ASSESSING ORGANISATIONAL FACTORS IN AIRCRAFT ACCIDENTS: METHODOLOGIES AND LIMITATIONS

Justin Debrincat, Cees Bil & Graham Clark
School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora, 3083, VIC, Australia

Keywords: *Accident Prevention, Reliability, Maintainability.*

Abstract

This paper discusses tools which can be used to identify key organisational factors which contribute to aviation accidents. The research uses a thoroughly-investigated helicopter accident as a case study, to determine the extent to which analytical and visualisation tools could be used to assess maintenance organisational issues which contributed to an accident.

1 Introduction

High levels of technological development in aviation make it particularly difficult to analyse aircraft accidents in which there is extensive structural damage. Even when technological issues are resolved, the complex management systems used to maintain safety then need to be analysed to identify the factors which contributed to the accident. Unfortunately, history shows that it is often easier to focus on technological causes rather than other deficiencies at an organisational level, such as training and maintenance, the work environment and the often complex cultural issues which can influence behaviour. These deficiencies can be difficult to identify and analyse, particularly when the investigation reveals a myriad of causal factors. Nevertheless, the purpose of the investigation is to prevent recurrence of the accident, and it is therefore essential to identify the underlying causal factors of an accident. The benefits are obvious - providing a basis for improvement in efficiency and overall safety, and maintaining public confidence in aviation.

This paper includes a discussion of the tools available for identifying and visualising the organisational factors that contribute to aviation accidents. It uses a major helicopter accident as a case study to assess some of these tools, and to determine which tools would assist with achieving organisational improvement to prevent recurrence.

2 Case Study

In April, 2005, a Royal Australian Navy Sea King helicopter N16-100 call sign 'SHARK 02' crashed on the island of Nias, Indonesia during an ADF humanitarian aid mission after a major earthquake (*Figure 1*). Nine Royal Australian Navy and Royal Australian Air Force members were fatally injured and two were seriously injured in the accident.

Figure 1: RAN Sea King Accident Site, Nias **[1]**

The key event immediately before, and leading to, the accident was identified as disconnection of a control linkage due to incomplete maintenance some two months before the accident, but the Board of Inquiry [1] found that the root cause went far beyond a simple maintenance error. Amongst the Findings were many causal events including serious organisational as well as engineering deficiencies. The report also made a large number (approx. 250) of recommendations with the aim of improving the overall management system for the fleet.

The helicopter crashed on approach to landing, where witnesses observed that it suddenly adopted a pitch-down attitude; the aircraft impacted the ground in a steep nose-down attitude. This is illustrated schematically in *Figure 2* [1] which shows some of the stages of the accident, leading to *Shark 02* crashing on the soccer field of the Tuindrao village.

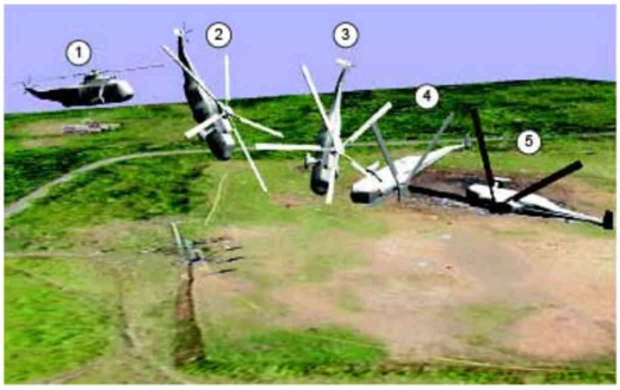

***Figure 2 Accident Sequence of Shark 02* [1]**

The mechanical cause was separation of a critical control system linkage, when a bolt slipped out of a linkage. The bolt and nut should have been secured by a split pin, which was missing or ineffective.

The crash was reported extensively in the media, and while the 'primary cause of the accident was the failure of mechanical linkages, there were also contributory causes including:

- Deficiencies in maintenance practices in both the Sea King detachment and the Squadron;
- Errors made by the Naval command and management systems; and
- Deficiencies in the levels of support provided by Navy and the Defence organisation's safety, airworthiness, training and logistics management systems.' [2]

Furthermore, it was reported that there was a 'damning report' written before the RAN Sea King accident, stating that the Squadron had insufficient staff and assets and was headed for 'an accident' [3]. Adding to this, the BOI report [1] highlighted 'a complex interaction of individual and systemic failings across the Australian Defence Organisation', and [4] that 'senior commanders and managers did not fully understand their responsibilities for airworthiness.' These issues, *inter alia*, give an indication of the nature of the causal factors identified in the investigation, and were explored further in this research.

