would benefit from a number of improvements. First, there was a general weakness in the area of documenting, recording and the indexing of evidence. As a minimum, witness statements, photographs, measurements and physical evidence should all be introduced in terms of process (how they were carried out) and then listed in the appendices. Further, by assigning a unique identifier to each piece of evidence, it can be introduced to substantiate fact, then cause and finally recommendation. Finally, the recommendations as a whole would benefit from some form of ranking, in terms of importance as well as 'low hanging fruit'. It is not a given that all recommendations will be carried out; it is best to identify those that will have the greatest mitigating and preventative effect up front so as to achieve the greatest cost benefit.

Comments Concerning the Veracity of the Causal Record

The causal record concerns the entire spectrum of evidence gathering, data collection, fact-finding and causal modeling. If the recommendations represent the heart of the process, the causal record is the conscience. To achieve full credit for the causal record, the client organization would necessarily have to exhibit some form of evidentiary control, organization of data and truth testing of facts. These investigative processes rightly are associated with Category 2 and 3 type events and their investigation. Preliminary analysis revealed that the mine/plant site did not practice this detailed an investigative methodology and therefore was largely exempt from this level of scrutiny, however all the investigations were credited with clearly articulated causal statements with strong correlations to the recommendations (Score of 78%, Category 1). Two of the investigations did demonstrate that they were moving in the right direction by ranking and organizing the determinants (causes) in terms of certainty and strength. Additionally, some cross-referencing of evidence with cause was evident, particularly in the instance of the investigation of the Primary Separation Vessel.

One investigation in particular, the Electrical Contactor/Switch Explosion of October 2000 is instrumental in illustrating the importance of scrutinizing the absence of evidence. In this investigation, the investigators found solid evidence that the electrical contactor in question was subjected to repeated and prolonged operational abuse (wear marks on the internal surfaces). Of issue and largely unexplored was the; who and when in this occurrence, moreover why was it not reported and corrected? This is the type of event that there may well have been many opportunities to correct and prevent, but in the absence of doing so brings into question the organizational ethos concerning error.

Comments Concerning the Efficacy of Investigations

The third part of the audit took into consideration the effectiveness of the investigation in terms of methods and methodologies. A clear distinction is made here between the methodology - the underlying systems and principles upon which an investigation is carried out, and methods - the analytical techniques used to determine causal relationships. As a group, the investigators were taken through a structured interview of their perceptions relevant to their understanding of the investigative methods and methodologies. This served a two-fold purpose: First, by soliciting the perceptions of the investigators the auditor received an appreciation for the level of empowerment, competency and functionality that they were experiencing. Second, the score represents a counter-point to the more objective and hard analysis of the first two parts of the analysis. The score achieved here was 79%, representing a somewhat competent and confident group of individuals who, without exception had no complaints or concerns respecting the support, resources or expectations of management.

What was revealing however was that they could not articulate any particular methodology to their investigations other than the methods (Root Cause, Fault Tree and TapRoot) in which they were familiar; if not practiced in. Of the structured questions, the two receiving the lowest score concerned the discipline (7.0) of the methodology and the extent to which the methods promoted or required competence (7.0). It is left to the mine operations to consider to what extent that these qualities may require redress.

Interestingly, the highest scores were awarded for the methodology meeting a standard (9.0) and their methods being realistic (8.75).

Boundary Condition and Decision Analysis

During the course of the audit, the investigators were able to expand with some candor as to what decisions were made by whom that contributed to the *event* scenario. Whereas, such details were often missing in the investigative report, the investigators seemed to have an intuitive grasp of the nature of decision errors and provide the auditor with 62 decision errors from which to conduct a Boundary Condition and Decision analysis. There are a number of observations that bear comment at this point.

First, two of the *events,* the Oiler's Crew Cab *event* and the Sanding of the Tailings Line *event*; turned out to be a series of two *events*. In the case of the former *event*, a previous attempt to tow the heavy hauler had been made by a wheeled loader in which a failed towline broke and the whiplash from the end attached to the wheeled loader smashed the windshield, narrowly missing the operator. In the case of the latter *event*, the process upset resulting in the sanding off of the tailing pipeline did not in and of itself contribute to the failed discharge spools. A second event occurred when the panel operator committed to doing what he thought was best in the circumstance (error of mistaken belief) and exacerbated the degrading scenario by pressuring the line beyond its design limit.

Second, as alluded to in the Executive Summary, there appears to be a curious bi-polarity in the results of the BCD analysis; significantly split between the error of commission and error of mistaken belief camps. One of the investigations; that of the Primary Separation Vessel was quite effective at getting at the system and root causes, but at the expense of specificity. Individuals making decisions were few and far between, further the investigation was strongly oriented towards errors of mistaken belief (100%). In fairness, there was a good argument to support this insofar as there were definite assumptions made respecting the similarity between the vessel in question and those existing at the Base Plant. Still, this particular investigation would have benefited (would still benefit) from being a little more discerning and constructively critical as to the roles of individuals in this *event* scenario.

In looking at the various BCD diagrams, the auditor is struck with the fact that there is a similar pattern evident of 'spiraling down' of the *event* scenarios. This pattern suggests a high degree of compartmentalization of operator's responsibilities; so much so that it would appear that they are not intervening in the risky behaviors of their colleagues, in some cases going so far as to assist them in transgressing a known boundary condition. On the one hand, this may appear as natural respect and a reluctance to interfere in the affairs of their colleagues however, should it prove to be as endemic as it appears, the mine management would do well to consider the efficacy of their Behavior Based Observation system.

The absence of proportionate numbers of errors of omission (11%) is an interesting observation. It is promising in as much it suggests that there is little predisposition toward cognitive deferral; the state of affairs in which the decision maker has too many expectations or expectations that are in conflict. In such an environment, a decision maker will attempt to reconcile one imperative only to violate another and in doing so, surrender to transgressing a boundary condition. That this is not the case is an indication that the mine/plant operations have appropriately established the values and beliefs that drive the process of decision-making. Further, a preponderance of this error class can be indicative of persons attempting to color or evade the truth in as much as the admission of errors of omission can be deemed more politically correct or palatable than errors of commission or mistaken belief. That the operators and investigators can be this honest and forthcoming is commendable.

Conclusions

The mine/plant operations have been credited with an overall score of 75% in Category 1 investigations. In doing so, they have demonstrated a strong foundation in *event* investigations, particularly oriented to achieving due diligence, determining causation and preventing reoccurrence. It is the opinion of the auditor, that within the limited context of the sample size (n=4), the causes determined by the investigators respecting these *events* and the recommendations that flow from them are correct and effective. They are not however, necessarily inclusive nor will they provide a high degree of certainty that *similar* occurrences will be prevented. In this vein, the following recommendations are proposed for consideration of management at the mine/plant site (in order of importance):

1) Adopt a structured format for the process of investigation that includes but is not limited to:
    a. The securing, identification and listing of evidence
    b. The validation of facts by corroboration
    c. The indexing of evidence, facts, causes and recommendations
    d. The ranking of recommendation in order of importance or ease

2) Initiate an internal incident/accident review process that will serve as a venue for the investigators to 'bounce' their causation models off of in a non-threatening manner, while at the same time promoting discovery and encouraging further avenues of inquiry

3) Once a year, evaluate your past investigations by audit or other analytic process to determine depth of investigations, the veracity of the causal record and the follow-up of recommendations.

4) Adopt the practice of identifying persons accountable for seeing that the recommendations come to fruition or are formally rejected on some basis consistent with due diligence; wherever possible identify a time frame or date in which a status update will be required.

5) Restrict the practice of having operators and technicians lead investigations of *events* within their own areas of responsibility. Their expertise is better utilized as content experts; or better yet witnesses. A fresh and objective pair of eyes as a lead investigator has the additional luxury of being able to walk away when the investigation is complete.

6) Promote the practice of identifying decisions made by persons contributing to an *event* scenario, while emphasizing the language of 'error' rather than 'cause' or 'responsibility for'. Avoid the attribution of error to systems, cultures or unidentified entities.

7) Promote the inclusion of evidence and facts that do not support the causation model and in particular acknowledge the absence of evidence and consider the context for its absence.

8) Consider the investigation of an *event* as a project to be managed like any other project, with dedicated resources,

commitment and some process of quality assurance. At the end of the day, recognize the investigator(s) for a job well done; one that is often not wanted and that offers unique and personal challenges.

Chapter 11: The Ethos of Error

Introduction

Up till this point, we have been considering the investigation of *events* as processes and the subject of considerable interest. The *events* themselves however have traditionally been the subject of many researchers, and it is one particular class of *events* or accidents that we now turn our attention. It has been generally acknowledged that *events* are rarely the result of a single determinant, and that the more complex the environment, the organization or the systems in which they occur; the more complex the *event* scenario is likely to be. Ostensibly, as we systematize industry or transportation, we do not necessarily eliminate error; indeed some event scenarios would suggest the reverse is true. Thus, we can draw an inference that on occasion our best efforts to preemptively design out error results in error propagation; simply stated, errors are as much a product of our cognitive processes as our physical processes. This special class of accidents in which errors interact to cause failures, and failures interact to cause *events* are *system accidents* and do provide a rare perspective into the ethos of error.

System Accidents

System accident is a term that has gained increasing popularity of late, and a provocative and erudite discourse on the subject is available in the definitive treatment (Perrow, 1999) under the title 'Normal Accidents:

Living with High Risk Technologies'. Perrow (1999a) defines *system accidents* as those 'involving the unanticipated interaction of multiple failures'. Perrow introduces the concept of *normal accidents* as a synonym for *system accidents*, the inference being that within organizations involving significant levels of risk and complexity, complex interactions of failure potentials are inevitable and can be considered 'normal' for risk level. Further, these failure potentials are predictable and as such preventable, yet within some industries (the maritime shipping and mining industries), we are not observing a substantial decrease of *events* with respect to time (Perrow, 1999). This observation is particularly worrisome insofar as in recent years there has been a significant introduction of new, safer technologies and controls that in other industries (aviation, chemical processing) have realized great improvements in safety. Something else is going on; some process or condition exists within these industries that effectively retards the effect of improvements in safety, not at the component or sub-system level, but at the system level.

System accidents are relatively rare, but as Perrow hastens to point out, their capacity to result in catastrophes (Three Mile Island, Bophal, Flixborough, Space Shuttle Challenger, Grand Teton Dam) affords us little reassurance. This class of accident is very much the subject of Perrow's examination and is illustrative that it is not only organizations that are subject to a culture or cognitive patterning supportive of accidents, but industries are as well. This is a powerful and troubling concept, one that bears examining closer and resonates with a recurring theme of this thesis: that within organizations and their cultures exist the very seeds of their destruction as a natural consequence of the way we design, build and interact with our systems.

Classification

Obviously, not all accidents are system accidents; thankfully very few accidents have the necessarily complex interactions to combine in unexpected and irreversible ways. The concept is deceptively simple: system accidents are not single component failures; they are accidents in which several if not many failure modes come together in unpredictable ways to combine with increasing potential; seemingly defeating safety systems and controls, then culminating in a catastrophic event. Those that do so, evince two characteristics of system failures that make unpredictable interactions of failure modes more likely. The first is the degree of *interaction* and the second the degree of *coupling* (Figure 11.1).

System Interaction

Interaction speaks to the complexity of the system. In general, the more complex the system, the more the components and subsystems interact in unpredictable and potentially uncontrollable ways. These interactivities may in fact include purposely-designed safety systems, redundancies and fail safes; or they may be complexities introduced unwittingly or in error. The irony here is that in many documented cases, the same parallel sub-systems and redundancies that were introduced to prevent errors interacted to produce the very failures they were designed to prevent. Apparently, the higher the risk of the enterprise, the more compelled we are to introduce complexities (controls and feed back loops), in an earnest and understandable attempt forestall error. Perrow observes however, that it is these complexities that present failure potentials or opportunities in which errors can occur. The simpler systems, those that exhibit linear interactions are less prone to failures and therefore lesser candidates for *system failure*.

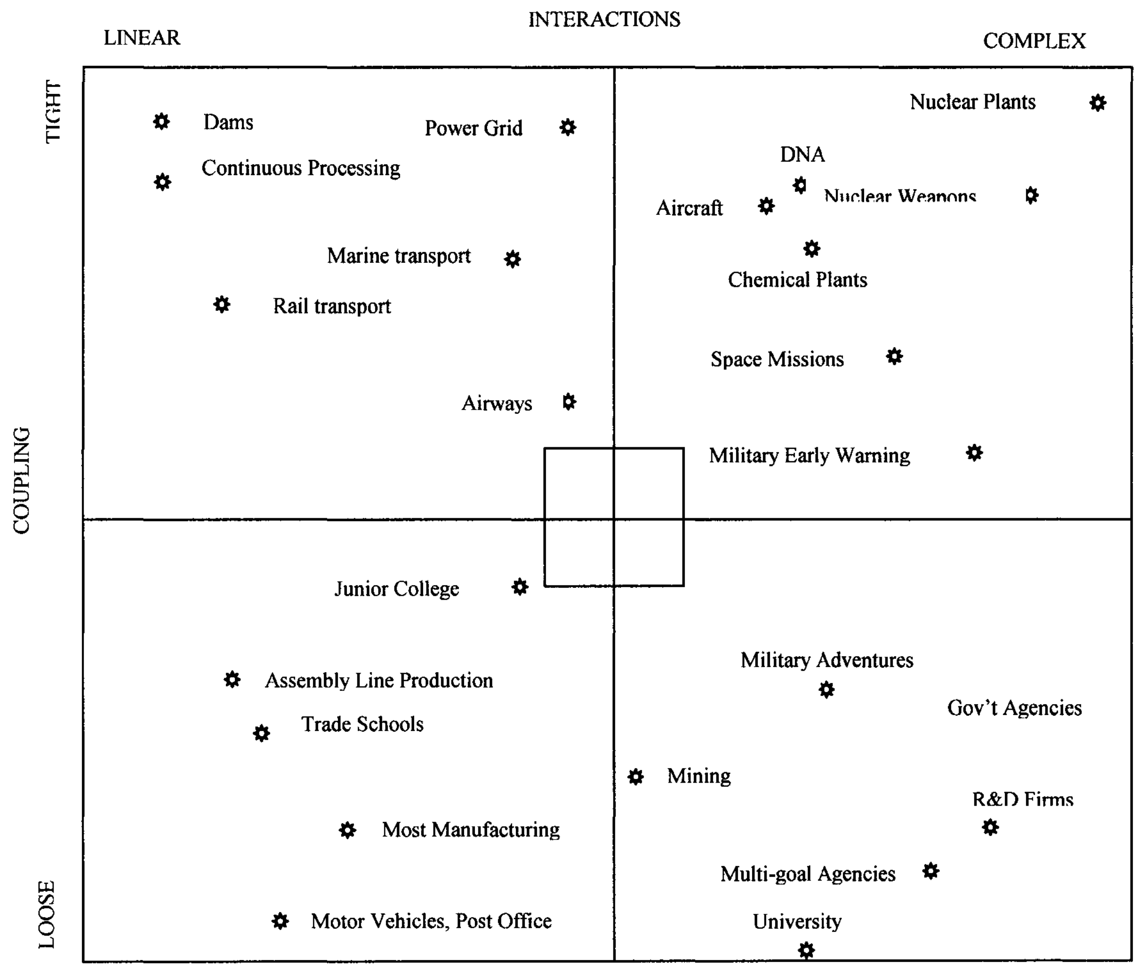


Figure 11.1: A schematic illustrating the degree of coupling and interaction across various industry sectors (Perrow, 1999b).

