Analysing the Dash 8 Accident with the Theory of Constraints

Introduction

An accident does not come 'out of the blue'. Any accident comes about as the a result of a variety of undesirable effects. In aviation, we find unsatisfactory conditions within systems, either during investigations of accidents or incidents, or during surveillance or audits. In dealing with unsatisfactory situations, we need to know:

- What to change
- What to change to, and
- How to change

It has been customary to try to address each of the unsatisfactory situations separately, and we find statements such as '43 safety recommendations were made in the course of this investigation' (AAIB, 1988). However, this approach diffuses the corrective effort available. It would be more efficient if one or two effective actions could be identified so that resources could be focussed on them. Further, Taylor has shown that, in reality, few safety recommendations are implemented, even when they originated from such prestigious authorities as the US National Transportation Safety Board (NTSB) and the British Air Accident Investigation Branch (Taylor, 1998). (For example, regulations to address flight crew fatigue have been on the NTSB's 'most wanted' list since 1990 (NTSB, 2004)). Either the proposed actions were rejected as being ineffective, or those in a position to implement the action were not persuaded of the need to do so.

Some organisations have argued that understanding the complex relationships that led to an accident is too time consuming. Instead, investigators should simply identify the failed defences that allowed the accident to happen. All that may be necessary is to make recommendations to improve those defences (Walker, 2003). However, this approach takes no account of the difficulty which the human mind finds in dealing with complexity. "A complex system cannot be managed in the head of a single person" (Stevens, Brook, Jackson, & Arnold, 1998); and as will be shown, an accident can be a very complex system. Knowing what happened is an essential step in an investigation, and attempts to deduce ‘unsafe conditions’ and produce ‘safety actions’ without really understanding what happened are unlikely to be effective in averting future accidents.

Because of the complexity of accident causation, formal methods are needed to enable investigators to see the system both as an entity, and at different levels of detail. Further, the use of formal methods will enable investigators to justify their conclusions should they be challenged - the need being illustrated in the report of the Coroner’s Inquest into the Whyalla accident (Chivell, 2003). The relatively high ‘visibility’ of failure should, of itself, be a sufficient incentive for taking pains with logical analysis.

It is in any case a misconception that construction of logical trees is of itself a lengthy process. Where extra time may be required, compared with present methods, is in finding additional information where gaps in the logic tree show the need. However, this is no more than proper investigation. It is not an argument for not using logical analysis, that it may indicate the need for additional information. Also, the existence of the logical tree may even speed up an investigation, by making the investigation more focussed. This may be a faster process than collecting an ocean of data without knowing whether it is relevant.

Formal Analytical Methods of Investigation.

Benner’s Multilinear Events Sequencing (Benner, 1994) was developed in the 1970s for the NTSB, and presents the evidence in such a way that the investigator has a ‘mental movie’ of what happened. However, it is often necessary to go a stage further, and determine *why* something happened – the backtracking advocated by Reason (Reason, 1991). The difficulty of attempting to achieve this by verbal analysis led Johnson to suggest the use of Petrie Nets (Johnson, Wright, & McCarthy, 1995). More recently, Ladkin’s ‘Why-Because Analysis’ (Ladkin & Loer, 1998) has started to become accepted. These graphical depictions of events and conditions can manage interacting networks in a way that is not possible with writing, which is essentially serial in nature (Johnson et al., 1995).

Despite the potential advantages associated with Petrie Nets and ‘Why-Because Analysis’, knowing why something happened, and being able to do something about it, are two quite different things. There have been many failures of safety recommendations, including the fact that they maybe ill-founded, impracticable, or politically unpalatable. A safety recommendation is an attempt to introduce a change mechanism. There are effective change mechanisms in use in business, and this is the province of the Theory of Constraints.

The Theory of Constraints (TOC) is a method for analysing and improving systems. It originated in the 1980s when Goldratt applied the logical methods of the physical sciences to business problems (Goldratt, 1987; Goldratt, 1990). The method was first applied to continuous flow processes. The ‘constraints’ in the title were bottlenecks in those processes, and Goldratt showed that it was better to concentrate efforts on dealing with the constraints, rather than seeking to make general improvements. The method is now widely used in many fields (see, for example, (Mabin & Balderstone, 1998; Mabin & Balderstone, 2003)). The objective remains the identification of core problems, so that these may be addressed, rather than trying to address all the undesirable effects to which the core problems give rise. Further, the Theory of Constraints not only has the ability to diagnose what is wrong, but to identify what changes to make, and how to implement them. Changes that might appear ‘too hard’ can be addressed in manageable steps, and potential obstacles to implementation can be foreseen and overcome.