3 Models

3.1 Background

The modern models of accident causation take a systems approach, where accidents can be attributed to a combination of active operator-level errors [5]. This change highlights the fact that there are some limitations associated with older models, i.e. too many restrictions on identifying causes as technological rather than considering the socio-economic climate

It is also widely recognised that there are both individual and organisational factors that contribute to maintenance performance, and these factors need to be identified to paint a credible, accurate and in-depth picture of the causes [6].

Leveson [7] argued that the problem with a "human error" approach is that after an accident, it will be 'easy to find someone involved in the dynamic flow of events that has violated a formal rule by following established practice rather than specified practice'. She argues that the way forward in accident investigations is to acknowledge human error as a 'deviation from a normal procedure', however that we should not stop there in the investigation; one must devise a more effective accident model that would require a shifting of focus from explaining human error to explaining organisational factors that shape this behaviour. This is a very important distinction. In support of this view, the need for a new model has also been suggested [8], stating that from 1972 to 1985, 83% of all fatal aeromedical helicopter accidents were attributed to "pilot error", while realistically, organisational and operational protocols and accepted practices may have created an environment, where an accident was waiting to happen; human error was just the catalyst of an accident sequence, laid down by a foundation of organisational deficiencies.

In summary, accident causation needs to be viewed as a complex process involving the entire socio-technical system, including legislators, government agencies, industry associations and insurance companies, company management, technical and engineering personnel, operations etc.

In the following sections, two models available for organizational analysis – the Reason model [9] and Rasmussen's AcciMap [10] will be described and their capabilities discussed. Both were applied to the case study, to allow a comparison, and to identify the extent the strengths and weaknesses which both might contribute if used in future accident investigations.

3.2 Reason Model

The James Reason Model is widely used and accepted; it was developed for analysing a wide range of organisational accidents. In his book *Managing the Risks of Organizational Accidents*, [11] Reason developed his previously published [9, 12] causation analysis and created a user friendly model that may be adapted to almost any workplace organisation. It bases itself on a diagrammatic representation of a system's defences, and highlights deficiencies in these defences that may lead to an accident [9].

Sometimes referred to as the *Swiss Cheese* Model, shown in *Figure 3*, the Reason Model represents deficiencies in a system's defences by holes in slices looking like Swiss cheese. When the holes line up in consecutive slices, an accident trajectory becomes possible. Reason [9] notes that 'these windows of opportunity are rare because of the multiplicity of defences and the mobility of holes', although they nevertheless are still a possibility. Furthermore, Reason adds that 'since no one can foresee all the possible scenarios of disaster, it is therefore inevitable that some defensive weaknesses will be present from the beginnings of a system's productive life…'

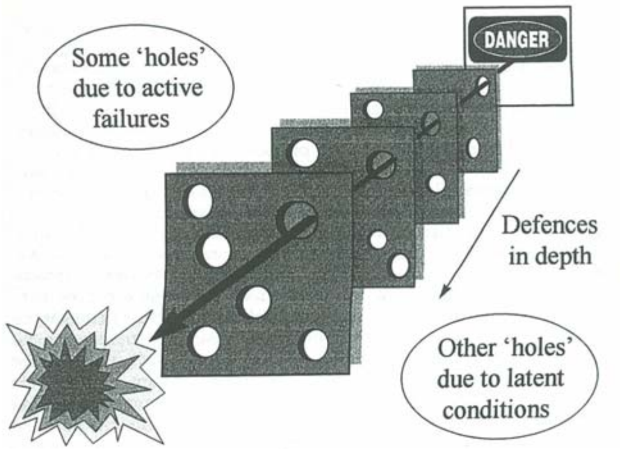

***Figure 3: James Reason's 'Swiss Cheese' Model* [11]**

The model explores two separate approaches to human error; the person approach and the system approach. Reason highlights that 'errors and violations committed at the *sharp end* of the system – by pilots, air traffic controllers, police officers, insurance brokers, financial traders, ships' crews, control room operators, maintenance personnel and the like' are related to immediate causes of accidents and if prevented, would most likely have broken the accident sequence. Until recently, this is where an accident investigation would stop, however Reason [11]&[12] explores the often neglected differentiation between *active failures* and *latent conditions*, and explores the notion of *latent conditions*, in which organisations that have experienced an accident may look beyond the *sharp end* to identify the causes to avoid a reoccurrence. These *latent conditions* include ‘poor design, gaps in supervision, undetected manufacturing defects or maintenance failures, unworkable procedures, clumsy automation, shortfalls in training, less than adequate tools and equipment’ etc.