Gemini VIII Mission

A good example of a system accident resulting from complex interactions was the Gemini space program. At this time in the history of the space program, astronauts were mainly on board the space capsules as subjects of experimentation and were afforded very little command and control of their capsule. This was not an oversight but a product of the simple expedient that the systems were highly automated and controlled through telemetry with Houston Control. However, increasingly the astronauts were lobbying for more of role in the operation of the space capsule; understandable given that they were all test pilots, such was their training. It finally came to pass during the Gemini VIII mission that an operator initiated escape hatch was installed in the landing capsule, such that the astronaut could 'blow the hatch' and evacuate the capsule upon splash down, if need be.

It is important to appreciate that heretofore there had not been any clear indication that such a safeguard was necessary as the capsules were water tight and not subject to buoyancy failures up till this time. Nonetheless one was installed in deference to the astronaut's wishes. During the 1965 Gemini VIII mission, Gus Grissom inadvertently detonated the newly installed escape hatch (admittedly a controversial characterization), flooding the capsule resulting in the need for his immediate evacuation. This event was followed by his failure to close his oxygen flow valve to his space suit resulting in the flooding of the very suit that would otherwise have acted as a very serviceable personal flotation device. Subsequently, a failure of procedure very nearly resulted in his drowning when the navy divers misinterpreted his distress signal for elation, as they were focusing their efforts on the recovery of the capsule. Grissom was able to close the valve in his space suit and barely escape a watery death. The Gemini mission was otherwise an unmitigated success, but this unpredictable and uncontrolled interaction of its components and sub-systems upon splash down, very nearly resulted in tragedy. This classic example of a system failure, illustrates how successive component failures can 'pile-up' or accrue to result in a total failure of the larger system; with potential catastrophic consequences. As a generalization, the higher the system interaction (complexity), the more prone are the systems to *system accidents*.

System Coupling

System coupling refers to the degree of connection, dependency or sequencing of components and sub-systems upon one another. Characterized by Perrow (Perrow, 1999) as loose or tight; coupling is a good predictor of the speed in which a failure scenario unfolds, or perhaps more precisely the lack of opportunity for intervention and mitigation. Tightly coupled systems are typically found in process control environments (the nuclear industry being a prime example) and often the sequencing of components or sub-systems occurs at a speed and scale offering little intervention on behalf of operators. In fact, in many instances observations of these interactions are restricted to indirect means such as the measurement of physical parameters or the opening or closing of a valve. In comparison, loosely coupled systems (the mining industry) are characterized as affording the operator a direct knowledge as to the realities unfolding as well as some opportunity to respond, substitute or re-sequence the tasks. As such, loosely coupled systems tend to be lesser candidates for system accidents.

The nuclear power industry is the extreme example of tight coupling. By necessity, nuclear power installations rely upon incredibly complex interactions of chemical, electrical, instrument and process flow systems. At stake, is the potential contamination of thousands of square kilometers of land and the exposure of untold tens of thousands of people occupying within its influence. The coupling of the sub-systems and components within nuclear power facilities is largely centrally controlled through process control feed back loops that incorporate fail-safe, parallel and redundant sub-systems. Unfortunately, many of the critical components comprising these sub-systems such as cooling circuits and emergency shut down devices cannot be directly monitored owing to their lethality. Operators instead, rely upon instrumentation that indirectly reports functionality of components in the form of parameters. Operators must in turn interpret these parameters to determine the status of a myriad of components and sub-systems, any one of which can fail and not be directly observed.

The operators are forced to 'model' based upon observed parameters in the vain hopes that their 'models' are correct and the correct action can be initiated to correct a failing or failed component. Unfortunately, the tightly coupled sub-systems do not allow for much time for diagnosis, much less remedy. In this particular industry errors on behalf of operators are extremely unforgiving; so much so that the errors compound and interact with the compromised components in unpredictable ways; ways that cannot be reversed and seemingly conspire toward a complete system failure.

Three Mile Island

Such is the case on a dark day in history for the nuclear power industry when in on March 29th, 1979 the Three Mile Island nuclear power plant near Harrisburg Pennsylvania, came perilously close to experiencing the first nuclear 'melt down' in the history of the industry. The technology and mechanics of the disaster are extremely complex and therefore the cause and effect relationships will not be covered in detail. In his treatment of the subject, Perrow (1999b) provides us with some the salient facts concerning the cognitive processes of the operators. Essentially, a variety of components (4) failed in non-sequential and unpredictable ways; that is, one failure did not cause the failure of another, some of the failures were latent and had other failures not occurred, would not have been detected, much less result in catastrophe. Valves that were supposed to be open were inexplicably closed, a leaky seal, moisture contaminated instrumentation and a plugged condenser all were at the heart of the issue and interacted in unpredictable ways that baffled the operators and were not considered by the designers. The operators failed to notice an obscured indicator light, a second indicator light failed and operators assumed a pipe breakage as the cause of what they were interpreting as a process-upset condition.

Things were going from bad to worse as the operators were interpreting the parameters that they were observing from their instruments in the light of what they thought was happening (cognitive modeling). They ended up intervening in exactly the wrong way, exacerbating the problem and critically exposing the nuclear core. The incomprehensibility and confusion of the scenario is captured in the testimony of a supervisor (Perrow, 1999c):

> I think we knew we were experiencing something different, but I think each time we made a decision it was based on something we knew about. For instance: pressure was low, but they had opened the feed valves quickly in the steam generator, and they thought that that might have been 'shrink'. There was logic at this time for most of the actions, even though today you can look back and say, well, that wasn't the cause of that, or, that shouldn't have been that long.

Perrow points out that the supervisor's dilemma is not unusual in normal or system accidents. In times of uncertainty, we are all trained to use our best judgment based upon experience, knowledge and instincts. What is interesting is that with the possible exception of one or two of the decisions leading up to the critical *event* (exposed core), nearly all of the erroneous decisions could be characterized as errors of mistaken belief. That is, the decisions that were being made by these highly trained specialists in their field were wrong and in many cases they had no idea that a boundary condition had been transgressed that, had they known would have resulted in totally different actions and outcomes on their behalf. Had the assumptions they were making been correct, then yes, there actions may very well have remedied the situation and the catastrophe averted. Yet, these were engineers, technologists and professionals all; their errors of mistaken belief speak of a fundamental lack of understanding of the processes over which they had dominion. How could this be? What cultural context could account for such a widespread and wholly inadequate ability of the operators to correctly interpret and manage the failing systems at Three Mile Island?

Profile of a System Failure

Perrow (Perrow, 1999) offers a number of explanations for the outcome of system accidents such as Three Mile Island, as well as a prediction. First, he makes the not surprising observation that the nuclear power industry is a young industry relatively speaking, and that in comparison to the chemical industry (two centuries of operational experience) the nuclear power industry was barely in its third decade at the time of Three Mile Island. Quite simply, the nuclear power industry is inherently inexperienced or immature, point of view of operational experience. The erroneous decisions of the operators were quite clearly a natural consequence or product of a much larger problem; a problem rooted in the absence of cognitive insight into nuclear technology. Perrow quite correctly arrives at this conclusion from another direction; nuclear incident records. In a 1980 Nuclear Regulatory Commission review of operating plants, 29% were found to be operating sub-standard to regulatory requirements of the day. Perrow (1999d) writes:

> It possibly the most dangerous industrial activity that humans have yet to engage in, the study described the twenty-one "below average" facilities in numbing, repetitive terms: inadequate technical staff, insufficient training, poor supervision, failure to follow procedures, radiation protection weaknesses, incomplete license event reports and failure to consider their implications, unmonitored and uncontrolled release of airborne radioactive material, non-compliance with quality assurance programs, inadequate control over solid and liquid radioactive waste, repetitive equipment problems, inadequate fire protection, failure to meet commitments made to the NRC, "repetitive instances of system misalignments, impaired ECCS equipment operability and containment integrity", personnel overexposure, and longstanding and uncorrected design problems.

Perrow takes the point further and provides excoriating evidence within the remaining 'average' nuclear plants that similar conditions are common. Based upon these observations and his insight into normal accidents system failures, Perrow makes the prediction that the nuclear power industry is a strong candidate for further catastrophes. Further, as a high-risk industry, the nuclear power industry represents the worst of two worlds; it is both highly complex and tightly coupled. Other industries that share this dilemma are: genetic engineering, nuclear weapons systems and aviation. As a profile, these industries share the some *event* characteristics, summarized in the following table.

	Event Characterization
1	Initial incomprehension about what was initially failing
2	Failure are hidden and even masked
3	A search for *de minimus* explanation, since *de maximus* explanation is inconceivable.
4	An attempt to maintain production, if at all possible.
5	Mistrust of instruments, since they are known to fail.
6	Overconfidence in ESD's and redundancies, based upon normal experience of smooth operation in the past.
7	Ambiguous information is interpreted in a manner to confirm initial (*de minimus*) hypothesis
8	Tremendous time constraints, in this case involving not only the propagation of failures, but the expending of vital consumables.
9	Invariant sequences, such as the decision to turn off a sub-system that could not be restarted.

Table 11.2: Table summarizing the event characteristics of system failures (Perrow, 1999e).

What is to be done?

To the extent that a facility, enterprise or industry adopts overly complex or tightly coupled systems, a remedy to avoid *system accident* type *events* would appear self-evident - move toward loosely coupled and more linearly interactive systems. Perrow (1999f) provides a summary in which this objective can be achieved in theoretical terms (Table 11.3).

Summary of System Failure Characteristics (Perrow, 1999f)

Complex Systems	**Linear Systems**
Tight spacing of equipment	Equipment spread out
Proximate production steps	Segregated production steps
Many common mode steps not in production sequence.	Common mode steps limited to power supply/environment.
Limited isolation of field components	Easy isolation of field components
Personnel specialization	Less personnel specialization
Limited substitution of supplies and materials.	Extensive substitution of supplies and materials.
Unintended or unfamiliar feedback loops.	Few unintended or unfamiliar feedback loops.
Many control parameters with potential interactions.	Control parameters few, segregated and direct.
Indirect or inferential information sources.	Direct, on-line information sources
Limited understanding of some processes.	Extensive understanding of some sources.

Tight Coupling	**Loose Coupling**
Delays in processing not possible	Processing and delays possible
Invariant sequences	Order of sequences can be changed
Only one method to achieve goal	Alternate methods available
Little slack between supplies, equipment or personnel.	Slack in resources available
Buffers and redundancies are deliberate and designed-in.	Buffers and redundancies available
Substitutions of supplies, equipment, personnel limited and designed in.	Substitutions fortuitously available

Table 11.3: Complex versus linear and tight versus loose coupling parameters, (Perrow, 1999f).

Error Inducing Systems

Perrow is careful to establish that while different industries share common characteristics of system interaction and coupling when experiencing *system failures,* they are disparate in terms of organization, regulation and risk aversion. A case in point is the maritime shipping industry, a dissident industry in terms of it's record, the maritime shipping industry within the United States stands out as the one industry in which the statistics are getting worse. Perrow (1999g) writes:

> The average number of ship accidents per year has been rising for decades. From 1970 to 1979 those involving only commercial vessels in U.S. waters rose 7 percent annually – from 2,582 to 4,665. The 1979 figures are 81 percent higher than the 1970 figures. The ton-miles also rose, but only by 6 percent a year; the 1979 was only 33 percent higher than the 1970 figure, going from 306 billion ton-miles to 409 billion. The best measure, the accident rate per ton-mile, increased 74 percent over the decade.

Here then is an industry; in existence for virtually a millennia, subject to international law and standards like any other; accessible to anti-collision systems, radar, metrological prediction and on board navigational systems as its aviation counterpart; yet experiencing what can only be described an unacceptable safety record. Perrow introduces us to the term *error inducing system* in part it is presumed, as an explanation for this wayward industry. Complicit in this *error inducing system* (the maritime shipping industry), are:

1) The maritime organizations that resist and evade international law and operational standards.
2) The federal regulatory agencies that repetitively investigate and make recommendations for improvement but who appear reluctant to intervene and sanction to the extent evident in other industries.
3) The ship operating companies who give in to production pressures over maintenance and safety issues.

4) The insurance companies that do not offer any incentive or require that shipping companies inspect or survey for 'fit for purpose'.
5) The ships masters (Captains) do not support with 'data recorder' systems or in some cases ships logs.
6) The crews themselves who are inculcated to believe in the absolute authority of the Captain, often to the detriment to all on board.

Decision Error Theory as a Predictive Model

There can be little doubt that there are strong organizational, cultural and historical biases that do not serve the maritime shipping industry well in terms of the safety record. It is suggested by this author that were we to examine the accident record of the maritime shipping industry under the lens of the decision error theory and Cognitive Patterning model, we would observe a revelation. It is predicted that the analysis would reveal shipping companies and individual crews highly disposed to errors of commission; where standards are discretionary and the seniority and tradition trump all but the Masters omnipotence. Further, it is predicted that such decisions flow from a culture of cognitive dissent in which erroneous decisions are supported if not cultivated by the complicit parties identified previously.

The Socialization of Risk

A second industry sector for which *events* are on the increase is the petrochemical industry. Perrow provides the caveat that this may be more a consequence of the increasing activity and diversity of within the industry, but none the less, there are apparently more fires and explosions within the industry than previously was the case. Competitive pressures being a huge error-inducing element in any industry, appear to be making insidious inroads in the petrochemical industry. This is manifested in a number of ways. Downsizing, out-sourcing and contracting-out are the principle means by which the petrochemical industry is responding to global competition and reducing costs in a bid to become more competitive. The result, Perrow posits, is being borne by the workers who increasingly are ill suited to the demands imposed upon them. Perrow (1999h) cites other researchers when he writes:

> Perron and Friedlander, reviewing accidents in the industry from the point of view of downsizing consequences show how downsizing, by increasing worries and work pressures and overload, changes the way employees interact and communicate critical information to each other, and how they can fail, under these pressures, to understand the systems they are trying to control (Perron and Friedlander 1996)

Human Factors Penalty

The phenomena of socializing risk is all too common in many industries, companies having identified high risk enterprises or tasks such as shut-downs and maintenance turn-around, attempt to contract out the risk, thus obviating the insurance and regulatory implications. However, those individuals left to carry out the work are often not as suitable, trained or competent to stand up to the rigors of the work demands and can easily fall victim to incomprehensibility, so far as identifying and mitigating risk is concerned. There is a penalty to be paid for the socializing risk, and that penalty is a human factored one borne by individuals who may be more prone to error, thus contributing to *system failure*.

Once again, were the accidents within the petrochemical industries to be analyzed using the decision error theory and Cognitive Patterning model, it is suggested that the results would be quite predictable. It is predicted that this scenario within the petrochemical industry would be pre-disposed to errors of omission due to the shear volume of demands placed upon the operators and their inability to reconcile production pressures and safety standards of operation. These operators are likely to be subjected to cognitive deferral, and would be overwhelmed on occasion by the immediacy of operational stimulus, thus rendering their decisions particularly susceptible to Perrow's observation of 'incomprehensibility'. Further, their ability to integrate and interpret information would be seriously compromised, making them prime candidates for hidden and unanticipated interaction with component failures; possibly culminating in system failure.