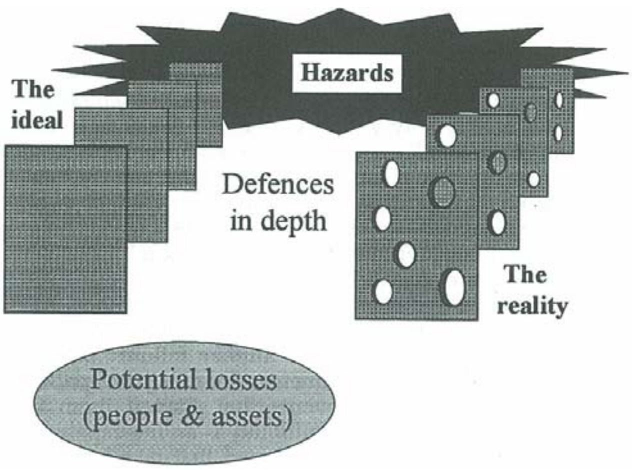

***Figure 4: Reason Model - The Ideal v The Reality* [11]**

In an ideal world, according to Reason [11], a system’s defences would all be intact, ‘allowing no penetration by possible accident trajectories’, however as illustrated in *Figure 4*, in the real world, ‘each layer has weaknesses and gaps’ of the kind shown in *Figure 3*.

More recently, the dynamic state of organisations systems has been highlighted - a time dimension has been introduced to the Reason model; in a review of the circumstances underpinning the crash of a RAF Nimrod aircraft [13], Haddon-Cave observed that a *culture of continual change* in a regulatory system can have a major impact. He introduced this parameter to the Reason model by noting that the defence layers may also need to be modified to represent the successive changes in the system. This approach indeed highlights concern that a defence which was appropriate and effective at one moment in time might in subsequent years be rendered ineffective by continual change; in effect, moving the holes around opens up the potential for a complete accident trajectory. For the purposes of the present study, however, this dimension was not included.

Reason Model - The Defences

In identifying and exploring the defences of a system, it is important to understand the various functions they serve and the way in which these functions are achieved. Defences are mechanisms put into place to counter inevitable mistakes from both human interaction and technology itself.

The functions of defence layers are:

- To create understanding and awareness of the local hazards.
- To give clear guidance on how to operate safely.
- To provide alarms and warnings when danger is imminent.
- To restore the system to a safe state in an off-normal situation.
- To interpose safety barriers between the hazards and the potential losses.
- To contain and eliminate the hazards should they escape this barrier.
- To provide the means of escape and rescue should hazard containment fail [11].

The ordering of the list above is not random and has significance in that the ‘defences-in-depth’ concept highlights the proximity of some defences to the accident. This concept involves successive layers of protection, where each defence is guarding against a possible breakdown of the one before it; the concept is weakened by the dynamics issue raised earlier, which allows opportunity for moving defences to reduce the reliability of the defences in-depth concept.

Reason Model Results

A Reason Model was created for the case study accident, using a number of key Findings from the BOI report. The key defence mechanisms identified as being in place (*Figure 5*) derived from; i) the Military Regulatory System, ii) Training, iii) Management Monitoring, iv) Standard Operating Procedures, v) Communication and vi) Helmet and Restraint.

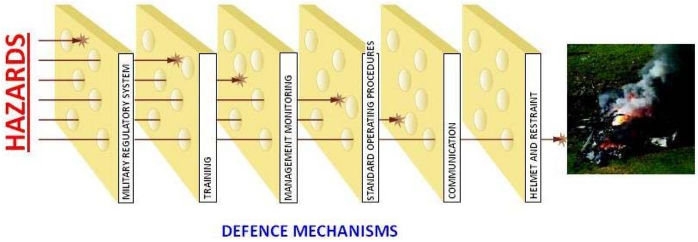

Figure 5: Key defence mechanisms in Reason Model of Sea King Accident

Although the model above illustrates and highlights the accident trajectory that caused the accident of N16-100, it fails to provide the required depth to identify all of the causal factors. Preventing the accident from occurring or recurring requires this additional depth to identify specific improvements in the existing defences or the need for additional defences. An interesting observation made during this study, and potential weakness, is that the Reason Model is constrained to one accident trajectory, while it is conceivable that several trajectories might come together to contribute to the outcome.