Discussion

Perrow's examination of *system accidents* provides a rich and insightful understanding as to the interactions of man, machinery and systems during sub-optimal conditions. Perhaps, this is the subtle lesson of *system accidents*, that while we live and work in a world subject to error, we design our systems for optimal conditions. Inevitably, as is implied by Perrow's reference to *Normal Accidents*, systems must degrade and when they do, the interaction between the operator and the degrading systems is unpredictable, to say the least. To the extent that Perrow has correctly analyzed both industries and *events* in terms of system accidents, he has provided the author of this thesis some opportunity to apply some predictive modeling of these accidents based upon the proposed Decision Error theory and Cognitive Patterning model.

Predictions

The following end-members of the Decision Error ternary diagram are suggested:

1) The nuclear power industry are likely to be predisposed to errors of mistaken belief, and report to the 'cognitive deficit' camp of the model.
2) The maritime shipping industry is likely to be predisposed to errors of commission, and report to the 'cognitive dissent' camp of the model.
3) The petrochemical industry is likely to be predisposed to errors of omission, and report to the 'cognitive deferral' camp of the model.

Chapter 12: Conclusions

There is no room for accidents by misadventure, particularly in the workplace; the airways; the highways or any other place where we as a society bring together people, processes and materials for the purpose of enterprise. *Events* represent our collective fallibility as architects of enterprise, the not so subtle reminder that our reliance on standards and procedures has no dominion over the immutability of laws of physics, of nature. Neither are *events* inevitable; this adjective is better applied to our own behaviors as we incessantly try to walk that fine line between risk aversion and entrepreneurial zeal.

Industrial *events* and the scenarios that produce them are processes; processes that are both unintentional and tragic, but processes none the less. They have a beginning, middle and an end. Until recently, we have failed to recognize this and in our anxiety to forestall the end have overlooked the beginning – the origins of error. Machines don't err; materials don't err; only people err. No revelation here, but perhaps we have taken this statement of the obvious on face value for too long. Is it just the individuals who err; can and do groups err; and if they do, is there a cultural context in which this error-type thinking is nurtured; can propagate?

The study of *events* in our industrial and public transportation sectors has grown from a minor field of some curiosity in the early years to a very specialized discipline with far reaching implications concerning how we implement technological innovations; how we harness our industrial might: how we manage.

This thesis introduces the reader to some of the foremost models, methodologies and authors in the field of accident causation. There is broad agreement that the investigation of *events* requires some innovation and rejuvenation, particularly as regards to standards, methodologies and quality control. Whereas the author does not presume to have a solution to contribute to this shortfall, a proposal in terms of how to generate more dialogue and interest in the matter is offered.

The first step is to establish some language of causation that forms a basis, a lexicon if you will - of *event* causation. When we can apply more precision and similitude in how we talk about event causation, we can better debate the substance of the matter on more of an equitable basis. Next we need to draw upon the largest untapped resource to date; the investigations themselves.

Much has been made within the context of management systems, of analyzing *events* to determine trends and common occurrences. To the extent that this is an obvious undertaking, it is still not a common practice; certainly not a well established analytical process. This thesis proposes an audit protocol and instrument designed to evaluate *event* investigations; the purpose of which is to promote the quality, veracity and efficacy of investigations as processes.

There are two expected outcomes of auditing *event* investigations. First, only through evaluation and oversight will sufficient attention be garnered respecting the investigation of industrial *events* to generate convergence of investigation theory and practice and to galvanize stakeholders into establishing standards. Second, it is perhaps timely to introduce the next generation of analysis, to open the door a little bit towards predictive models and methods for the characterization of those cultures or organizations in which industrial *events* are occurring; indeed are likely to occur. To date, considerable progress has been made within the investigative process itself to try and 'get at' those causal determinants that, at the heart of the matter owe their provenance to the human factors class of errors. Presumably, investigations benefiting from these models have identified the human factors and thereby prevented further *events*. Yet there is a sub-class of human factors that appears to elude us; partly as a consequence of our lack of insight; partly for lack of intent - decisions. Decisions are events. As events, they are potent executors of will, or the lack of it. This thesis proposes a theory that all decisions that have a priori been determined through the process of investigation to be contributory to accidents can be classified as being: errors of commission, errors of omission or errors of mistaken belief. In so far as this is true, there must be a reason or some mechanism in force behind it. This paper also proposes that the mechanism behind decision errors resulting in *events* is rooted within the culture of an organization (or industry) and that this cognitive patterning of persons within its influence can be determined through analysis of the investigations of *events*.

The method for achieving this is the Boundary Condition and Decision analysis, which once having been applied to the results of an audit of investigation(s) will yield some insight in terms of the *event* under investigation, moreover will yield some insight into the cognitive context of the organization in which the *event* transpired. Organizations support and promote cognitive patterns, both advertently and inadvertently. The inadvertent patterns are the ones that escape notice and often, it is surmised, become the fertile grounds for cognitive processes that have detrimental influence on decisions and those that make them.

Cognitive dissent, cognitive deferral and cognitive deficit are three such patterns presented within this thesis that may have strong governance over decisions of persons unaware of their influence. Further, a direct linkage is suggested between the decision errors exhibited in *event scenarios* and these cognitive patterns. It is proposed that errors of commission are a product of a culture in which cognitive dissent is condoned; a culture which promotes the right of workers to elect to disregard rules, standards or norms on the rationale that better interests are served. It is proposed that errors of omission are a product of cultures in which cognitive deferral is common; a culture that expects too much of their workers as regards to their mental acuities and in so doing, deprives them of their decision making efficacy. It is proposed that errors of mistaken belief are a product of a culture in which cognitive deficits are common; a culture in which rules, standards and norms have not been sufficiently developed or disseminated; to the detriment of both the workers and the organization.

The author does not lay claim that there is a body of evidence, as yet, that directly supports the correlation of decision errors with cognitive patterns; rather, opens the door for further investigation and research into what promises to be a fascinating and revealing field of interest within the discipline of *event* causation theory.

Opportunities for Further Research

The following recommendations are made for consideration by the University of Alberta, organizations or persons, interested in further investigating the relationships between organizational cognitive patterns and decision errors contributing to industrial *event* scenarios:

1) It is recommended that as a possibility for further research, consideration be given to applying the proposed Boundary Condition and Decision analysis to a large selection of industrial events within diverse and known corporate cultures. With a sufficiently large database of boundary conditions and a comprehensive analysis of event decisions, the author is confident that strong correlations will exist between the decision errors and cognitive patterns.
2) It is recommended that organizational psychologists be consulted as to the validity and relevancy of these cognitive patterns. Further, experts in this field could be solicited to propose tests or measures

of these cognitive patterns and the degree to which they influence decisions within the operational theatre.

3) It is recommended that consideration be given to expanding on post investigation analysis of industrial events beyond the audit protocol and instrument proposed herein, with the intent of developing more methods and methodologies in which causal determinants and precursors to industrial events can be discerned.

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Appendix I: Supportive Documents

Appendix I(a): Investigative Technique Analysis by Livingston, 2001

SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12
MORT	Public	Nuclear	>20	Y	Y			Y	Y		Y	
SRP	Unknown	Nuclear	>5	Y	Y	Y	Y	Y	Y	Y	*	
TapRooT™	Proprietary	General	<5	Y	Y	Y	Y	Y	Y	Y	*	
HPIP	Unknown	Nuclear	<5	Y	Y			Y	Y			
HPES	Proprietary	Nuclear	>10	Y	Y			Y	Y	Y		
SCAT	Proprietary	General	>10	Y		Y	Y	Y	Y		#	
TOR	Proprietary	General	>20			Y	Y			Unknown	Y	
SACA	Public	Offshore	>5			Y	Y		Y			Y
CAUSAL TREE	Proprietary	Chemical	>15			Y	Y			Y		

Is the system publicly available?
2. What industries has the technique been applied in?
How many years has the technique been in existence?
4. Is it a structured methodology?
Is a schematic diagram drawn first?
6. Is this a stand alone technique (i.e. not part of a battery of diff methods?

Can the method be summarised on 2 sides of A4?
8. Is there supporting documentation for analysts?
Can this method be applied by a single analyst?
10. Is the training requirement less than 2 days?
Is the emphasis on organisational arrangements rather then human performance?
12. Developed in the UK?

...ers management issues and equipment issues although there is a focus on human performance
...eral management, although goes into detail on human performance issues

Appendix I(b): Investigative Methodology Analysis by Benner

(Benner, 1985)

TABLE 4
CRITERIA FOR ACCIDENT INVESTIGATION METHODOLOGY EVALUATION

CRITERIA	REQUIREMENTS
Encouragement(1)	investigation methodology promote *harmony* by encouraging parties to participate in investigations and have their views heard, minimize conflict by disclosing gaps in the investigation, and efficiently but harmoniously control the presentation of individual views with appropriate technical disciplining techniques during the investigation? 2(b)(1)
Independence(2)	Methodology must produce blameless outputs: Does the investigation methodology identify the full scope of the accident, including the role of management, supervisors, and employees in a way that explains the effects and interdependence of these roles in the accident without imputing blame, fault, or guilt?
Initiatives(4)	Methodology must support personal initiatives: Does the methodology provide for positive descriptions of accidents that show convincingly what is needed to achieve adequate control of risks in a specific workplace, in a way that promotes informed and valid individual initiatives, without unnecessarily conveying blame, fault, or guilt?
Discovery(6)	Methodology must support timely discovery process: Is the investigative methodology able to discover safety and health problems when applied to these problems areas? Does methodology enable timely discovery, or must discovery be delayed until credibility of sample sizes and casualty requirements are met?
Competence(8)	Methodology must increase employee competence: Does the investigation methodology provide direct inputs that will increase the competence and safety effectiveness of personnel through training in the detection, diagnosis, control, and amelioration of risks? Are outputs resulting from the application of this investigative technology being used in training with demonstrable safety effectiveness?
Standards(9)	Methodology must show definitive corrections: Does the investigation methodology provide a timely, comprehensive, credible, and persuasive basis for establishing or reviewing efficacy of safety and health standards? Does it document accidents in a way that countermeasure options can be systematically defined, evaluated, and selected, avoiding personal opinions and judgments during multiple reviews for this purpose?
Enforcement(10)	Methodology must show expectations and behavioral norms: Does the investigation methodology support the required enforcement program by providing information about perceptions of duties under a standard, its practicality, and its effects on risk levels by (a) defining the degree of compliance or nature of compliance problems and (b) showing the role of a standard in a specific accident in a way that objective observers can trust and rely on?
States(11)	Methodology must encourage States to take responsibility: Does the investigation methodology encourage States to fulfill their occupational safety an d health mandates by providing them practical ways to produce consistent, reliable accident reports, pretested for completeness, validity, and logic before they are submitted, thus multiplying the effectiveness of their contributions?
Accuracy(12)	Methodology must help test accuracy of outputs: Does the methodology describe each accident in a way that can be technically "truth-tested" for completeness, validity, logic, and relevance during the investigation, to assure the quality of the information in each case?
Closed Loop (Sec. 26) Methodology must encourage harmonious participation: Does the	Methodology must be compatible with "pre-investigations" (or safety analyses) of potential accidents: Is investigation methodology compatible with the pre-investigation or analysis methodologies so those predictions can be used during investigations, so expected vs. actual performance of tasks and controls can be measured or validated by investigations, and so the results can be linked routinely to work flow design improvements?

Appendix I(c): Investigative Model Analysis by Benner

(Benner, 1985)

TABLE 3
CRITERIA FOR ACCIDENT MODEL EVALUATION

CRITERIA	DESCRIPTION
Realistic	Model must represent reality, e.g., the observed nature of the accident phenomenon; model must represent both sequential and concurrent events and their *interactions with time;* model must permit representation of the risk-taking nature of work processes in which accidents occur.
Definitive	Model must define nature and sources of data required to describe the phenomenon; model must drive the investigation and analysis methods, rather than be driven by those methods; model must use definitive descriptive building blocks.
Satisfying	Model must contribute to demonstrable achievement of an agency's statutory mission and not undermine that mission because of technical inadequacies or inability to satisfy agency performance and credibility demands.
Comprehensive	Model must encompass the development and consequences of an accident; model must define the beginning and end of the phenomenon being investigated and lead to complete description of events involved; model must help avoid ambiguity, equivocation, or gaps in understanding.
Disciplining	Model must provide a technically sound framework and building blocks with which all parties to an investigation can discipline their investigative efforts in a mutually supportive manner; model must provide concepts for testing the quality, validity, and relationships of data developed during an investigation.
Consistent	Model must be theoretically consistent with or provide consistency for agency's safety program concepts; model must provide guidance for consistent interpretation of questions arising during an investigation and for consistent quality control of work products.
Direct	Model must provide for direct identification of safety problems in ways that provide options for their prompt correction; model must not require accumulation of a lengthy history of accidents before corrective changes can be identified and proposed.
Functional	Model must provide functional links to performance of worker tasks and work flows involved in an accident; model must make it possible to link accident descriptions to the work process in which the accident occurred; model should aid in establishing effective work process monitoring to support high-performance operation.
Noncausal	Model must be free of accident cause or causal factors concepts, addressing instead full description of accident phenomenon, showing interactions among all parties and things, rather than oversimplification; model must avoid technically unsupportable fault finding and placement of blame.
Visible	Model must enable investigators and others to sec relevance of model to any accident under investigation easily and credibly; interactions described should be readily visible, easy to comprehend, and credible to the public and victims as well as investigators

Appendix II: Completed Field Trial Audit Work Sheet

Section 1: The investigation demonstrates the existence of investigative processes in accordance with the following requirements:

Specified requirement (see protocol)	Evidence	Ref.	
1.1 Have established or defined the 'Need' in terms of objectives, processes or policy regarding the investigation of industrial events.	Yes ✔ No	EVENT	
1.2 Have demonstrated the capability or capacity of being prepared for an event and the subsequent process of investigation.	Yes ✔ No	EVENT	
1.3 Have demonstrated a valid process for the gathering of evidence, data and information.	Yes No X	EVENT	
1.4 Have demonstrated the ability to analyze the evidence, data and information in a meaningful, repeatable and verifiable way.	Yes No X	EVENT	
1.5 Have developed and presented conclusions attributable to the evidentiary record and supportable in terms of reasoning.	Yes ✔ No	EVENT	
1.6 Have evaluated, organized, verified or otherwise analyzed the conclusions with an eye towards validity and certainty.	Yes ✔ No	EVENT	
1.7 Have prepared a comprehensive, complete and definitive investigative report.	Yes ✔ No	EVENT	
1.8 Have compiled recommendations that are ranked and indexed and attribute determinacy.	Yes No X	EVENT	
1.9 Have established corrective action that can immediately ameliorate conditions, prevent recurrence or mitigate an event.	Yes ✔ No	EVENT	
1.10 Have demonstrated the intent and the ability to follow up on the recommendations within the report.	Yes ✔ No	EVENT	
1.11 Have evaluated the investigation process internally (debriefing and soliciting feedback from the participants) and externally (professional colleague, consultant, objective reviewer).	Yes ✔ No	EVENT	
1.12 Have demonstrated the intent and the ability to follow up on corrective action within the report.	Yes ✔ No	EVENT	
1.13 Have demonstrated the intention and the capability to conduct an analysis of investigations, at least once per annum.	Yes No X	EVENT	
1.14 Have available, trained and qualified investigators.	Yes ✔ No	EVENT	

Section 2: The investigation demonstrates accuracy, correctness and truth (veracity) in accordance with the following requirements:

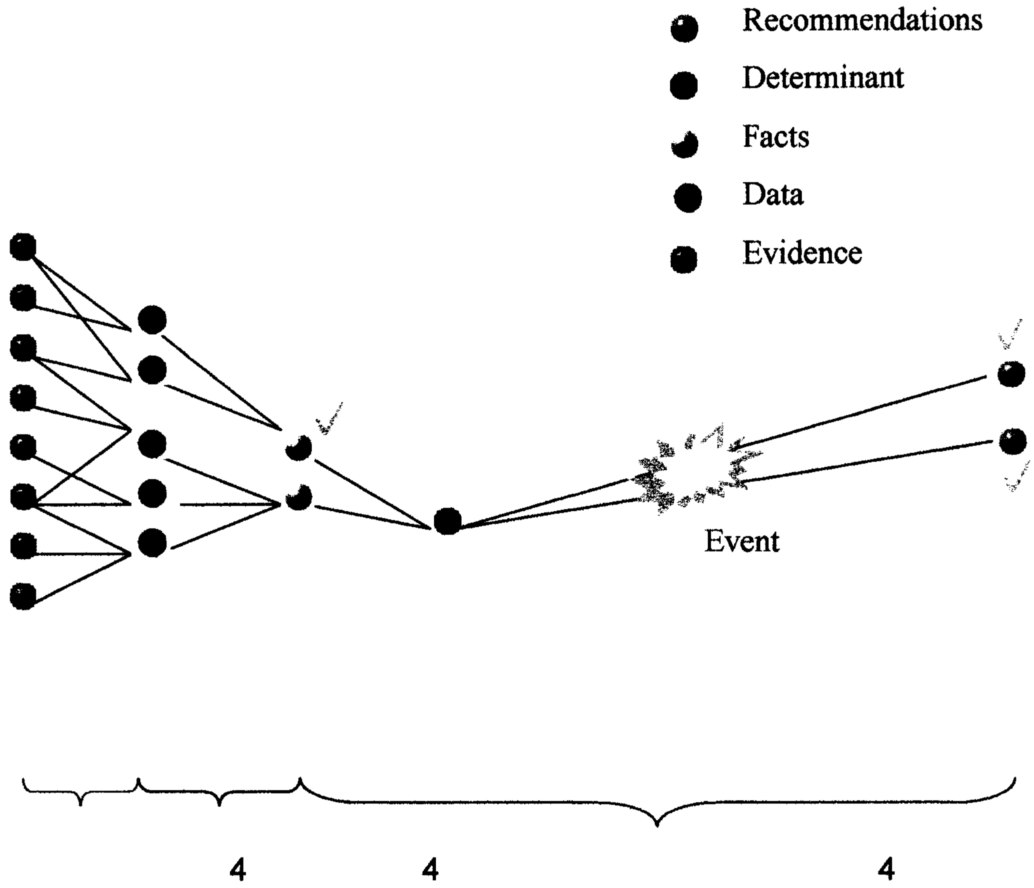
Specified requirement (see protocol)	Evidence	Ref.	
2.14 Recommendations are summarized and codified in a manner that reflects consideration of how they will be carried out; in what order; in what time frame; expediency.	Yes No X	EVENT	
2.13 Recommendations have some connection or link to the determinants established within the causal analysis portion of the investigation and are limited to one-to-one linkages.	Yes No X	EVENT	
2.12 Determinants have been analyzed and subsequently organized in terms of ascendancy of influence, chronology or other scheme that makes sense to the *event* scenario.	Yes ✔ No	EVENT	
2.11 Determinants have been established on the merit of evidence and facts. Do the determinants reflect all of the evidence and facts with no unaccounted-for evidence.	Yes ✔ No	EVENT	
2.10 Facts have been analyzed in terms of their relationship with each other; their sequential nature; their concurrency; their completeness or absence therein.	Yes X No	EVENT	
2.09 Facts have gone through a process of verification or validation in terms of their relevancy; their candidates for inclusion or exclusion or reliability.	Yes No X	EVENT	

Section II (Continued): The investigation demonstrates accuracy, correctness and truth (veracity) in accordance with the following requirements:

Specified requirement (see protocol)	Evidence	Ref.	
2.08 Facts have been organized in such a way that makes sense either to the logistics of the investigative processes (division of labor) or for the purpose of following up leads.	Yes No X	EVENT	
2.07 Facts have been grouped or segregated from data or random information that may have no relevance to the determinacy of causation.	Yes No X	EVENT	
2.07 Data have been transformed from data thought to have promise in terms of relevancy to data that has some merit in supporting or corroborating a theory or fact.	Yes ✔ No	EVENT	
2.06 Data has been validated as having some connection with the established events, actors, actions or decisions.	Yes No X	EVENT	
2.04 Data has been organized in some meaningful way; listed by chronology, source or provenance.	Yes No X	EVENT	
2.03 Data has been collected though some means or method that ensures completeness and chain of custody.	Yes No X	EVENT	
2.02 Evidence has been expeditiously examined, documented, tested and considered for further analysis by persons objective and experienced in investigative procedures.	Yes No X	EVENT	
2.01 Evidence and materials pertaining to the event scenario is under the command and control of the investigators and that the evidence has been secured in order of perish ability.	Yes No X	EVENT	

Incident #1: Tailings Line Sanding Incident: July 14, 2003

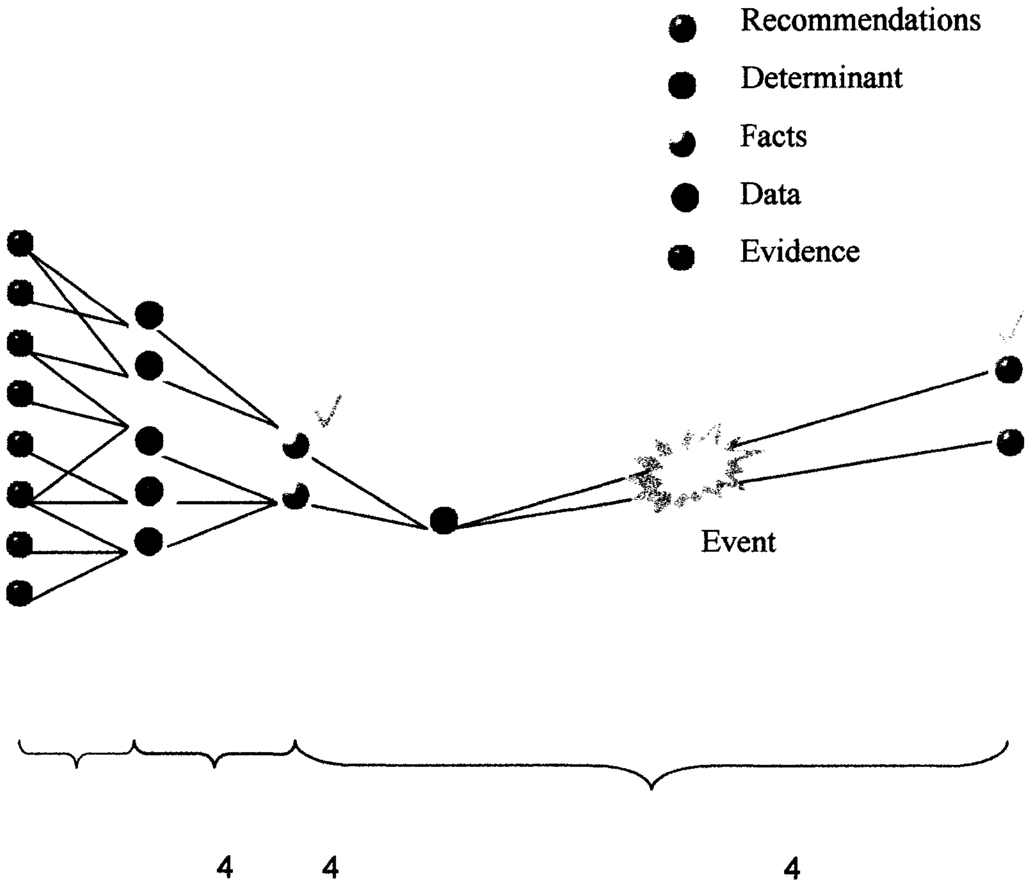
<u>Determinant #2</u>: Panel Operator overload



Score: 3 out of 4

Incident #1: Tailings Line Sanding Incident: July 14, 2003

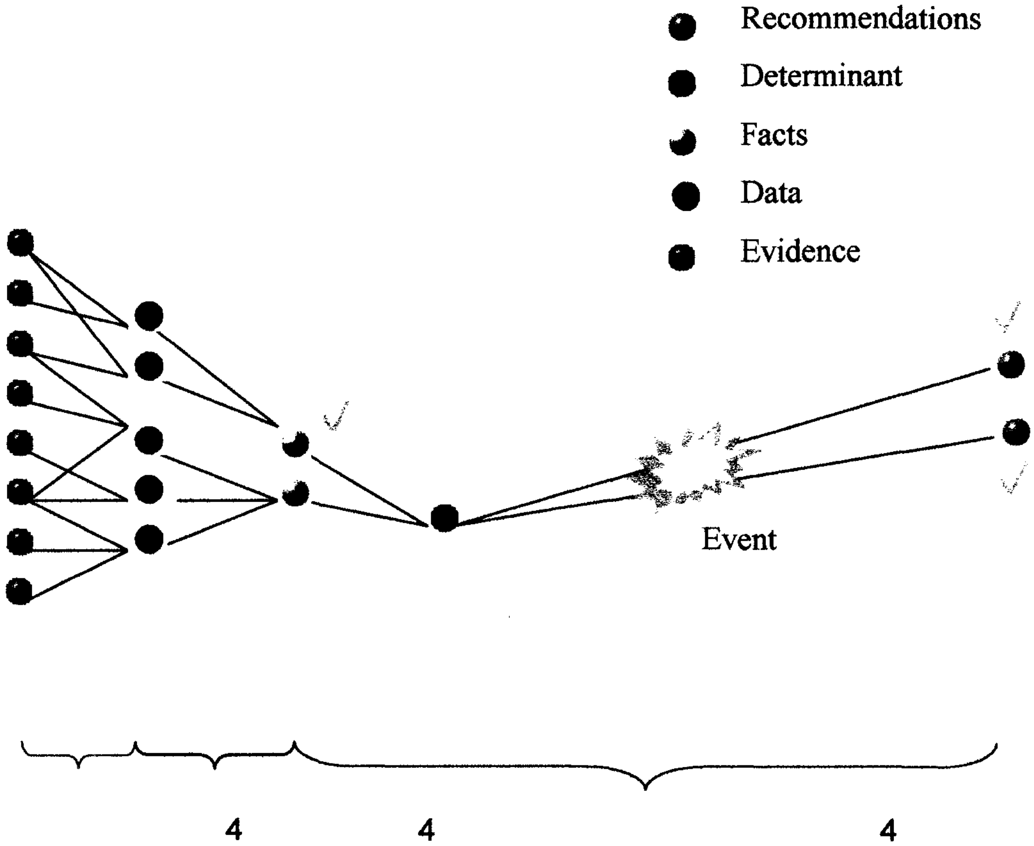
<u>Determinant #2</u>: Information was not fully communicated between the operating team and the fixed plant team leader concerning current plant status on day shift.



Score: 2 out of 4

Incident #1: Tailings Line Sanding Incident: July 14, 2003

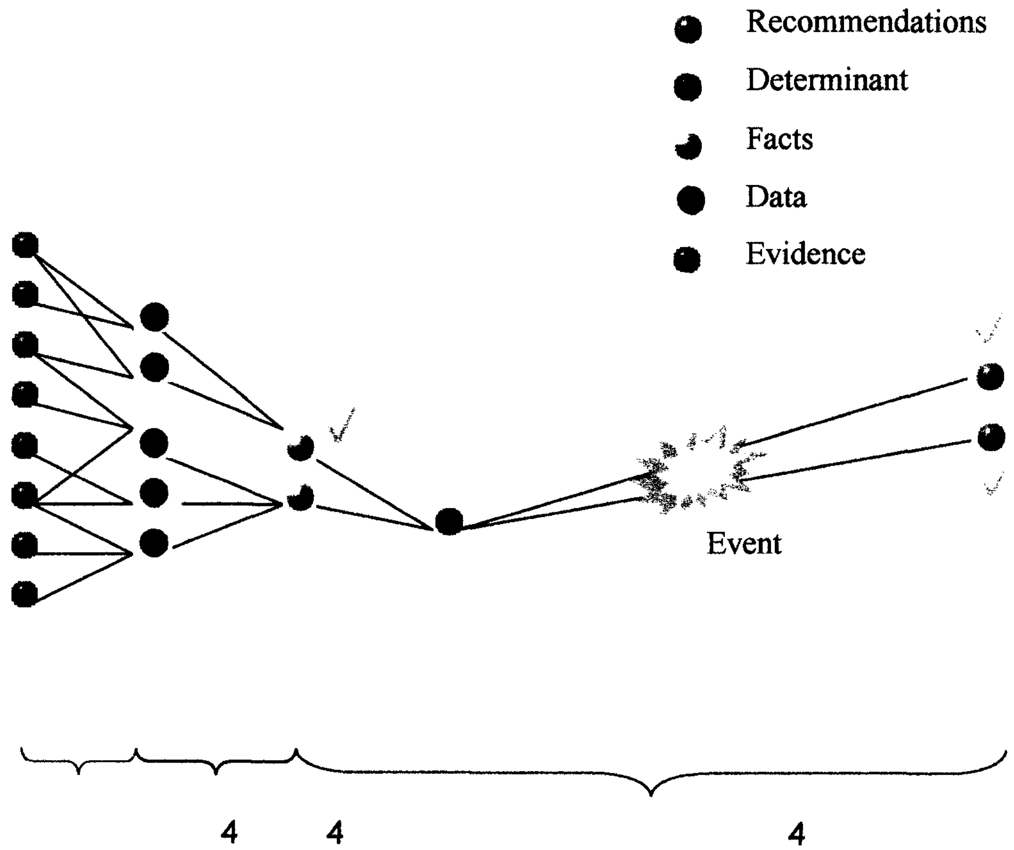
Determinant #3: The mining dispatcher had a deficit of knowledge concerning sole-sourcing the course material.