Selecting Defences

In selecting the defences, the main themes from the BOI report were once again identified and summarised. The existing defence mechanisms put in place by the Squadron, and the Navy organisation as a whole were identified and categorised. Relevant organisational findings were identified, and the defences (and more specifically, the deficiencies in them) that were selected are listed below.

Defences Breakdown

Below is a breakdown of the defences, and more specifically their deficiencies or weaknesses that represent the “holes” in the Reason *Swiss Cheese* model. The higher level headings refer to the key defence mechanisms identified earlier in *Figure 5*.

1. Military Regulatory Systems

- Outdated FAR 29 Regulations
- 30 minute change-over procedures
- No legal obligation to comply with civil aviation safety standards

2. Training systems

- Failure to correctly certify and document maintenance procedures
- Staff not qualified to carry out certain maintenance operations
- No accompanying explanation as to why safety procedures exist
- Ineffective training days, lack of structure, planning and follow up testing and documentation

3. Management Monitoring

- Management did not ensure that staff carrying out maintenance activities were certified to do so
- Officers who held specific positions were often not trained or experienced enough, a result of fast tracked promotion to fill gaps
- Inadequate supervision

4. Tested Standard Operating Procedures

- Pressure on increased fleet availability and a significant lack of resources forced practices away from established standard operating procedures
- Failure amongst junior maintenance engineers to understand the relevance and importance of standard operating procedures

5. Communication systems

- Breakdown of communication between watches

- Inadequate communication of audit findings and near misses
- Warnings from engineers largely went unheeded

6. Personal Protective Equipment

- Non-crashworthy seating

3.3 Rasmussen AcciMap

Rasmussen developed the AcciMap, a multi-layered causal diagram that arranges the various causes of an accident in terms of their causal remoteness from the accident [10]. According to the Defence Science and Technology Organisation [14], who have used the approach, the feature that distinguishes this method from that of an ordinary accident causation model is that it identifies causal factors from all parts of the system in which the accident occurred, ranging from the physical accident sequence of events and activities of the individuals involved, right up to the governmental, regulatory and social influences.

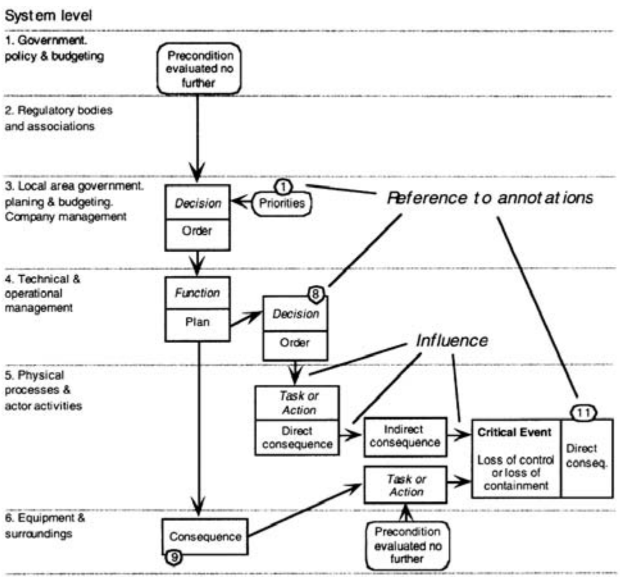

***Figure 6: Potential Structure and Standardised Symbols of an AcciMap* [10]**

Figure 6 above highlights the skeletal structure of the AcciMap, where levels of proximity are arranged vertically. The further down the chain of events, the closer to the accident sequence and final lines of defences. According to Svendung & Rasmussen [15] the focus of this analysis is the control of the hazardous process at the bottom of the socio-technical system, therefore a vertical analysis covering all levels of influence is necessary as opposed to a horizontal, somewhat restricted approach.

The AcciMap arranges these causal factors in a coherent, one page diagram that highlights the interrelationships between them, thereby highlighting the problem areas within the organisation that need to be addressed in order to prevent a similar chain of events occurring [14]. With this method, a broad situational view of the organisational and systemic inadequacies that contributed to the accident can be gained from essentially one concise, interlinking and user friendly map. To further increase clarity, any ambiguity of the AcciMap and the nodes and arrows can be resolved through a textual argument.