Score: 3 out of 4

Incident #1: Tailings Line Sanding Incident: July 14, 2003

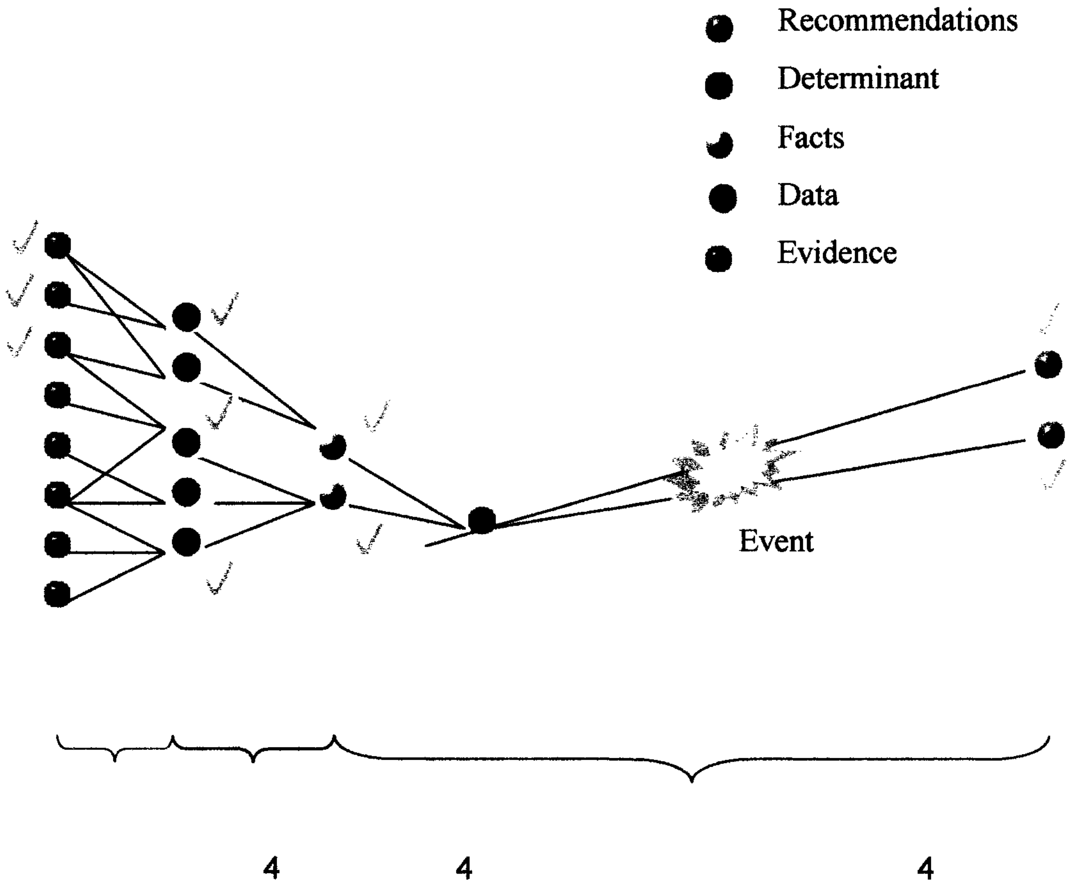
Determinant #4: The panel operator displayed an operating bias toward ore tonnage as opposed to ore grade.



Score: 3 out of 4

Incident #1: Tailings Line Sanding Incident: July 14, 2003

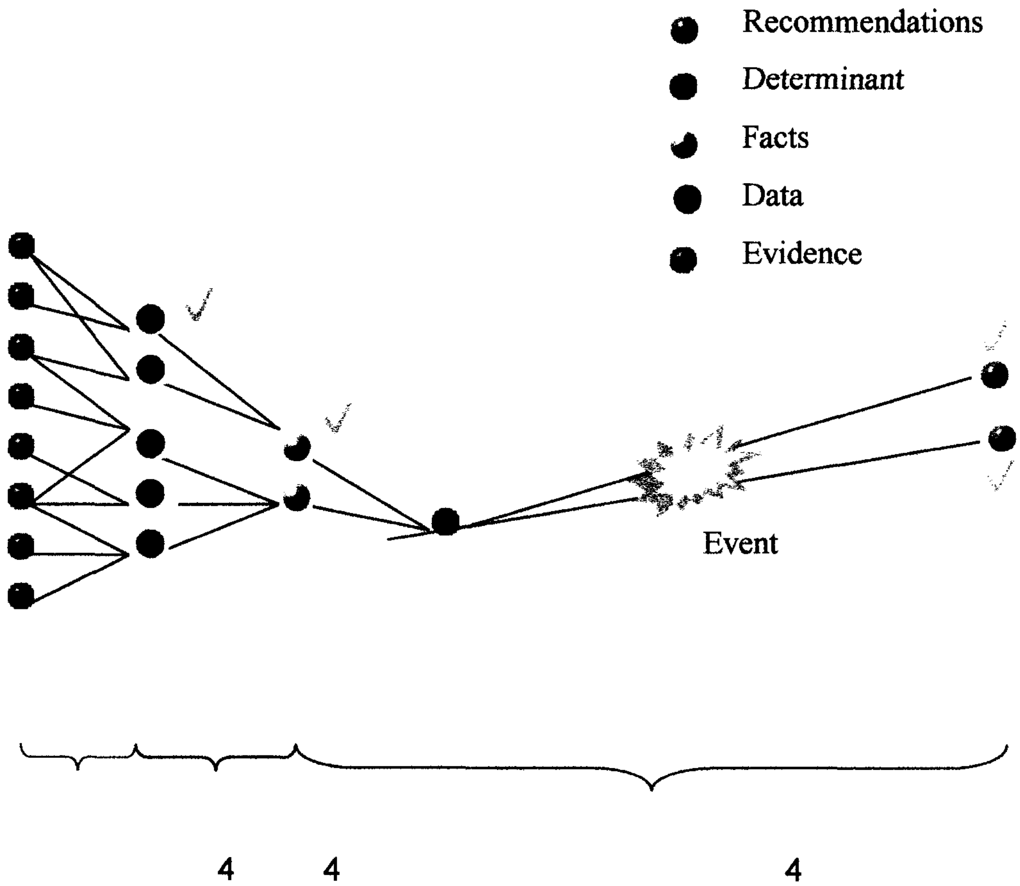
Determinant #5: The d50 passing size criteria of Train 1 was greater than 450 um; in excess of the 300 um design size.



Score: 4 out of 4

Incident #1: Tailings Line Sanding Incident: July 14, 2003

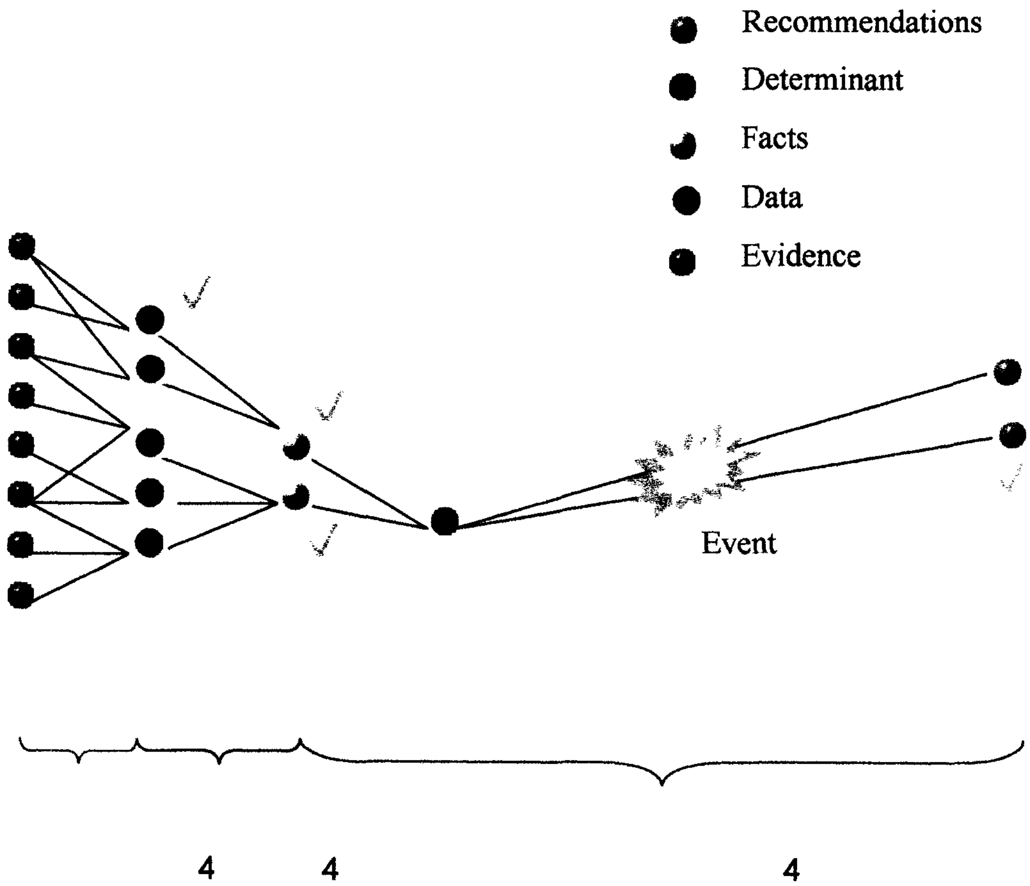
<u>Determinant #6</u>: The unscheduled delivery of 16 consecutive truck-loads of base of feed with very low fines – 14%.



Score: 3 out of 4

Incident #2: Electrical Contactor/Switch Explosion: October, 2000

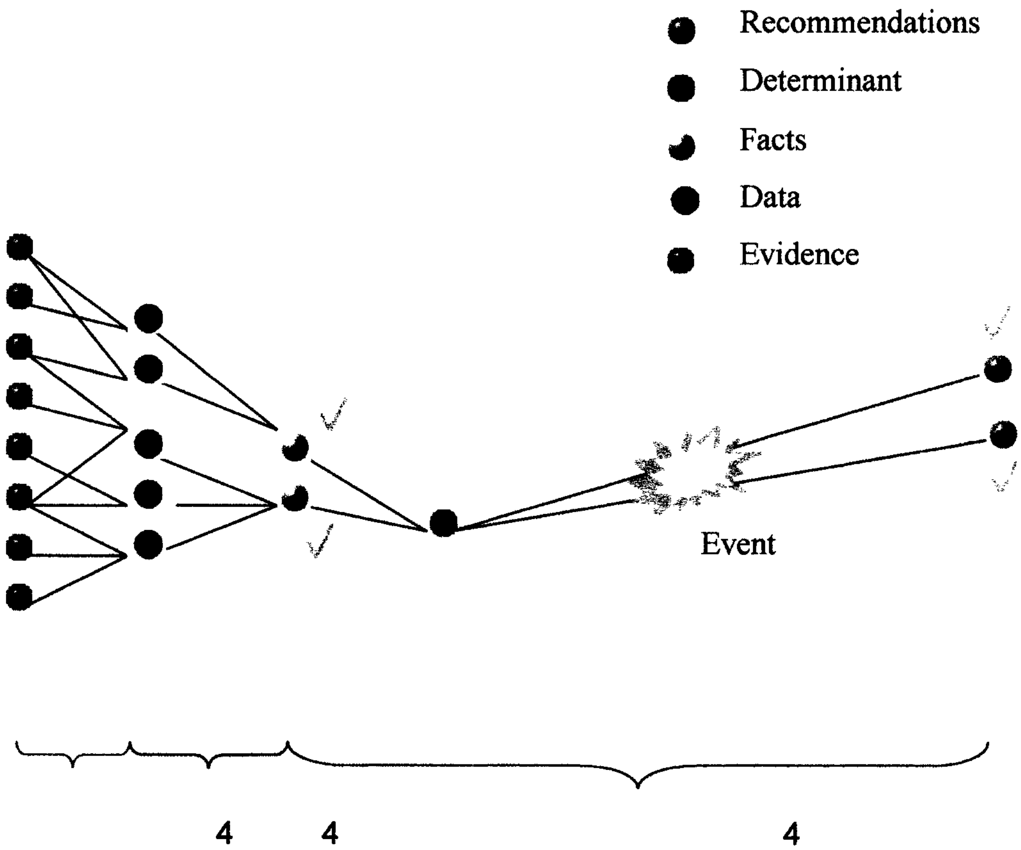
Determinant #1: Deficit procedures not followed.



Score: 3 out of 4

Incident #2: Electrical Contactor/Switch Explosion: October, 2000

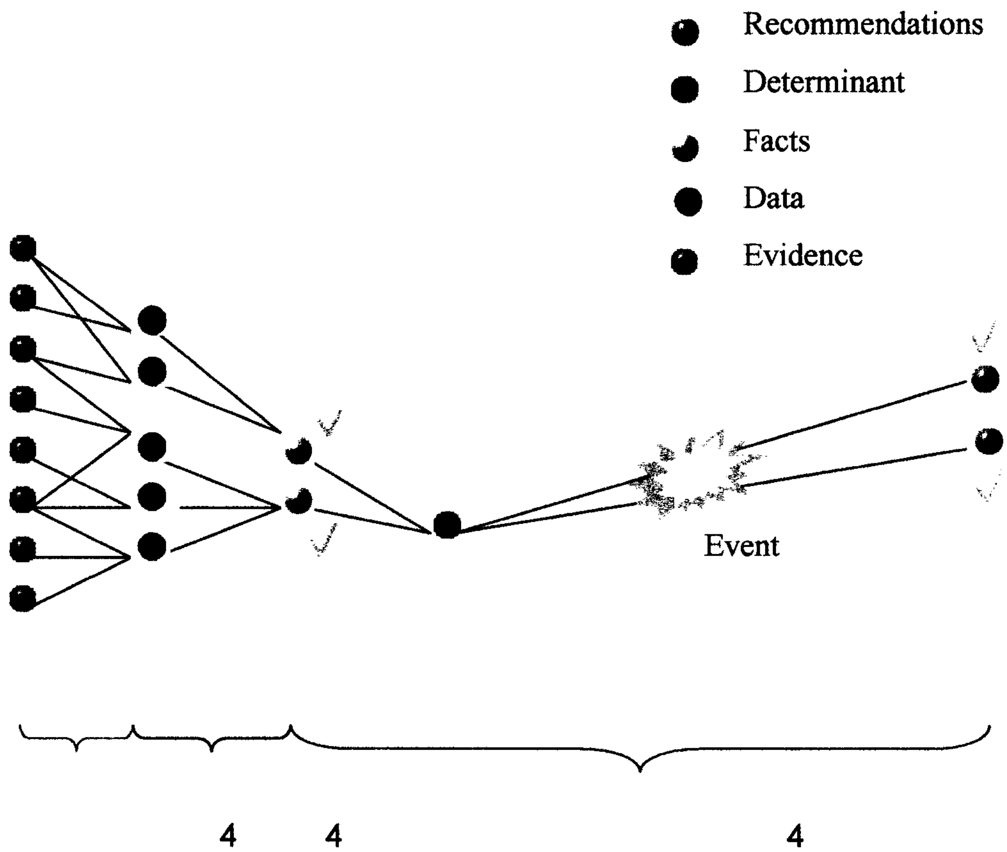
Determinant #2: Failure of the interlock/mechanical linkage.



Score: 4 out of 4

Incident #2: Electrical Contactor/Switch Explosion: October, 2000

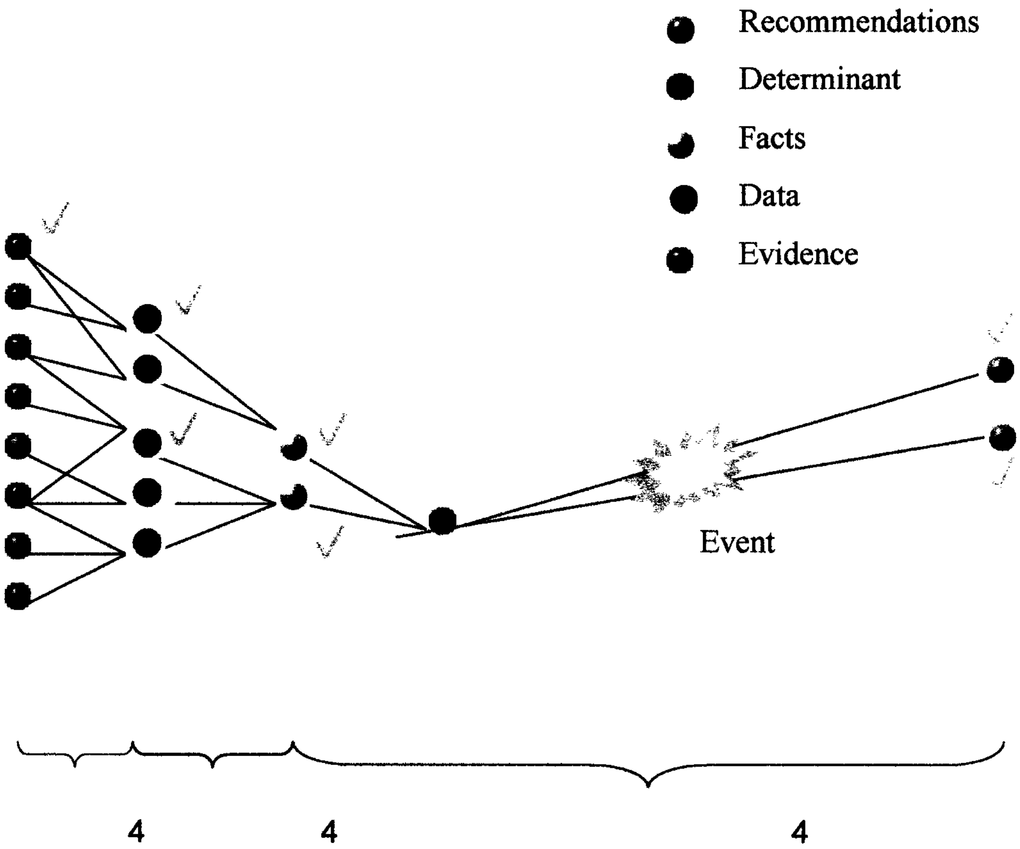
Determinant #3: Deficit switch opened under load.



Score: 4 out of 4

Incident #3: Primary Separation Vessel Incident: January, 2003

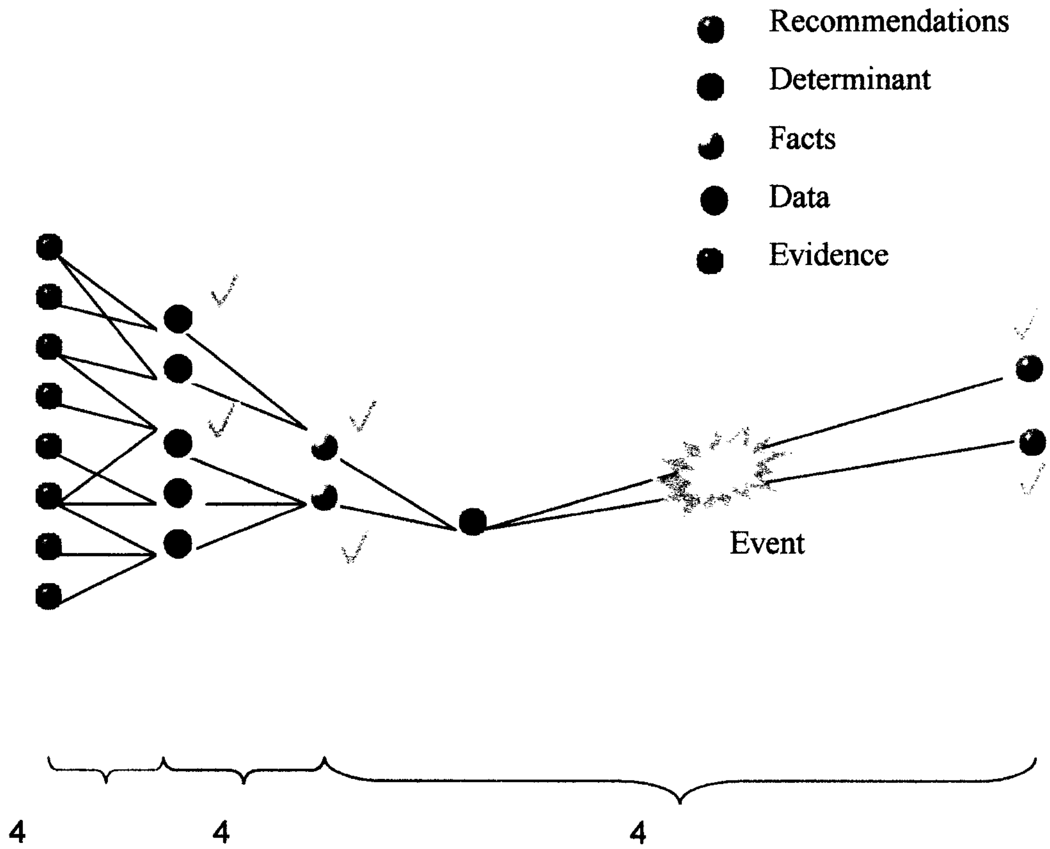
Determinant #1: Thinning of the base metal of the exposed ¾" PSV vessel wall by erosion/corrosion.



Score: 4 out of 4

Incident #3: Primary Separation Vessel Incident: January, 2003

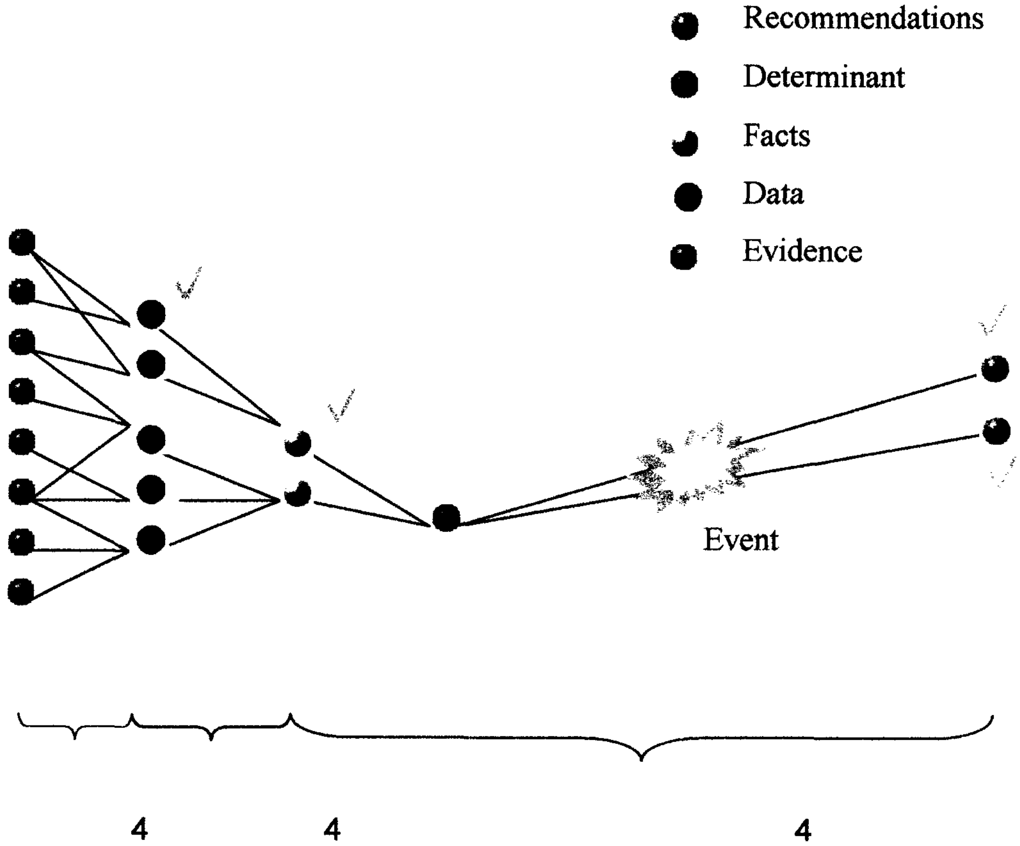
Determinant #2: The lack of understanding of the potential to experience wearing of the PSV vessel.



Score: 4 out of 4

Incident #3: Primary Separation Vessel Incident: January, 2003

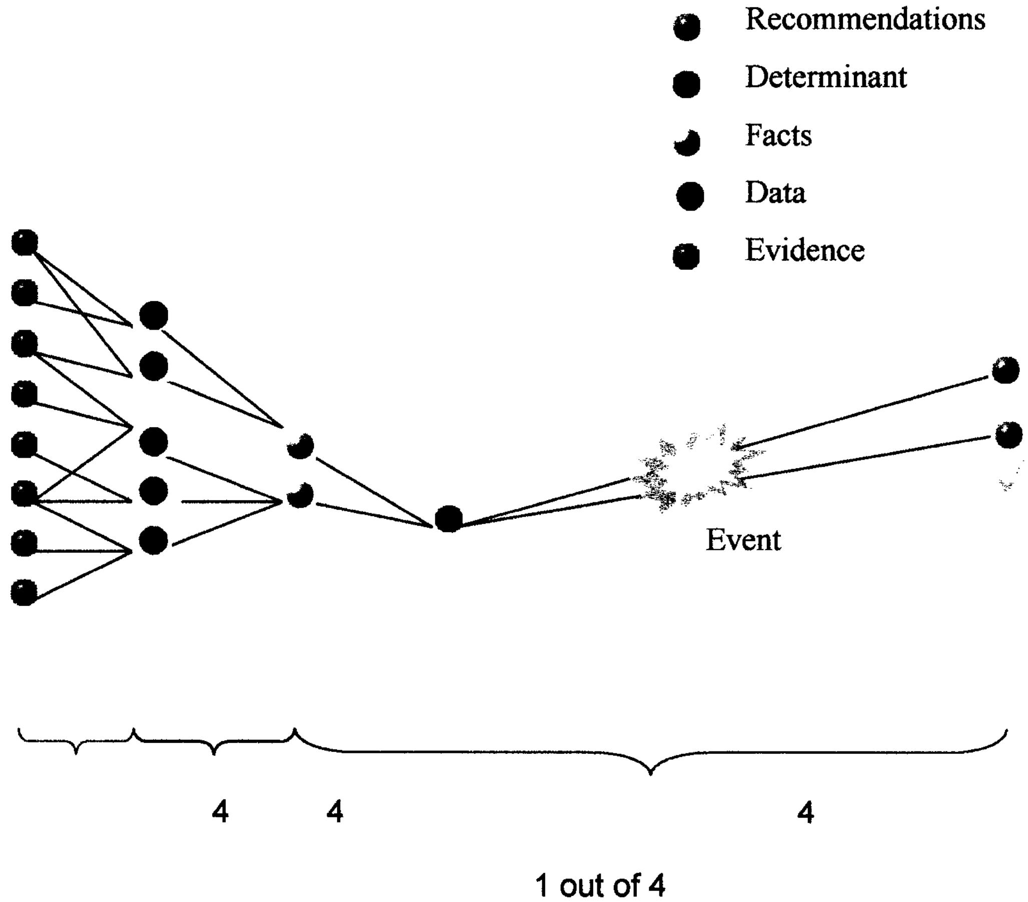
Determinant #3: Lack of process modeling that would have indicated wear rates or indicative of material selection.



Score: 3 out of 4

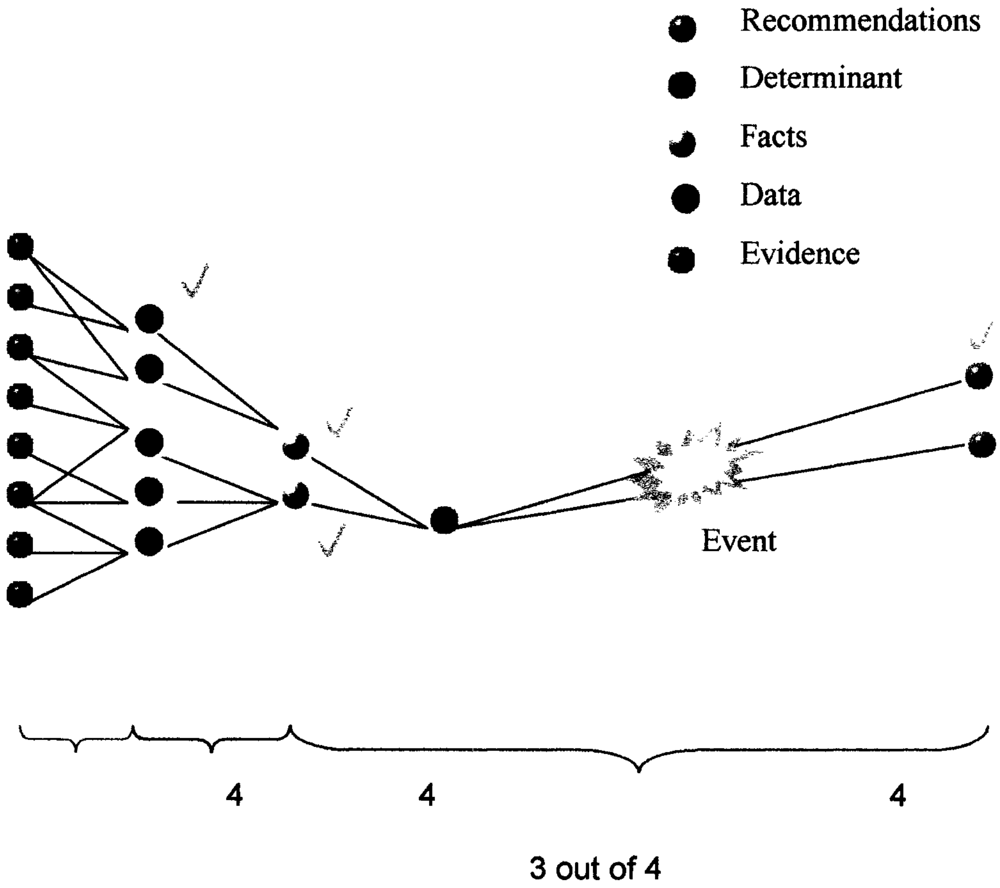
Incident #3: Primary Separation Vessel Incident: January, 2003

Determinant #4: Failure to communicate the expectation that Aurora engineers were responsible or required to monitor wear-patterns.



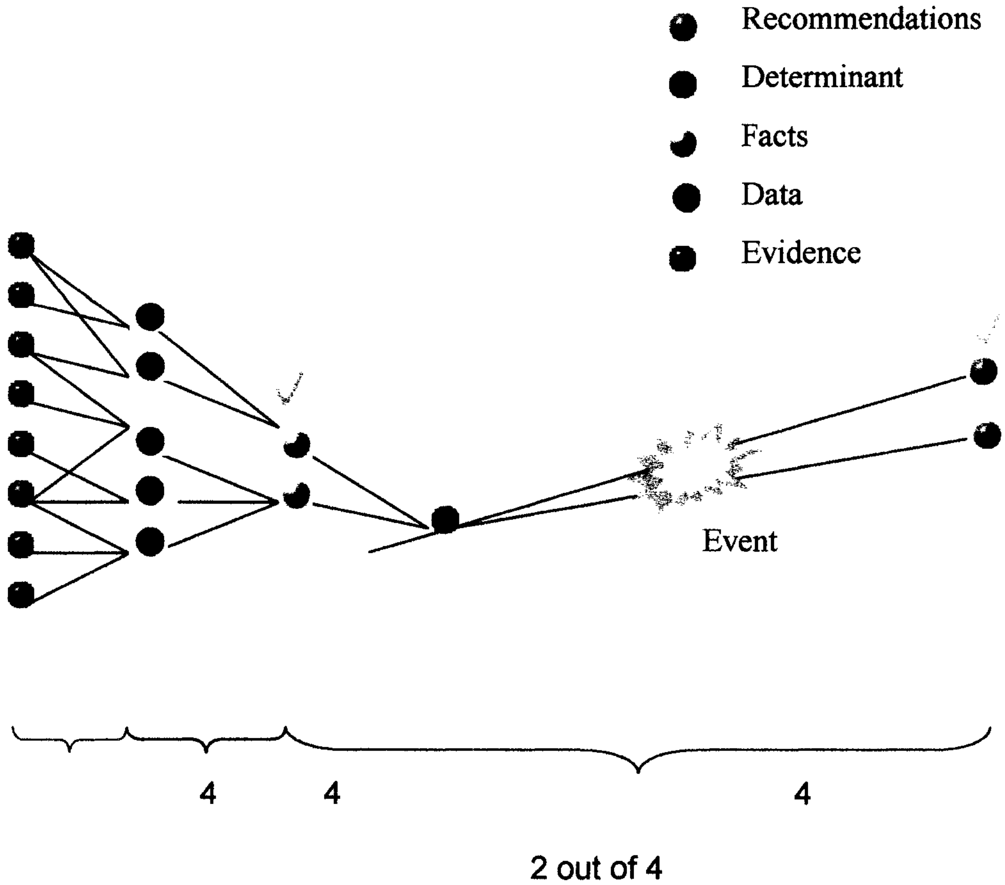
Incident #3: Primary Separation Vessel Incident: January, 2003

Determinant #5: The routine wear monitoring was not well defined and measurement results were not well documented for this vessel.