The AcciMap approach has been applied to a number of case studies, all but one without aviation significance. In particular, it was used to highlight causal factors of a major (Esso Australia) gas plant explosion [16], and the results of that analysis were used to guide the development of an AcciMap in the present study.

Selecting Causes/Identifying Factors

As discussed above, many past accident investigations have stopped once the objective of attributing blame has been achieved, and there is still enormous public pressure to attribute blame. In selecting potential nodes (issues/causes) for the RAN Sea King accident, it was necessary to go beyond such arbitrary barriers of causation analysis, to identify not only the fact of the missing split pin, and that this was due to an error involving a shift changeover and inadequate supervision, but *why* personnel were not inadequately supervised and *why* this simple error in communication contributed to the event.

Some of the challenges involved in building the model included:

- Developing a process for identify key causal factors from a large and detailed data set - the BOI Report. (A key issue is that while the Reason model can be built around pre-identified defence systems, the AcciMap structure does not benefit from an initially defined structure, and may require substantial tailoring),
- construction and layout of the AcciMap (especially interlinking and crossovers), and
- selecting nodes for inclusion in the model.

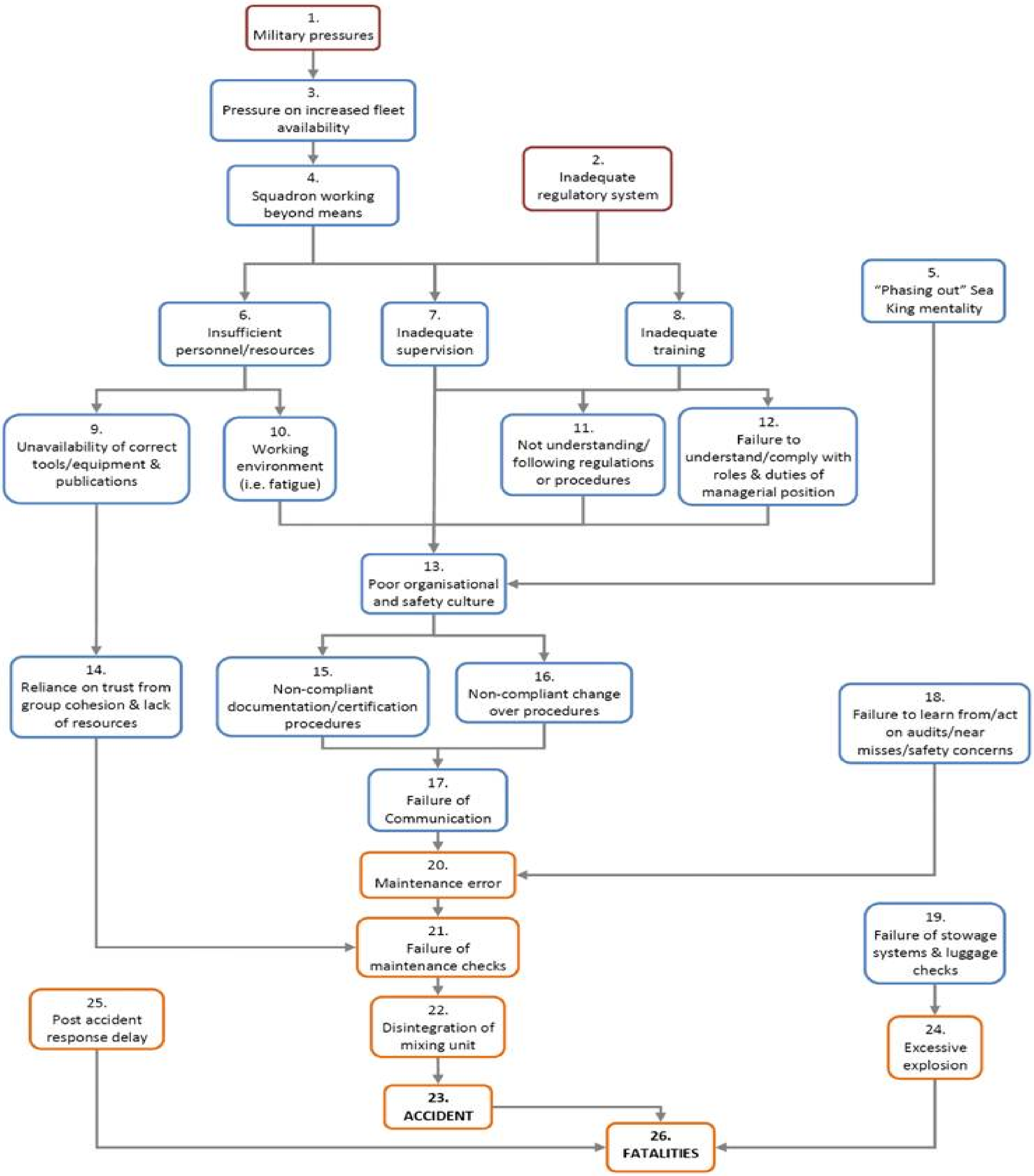

Figure 7: AcciMap developed for Sea King accident

AcciMap Results

The AcciMap developed and shown in *Figure 7* explores the causal factors that interlinked to cause the fatal accident of *Shark 02*. The causal remoteness increases as you move up the vertical axis from the accident. The red boxes indicate societal and governmental forces, the blue boxes the organisational deficiencies and the orange boxes, the physical accident sequence.

4. Discussion

One limitation of a study of this kind is that it necessarily based its structure on the use of just one source, the BOI report. However, that source is a well funded, detailed, elaborate and non-subjective report that aimed to explore all causal factors contributing to the accident. For these reasons, this specific case study, due to the depth and transparency of the investigation, was believed to be suitable for trialling the AcciMap method paralleled with the Reason Model.

Comparison of models

Throughout the analysis, a comparison was made between the AcciMap and the Reason models. The two methods provide very different outputs, and each may have value for different purposes. Notable features observed include:

(a) The Reason Model is constrained to one accident trajectory. In contrast, the AcciMap provides a networked analysis, with multiple nodal streams, and therefore is capable of offering a better "big-picture" view of the overall accident causal issues than does a linear sequence model.

(b) Since the Reason model focuses specifically on defences it provides an excellent base for identifying and rectifying weaknesses in existing defensive measures.

(c) AcciMap offers the opportunity to identify, highlight (and hence modify or improve) a somewhat wider range of issues which contributed to the accident.

(d) The identification of AcciMap nodes is to some extent subjective, and it is not clear how the specifics of the results may be influenced by personal experience and understanding. Perhaps a more structured approach, based on developing a range of standard options for nodes, would be of value by providing a more robust approach to AcciMap generation. Ideally, an effective process will be sufficiently robust as to lead to identification of an essential causal chain and factors.

Potential for combined application

This study suggested that there could be benefit in using both models in parallel, to take advantage of the principal strengths of each. More specifically, the strength of the AcciMap is that it provides a broad and comprehensive picture of the important issue–the nodes–which are involved in the accident. The Reason model strength is its focus on defences, and hence on potential improvements to the system. Use of the two models together – in a sequence where the key nodes identified in the AcciMap could then be explored individually using a Reason approach – might provide a more robust outcome than using the either model alone.

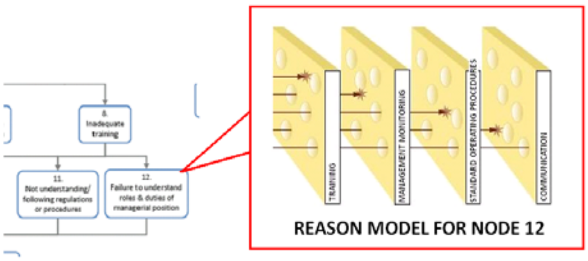

Figure 8: Hybrid AcciMap and Reason Model

Potential for higher-resolution application

A means of overcoming the limitations of performing the analysis as high level, is to explore the potential for use of the models recursively, i.e. can we re-apply the analysis to specific nodes of interest in the AcciMap, to access finer detail in the organisational structure? In the Reason Model, subdivision of defences seems relatively simple, and such subdivision should not be difficult.

Potential for pro-active application

A major conclusion from this work is that since the focus of both models is to identify potential weaknesses in a system, there would be enormous benefit if the analyses could be conducted BEFORE an accident occurs. So how could we apply the models pro-actively? A key observation in the Sea King accident was that there had been a high number of "maintenance breakdowns" i.e. events which were noted before the accident, and which were intercepted before they could lead to an accident. This suggests that these "maintenance breakdowns" could be regarded as unfulfilled accidents, and application of the AcciMap and Reason models to these "maintenance breakdowns" would allow the organisation to improve its performance and safety levels.