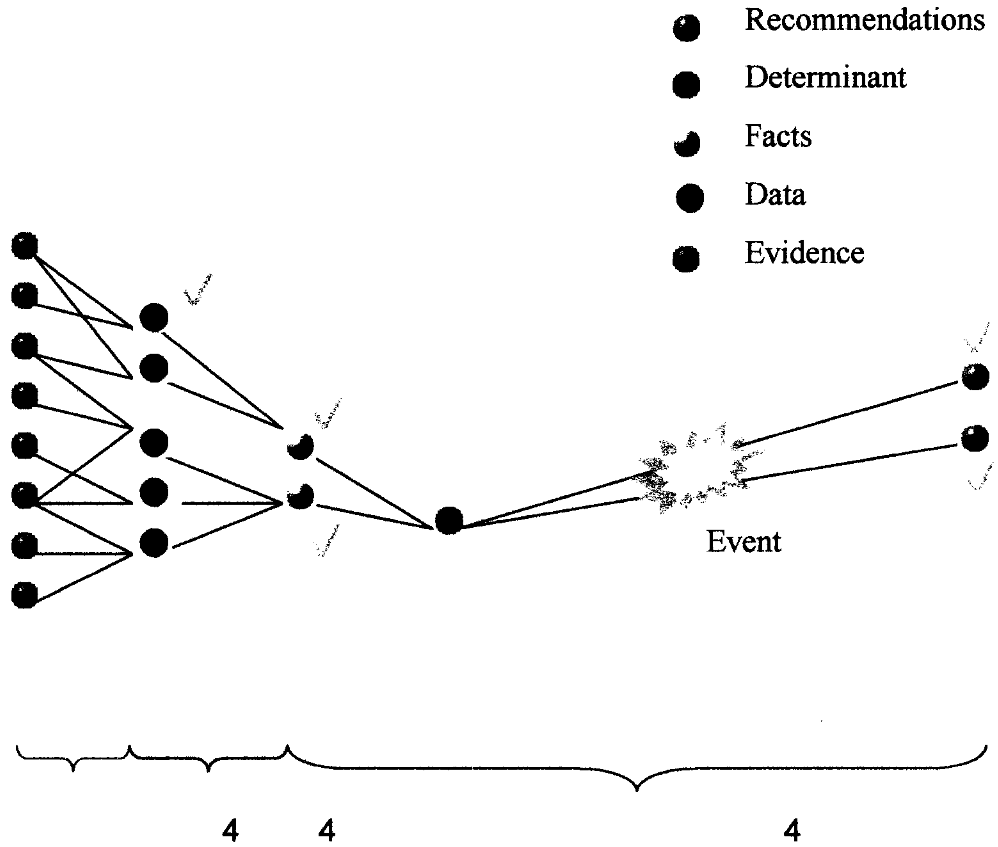
Incident #3: Primary Separation Vessel Incident: January, 2003

Determinant #6: Mechanical changes could have been modeled for solids dispersions and/or wear patterns within the vessel, as part of the Management of Change Process.



Incident #4: Contact Incident with Oiler's Crew Cab

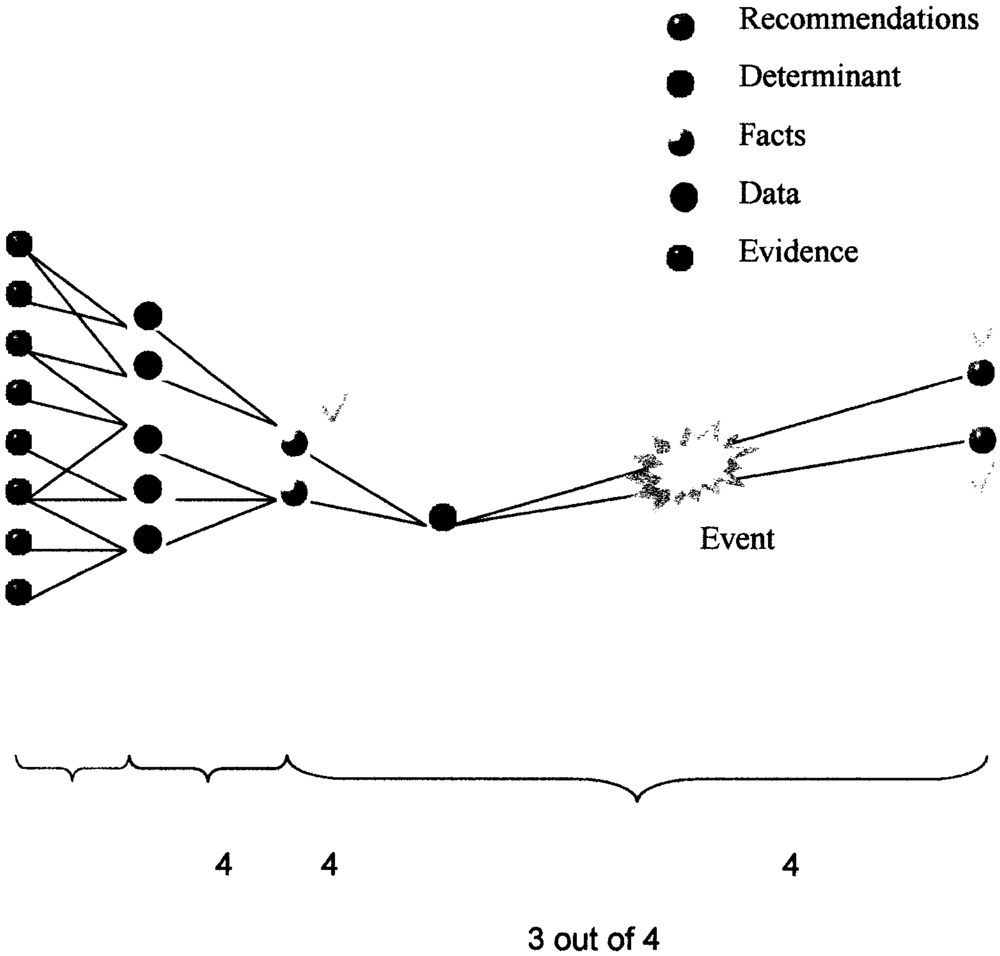
Determinant #1: Mine towing procedures were not widely known; nor were they known to be critical.



4 out of 4

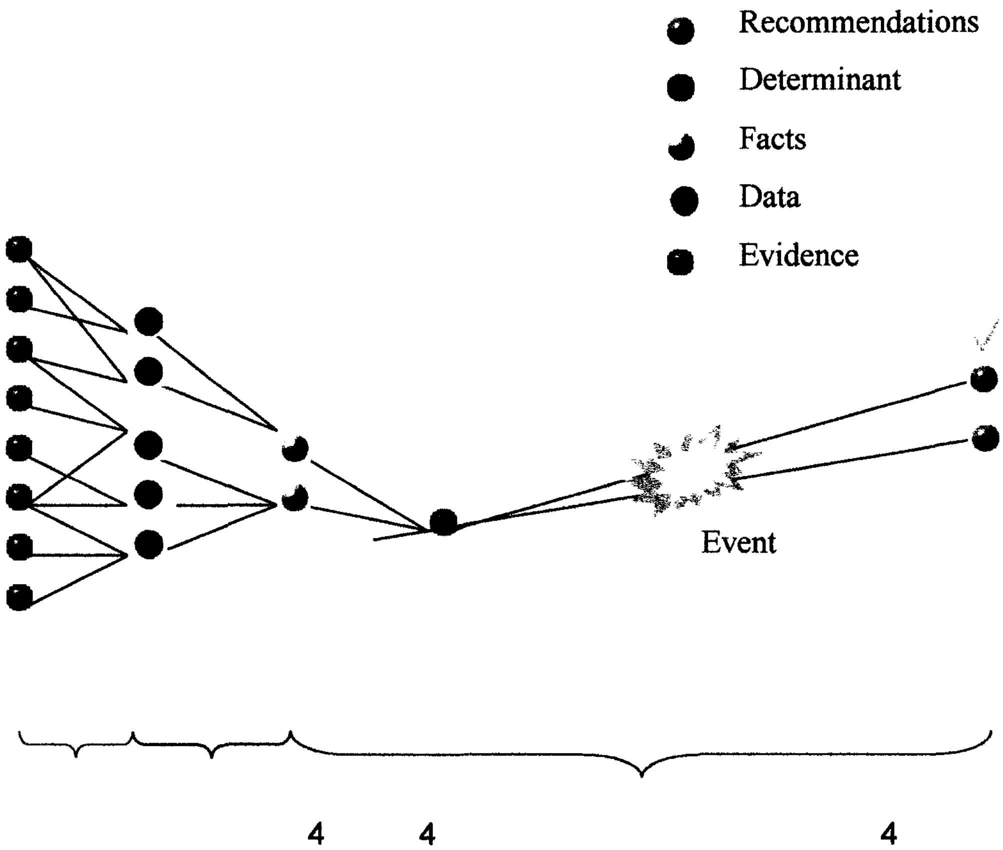
Incident #4: Contact Incident with Oiler's Crew Cab

<u>Determinant #2</u>: Safe approach and parking standard not followed.



Incident #4: Contact Incident with Oiler's Crew Cab

<u>Determinant #3</u>: TAS system is inconvenient to use.



Score: 1 out of 4

Total of 55 out possible 72 (Category 1); equal to 78%

Evaluating the Efficacy of Methodology

On a scale of one to ten, ten representing certainty and one the near absence of, how do you rank the investigation in terms of answering the following questions?

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting DISCOVERY?

Responses of four investigators: 8 7 8 9 8.0

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting COMPETENCE?

Responses of four investigators: 5 7 6 10 7.0

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting ACCURACY?

Responses of four investigators: 8 9 8 8 8.25

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting STANDARDS?

Responses of four investigators: 9 8 9 10 9.0

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting ENCOURAGEMENT?

Responses of four investigators: 9 5 8 9 7.75

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting DISCIPLINE?

Responses of four investigators: 5 6 8 9 7.0

To what extent do you consider the methodology incorporated within your investigation as requiring, demonstrating or promoting INTEGRITY?

Responses of four investigators: 7 8 7 10 8.0

Evaluating the Efficacy of the Method

On a scale of one to ten, ten representing certainty and one the near absence of; how do you rank the investigation in terms of answering the following questions?

To what extent do you consider your method of investigation REALISTIC?
Responses of four investigators: **9 7 9 10** 8.75

To what extent do you consider your method of investigation CONSISTENT?
Responses of four investigators: **7 5 8 9** 7.25

To what extent do you consider your method of investigation VISIBLE?
Responses of four investigators: **6 8 10 10** 8.5

To what extent do you consider your method of investigation FUNCTIONAL?
Responses of four investigators: **6 8 8 8** 7.5

To what extent do you consider your method of investigation DISCIPLINING?
Responses of four investigators: **8 4 8 8** 7.0

To what extent do you consider your investigative method COMPREHENSIVE?
Responses of four investigators: **8 6 8 9** 7.75

To what extent do you consider your method of investigation GRAPHICAL?
Responses of four investigators: **9 9 7 9** 8.5

110.25/14 = 79% Overall

Audit Scoring Scheme

Section I: Possible Yes responses — Actual Yes responses

Box 1a: 14 — Box 1b: 10

Percentile Score: 70 — Box 1c = (Box 1b / Box 1a) x 100

Section IIa: Possible Yes responses — Actual Yes responses

Box 2a: 6 — Box 2b: 2

Percentile Score: 33 — Box 2c = (Box 2b / Box 2a) x 100

Section IIb: Add all of the scores for each determinant and determine the total.

Total: 55 — Box 2d

Percentile Score: 78 — Box 2e = Box 2d/No. of determinants.

Section III: Calculate the average score for each question

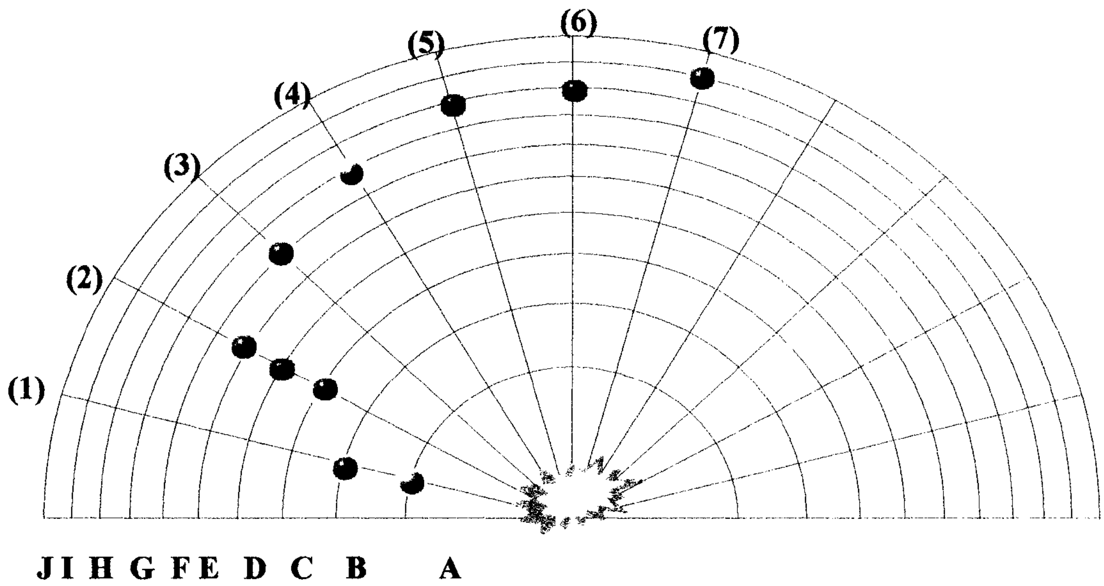
Add up all of the averages for each respondent: Box 3a: 110