What form would such a pro-active preventative analysis tool take? To be effective, it would need to be user-friendly and rapid, and capable of interrogating an organisation's existing records – something that should be feasible in a well-controlled environment such as the aviation industry. Such use of the analysis models - as a preventative measure - will be explored in further research. One issue is the need to better define a process for identification of key nodes in the AcciMap, not to produce different outcomes and results, but to reduce the amount of time and effort an organisation would need to put into the construction and maintenance of a preventative analytical tool.

5. Conclusions

This study has applied two organisational analysis tools to the case study of a major helicopter accident. The results of the processes led to several key conclusions:

The models have different strengths – the AcciMap approach provides a better "big-picture" view of the accident, with multiple causal streams. In contrast, the Reason model provides a more focused view of the system's defences and how they were breached to arrive at the accident.

The identification of nodes in the AcciMap invites some subjectivity, and it is not clear to what extent, if any, this might affect the results.

The study identified some interesting potential applications, some of which would exploit the strengths of the two models:

Firstly, there is potential for using the two models together in an analysis which will use the AcciMap to identify (potentially) multiple strands of causal factors, then using the Reason approach to identify the defences within the key nodes which can be improved.

Secondly, the models could be re-applied to individual nodes in the AcciMap, to acquire a higher-resolution view of that aspects of system performance.

Thirdly, the use of the two models, together, as a pro-active safety tool is proposed. Such a tool could be applied to recorded "maintenance breakdowns" in a safety-critical organisation. In effect, these recorded breakdowns can be viewed as incomplete accidents, allowing the organisation to self-assess its effectiveness and safety levels, and put in place improved safety methods.

6. References

[1] Royal Australian Navy. (2007). *Nias Island Sea King Accident - Board of Inquiry Report.* Australian Capital Territory: Commonwealth of Australia.

[2] Machin, C. P. (2007, July 2). *Series of Errors in Sea King Crash.* Retrieved March 18, 2009, from Royal Australian Navy: www.navy.gov.au/Series_of_errors_in_Sea_King_crash

[3] Banham, C. (2005, December 3). *Australia's Navy report foretold Sea King accident*. Retrieved May 24, 2009, from Aviation Human Factors Industry News: http://www.system-safety.com/Aviation%20HF%News/Issue%201%20Volume%204.htm

[4] Kerr, J. (2007). Inquiry attributes RAN Sea King crash to 'culture' of shortcuts. *Jane's Defence Weekly* , 1-2, 4 July 2007)

[5] Peters, G. A., & Peters, B. J. (2006). *Human Error - Causes and Control.* Florida: Taylor and Francis.

[6] Fogarty, G., & Saunders, R. (n.d.). Developing a Model to Predict Aircraft Maintenance Performance. *Tenth International Symposium on Aviation Psychology*, (p. 6). Ohio.

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

[8] Collett, H. M. (1986). The Safety Challenge. *Hospital Aviation 5(3)* , 5-8.

[9] Reason, J. (1995). A systems approach to organizational error. *Ergonomics* 38(8), 1708-1721.

[10] Rasmussen, J. (1997). Risk Management in a Dynamic Society: A Modelling Problem. *Safety Science,* 27(2/3*)*, 183-213.

[11] Reason, J. (1997). *Managing the Risks of Organizational Accidents.* Ashgate Publishing Limited, England.

[12] Reason, J. (1990). *Human Error.* Cambridge University Press, Cambridge, United Kingdom.

[13] Haddon-Cave, C. (2009). *An independent review into the broader issues surrounding the loss of the RAF Nimrod MR2 Aircraft XV230 in Afghanistan in 2006.* London: The House of Commons.

[14] *Defence Science and Technology Organisation.* (2005, February 21). Retrieved March 6, 2009, from AcciMap Analysis - Further Information: www.dsto.defence.gov.au/research/page/3273

[15] Svendung, I., & Rasmussen, J. (2002). Graphic representation of accident scenarios: mapping system structure and the causation of accidents. *Safety Science , 40*, 20.

[16] Hopkins, A. (2000). *An AcciMap of the Esso Australia Gas Plant Explosion.* ACT: Australian National University.

Copyright Statement