Percentile Score: 79 — Box 3b = Box 3a/0.14

Overall Audit Score = (2x(Box 1c) + 2 x (Box 2e) + Box 3b) / 5

Audit Score (%): 75% **(Category 1)**

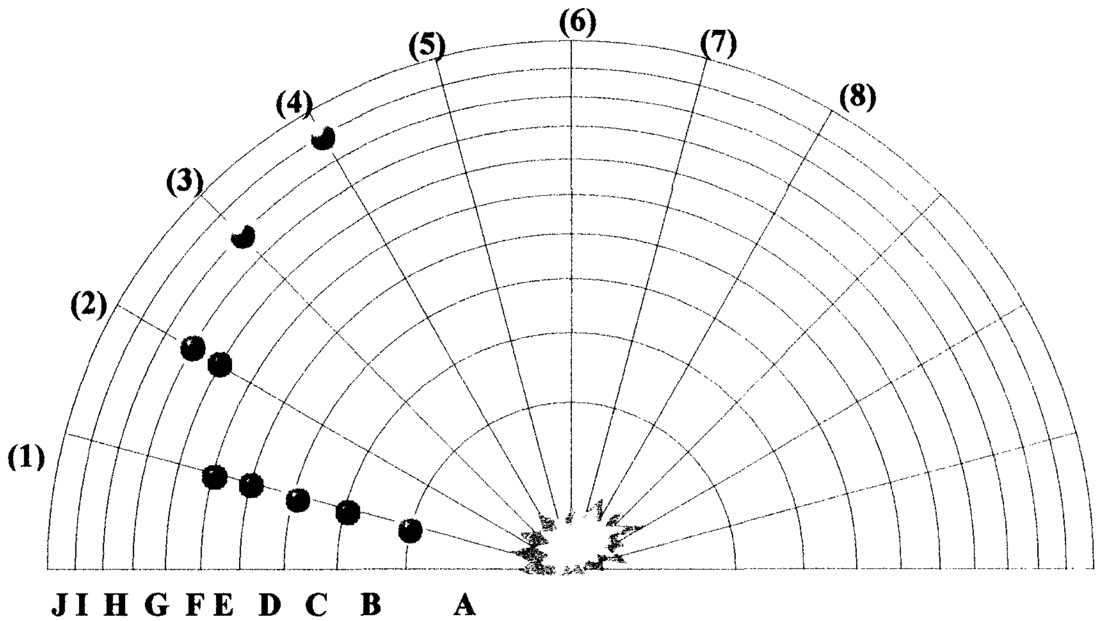
BCD Analysis: Tailings Line Sanding Incident: July, 2003



A	Condition of line operated outside of design parameters wrt d50
B	Condition of panel process operated outside of procedures (alarm status)
C	Condition of panel operator having operational bias towards tonnage
D	Condition of panel operator not having back-up support or supervision
E	Condition of supervisor not accessible to operator (attendance elsewhere)
F	Condition of supervisor being in deficit of information wrt to unstable ops
G	Condition of deficient communication between operations and fixed plant
H	Condition of Crusher and Slurry Prep not initiating appropriate action
I	Condition of Dispatcher being at a deficit of information

(1)	Panel Operator	(6)	Crusher
(2)	Panel Operator Supervisor	(7)	Dispatcher
(3)	Cross shift Supervisor (days)	(8)	Slurry Operator
(4)	Mine Operations Personnel		

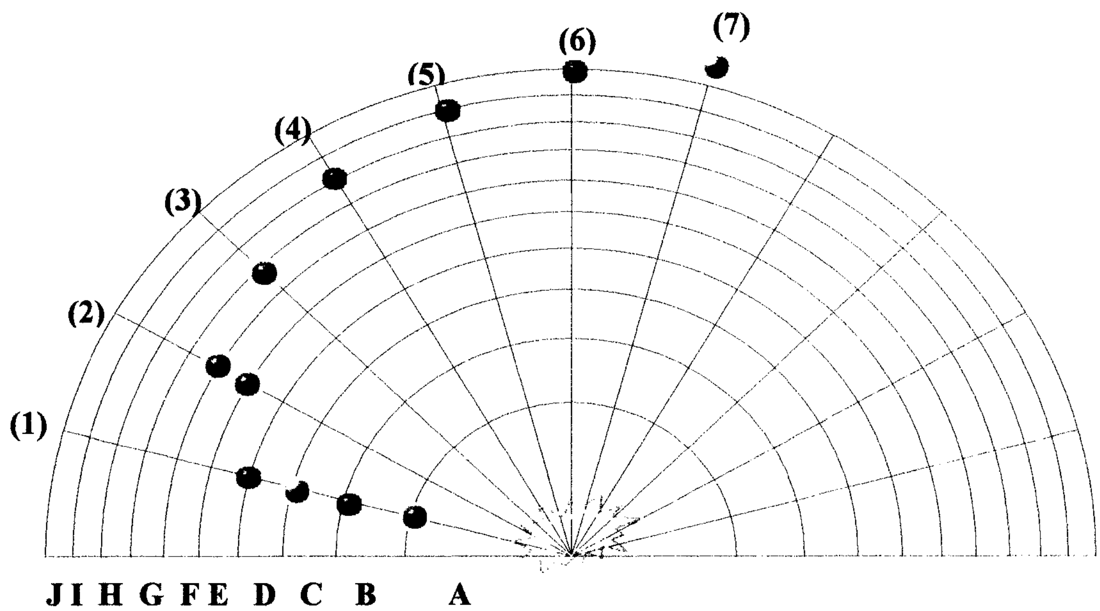
BCD Analysis: Discharge Spool Failure: July, 2003



A	Condition of panel process operator over-pressurizing tailings line
B	Condition of panel process operated outside of procedures (alarm status)
C	Condition of panel operator believing that he had process flow
D	Condition of panel operator operating in a high state of anxiety
E	Condition of panel operator being over stimulated by instrumentation
F	Condition of panel operator not having back-up support or supervision
G	Condition of supervisor not accessible to operator (attendance elsewhere)
H	Condition of supervisor being in deficit of information wrt to unstable ops
I	Condition of alarms set-points being in need of calibration – too low

(1)	Panel Operator
(2)	Panel Operator Supervisor
(3)	Cross shift Supervisor (days)
(4)	Process Operations Leader

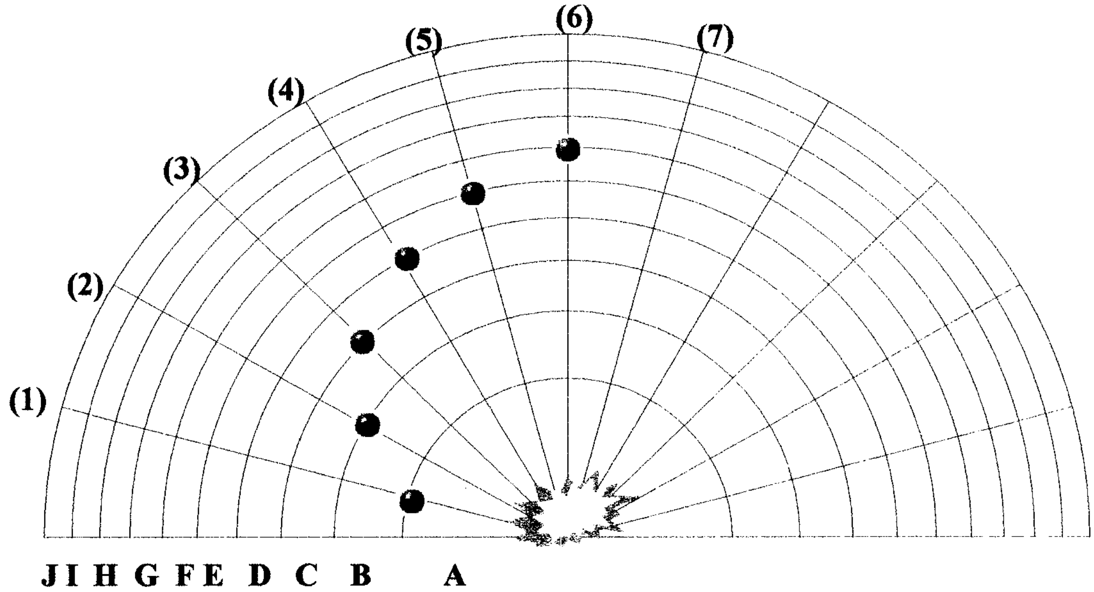
BCD Analysis: Electrical Contactor/Switch Explosion: Oct, 2000



A	Condition of electrical contactor being under VFD load
B	Condition of electrical contactor being subjected to excessive force
C	Condition of electrical contactor being operated outside of procedures
D	Condition of injured party not competent to Deficit electrical contactor
E	Condition of wrong person selected to carry out the task of Deficit
F	Condition of no verification of training records for competency
G	Condition of practice of grandfathering persons without qualification
H	Condition of dysfunctional electrical contactor 'log' not being followed up
I	Condition of electrical contactor being damaged and then not reported
J	Condition of electrical contactor being repeatedly subj. to excessive force
K	Condition of installation of VFD gear not being communicated

(1) Injured Operator
(2) Supervisor Of Injured Operator
(3) Unidentified Operations Leader
(4) Unidentified Maintenance Supervisor
(5) Unidentified Persons
(6) Unidentified Persons
(7) Unidentified Leader

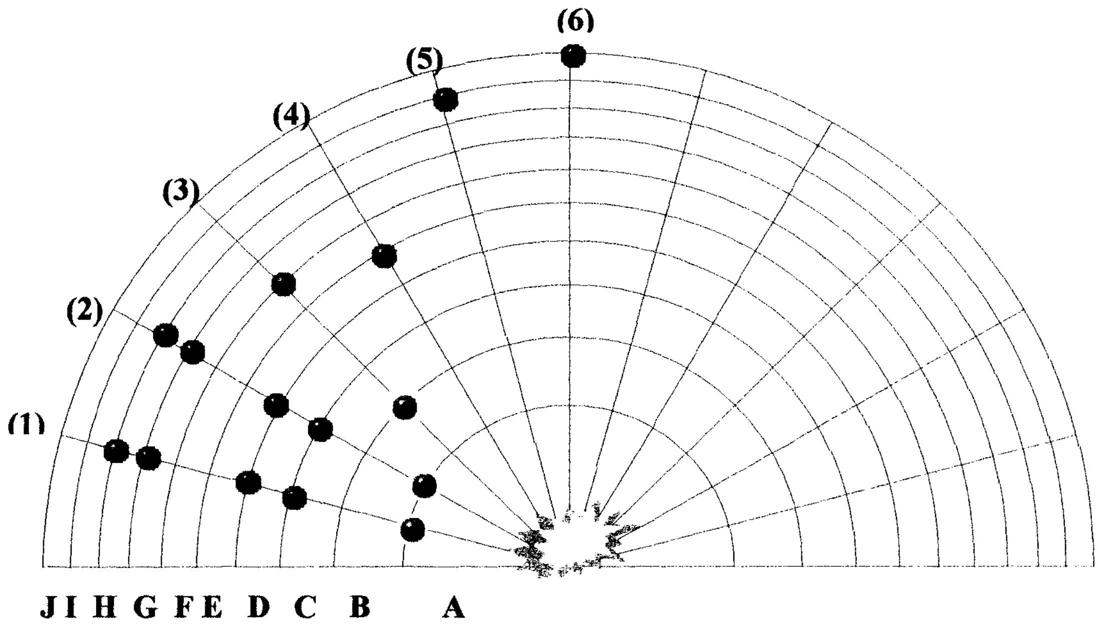
BCD Analysis: Primary Separation Vessel Incident: Jan, 2003



A	Condition of PSV being operated in a state of compromised structural integrity
B	Condition of PSV being operated without the benefit of erosion/corrosion control
C	Condition of PSV being operated without sufficient QA standards
D	Condition of Design Team assuming that operating conditions were similar to base plant
E	Condition of deficiency of Change Management strategy
F	Condition of presumption of similarity to Base Plant by those conducting Due Diligence

(1) through (6): Unknown persons; presumed to be system errors.

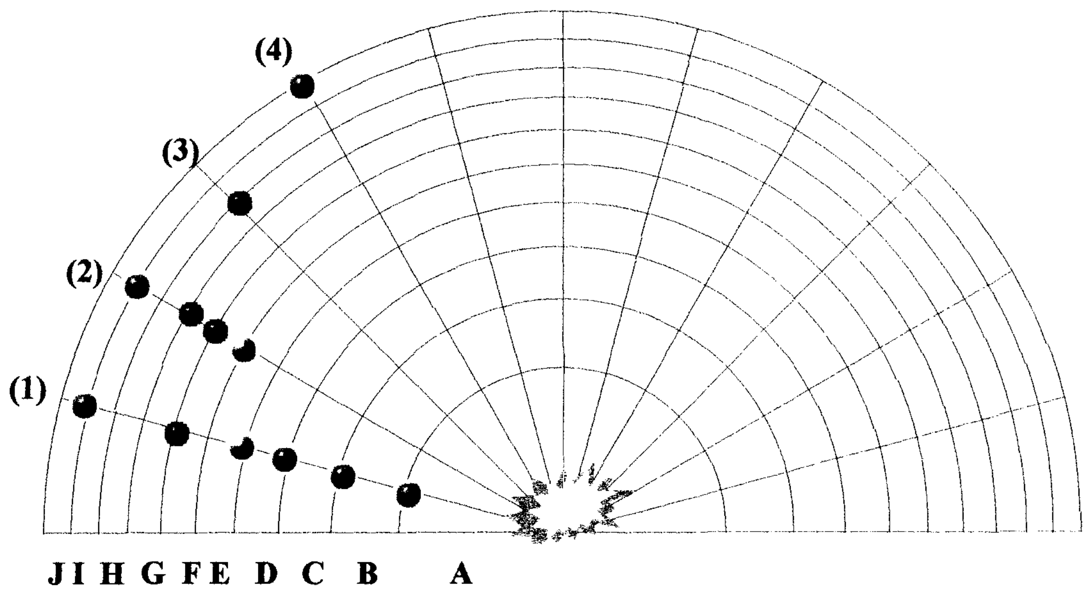
BCD Analysis: Contact Incident With Oiler's Crew Cab



A	Condition of Oilers (2) being in imminent danger w.r.t heavy hauler
B	Condition of heavy hauler operator believing the task was complete
C	Condition of the Oilers (2) failing to establish their presence with HH
D	Condition of the Oilers (2) failing to communicate their intentions
E	Condition of the Grader Operator to intervene on behalf of Oilers
F	Condition of the Heavy Hauler Operator to intervene on behalf of Oilers
G	Condition of Oilers failing to communicate with HH as per procedure
H	Condition of Oilers encroaching on HH beyond procedural offset
I	Condition of procedures being not followed by general mine operators
K	Condition of Leaders in violation of encroachment procedures

(1) Oiler Operator One
(2) Oiler Operator Two
(3) Heavy Hauler Operator
(4) Grader Operator
(5) General Mine Operators
(6) Mine Leaders

BCD Analysis: Damage To Window Of Wheeled Loader



A	Condition of Wheeled Loader Operator being in imminent danger
B	Condition of Wheeled Loader Operator subjecting tow rope to shock load
C	Condition of Wheeled Loader Operator misunderstanding instructions
D	Condition of Wheeled Loader Operator with inadequate communications with Ground Assistant giving assistance.
E	Condition of Ground Assistant with inadequate communications
F	Condition of Wheeled Loader Operator not competent to tow
G	Condition of Ground Assistant giving inappropriate direction
H	Condition of Heavy Hauler Operator not intervening on critical task
I	Condition of WLO & GA not knowing towing was critical task
J	Condition of Wheeled Loader Op. not knowing towing was critical task
K	Condition of TAS system being inconvenient and cumbersome

(1) Wheeled Loader Operator
(2) Ground Assistant
(3) Heavy Hauler Operator
(4) Mine Operators