It could be argued that the future is unknowable, but this is not necessarily the case. Audits and surveillance bring to light undesirable effects, in exactly the same way as an incident investigation. If, by analysis of audit and surveillance information, the systemic deficiencies could be found before an accident occurred, the trauma of an accident could be averted.

Methodology

The Theory of Constraints appears as though it should be useful. However, it has not previously been used in an aviation safety context. One aim of this thesis is to determine whether it can be applied to reducing the ‘undesirable effect’ of an aircraft accident. Specifically, this thesis seeks to determine

- whether the information from an accident investigation can be put into the form required for analysis using the methodology of the TOC and,

- whether the TOC can be used to formulate safety recommendations that are likely to be effective.

If the first issue can be resolved satisfactorily, the second should be largely a matter of form, since the TOC has been demonstrated to be an effective change mechanism. A case study approach has been adopted to investigate the utility of the TOC in aircraft accident investigation.

This case study pertains to an Ansett Dash 8 accident at Palmerston North, New Zealand . This case was selected since , as a result of litigation, full documentation was available, and it had been examined in depth[1].

AAIB. (1988). Report on the accident to Boeing 737-236 G-BGJL at Manchester Airport on 22 August 1985 (Aircraft accident report 8/88). London: HMSO.

Benner, L. (1994). Ten multilinear event sequencing guides. Sterling, Va.: ISASI.

Chivell, W. C. (2003). Finding of inquest (Coroner's inquest). Adelaide: Coroner's Court.

Goldratt, E. M. (1987). The Goal. Great Barrington, MA: The North River Press.

Goldratt, E. M. (1990). What is this thing called the Theory of Constraints and how should it be implemented. Croton-on-Hudson: The North River Press.

Johnson, C. W., Wright, P. C., & McCarthy, J. C. (1995). Using a formal language to support natural language in accident reports. Ergonomics, 38, 1264-1282.

Ladkin, P. B., & Loer, K. (1998). Why-Because Analysis: formal reasoning about incidents. Bielefeld: University of Bielefeld.

Mabin, V., & Balderstone, S. (1998). A bibliographic review of the Theory of Constraints. Wellington: Victoria University.

Mabin, V. J., & Balderstone, S. J. (2003, Jan 15-16 2003). The performance of the Theory of Constraints: a review of published reports of Theory of Constraints applications. Paper presented at the Theory of Constraints Conference 2003: Profitting from strategic constraint management, Kuala Lumpur.

NTSB. (2004). FedEx landing crash in Tallahassee. Washington, DC: National Transportation Safety Board.

Reason, J. (1991). Identifying the latent causes of aircraft accidents before and after the event. Paper presented at the 22nd International seminar of the International Society of Air Safety Investigators.

[1] Where not otherwise stated, information comes from the official investigation report (TAIC, 1995)

Stevens, R., Brook, P., Jackson, K., & Arnold, S. (1998). Systems engineering: coping with complexity. Harlow: Pearson Education.

Taylor, A. F. (1998). Airworthiness requirements: accidents investigation and safety recommendations. Paper presented at the 29th international Seminar of the International Society of Air Safety Investigators, Barcelona.

Walker, M. (2003, 31 May - 1 June 2003). Reasoning with the Reason model. Paper presented at the ANZSASI Regional Seminar 2003, Maroochydore.

Ansett Current Reality Tree

The aircraft was on a non-precision instrument approach to Palmerston North. The starboard main leg stayed up when the undercarriage was selected down. The crew attempted to lower the leg using the emergency system, and while they were doing this the aircraft struck a hill. Of the 21 occupants, 4 were killed, and fourteen were seriously injured.

Formal analyses using Multilinear Events Sequencing (showing the timeline and interrelationship of events) and Why-Because Analysis (showing the causal relationships between events and underlying conditions) were performed, with the available information, as a necessary preliminary.

The TOC uses a set of logical networks to depict the existing situation, the situation one would like to bring about, and the way to make the transition from the existing situation to the desirable, future situation. The existing situation is called the 'Current Reality Tree', and it is the formation of the current reality tree from the accident information that is the subject of this paper. The analysis starts by listing the undesirable effects brought to light by the preliminary analysis.

The impact of an aircraft on a mountain is clearly an undesirable effect, but so is a Ground Proximity Warning System (GPWS) that does not function properly, an undercarriage that malfunctions, a pilot who is untrained in emergency procedures, and so on. These undesirable effects can be put into a chronological array (Figure 56). Notice that the entities are called 'effects'. They are not causes. They have come about because of underlying conditions. It is those conditions that are now sought, as the linkages between effects are identified. This can be done in any order, but it may be convenient to start near the base – that is, early in time.

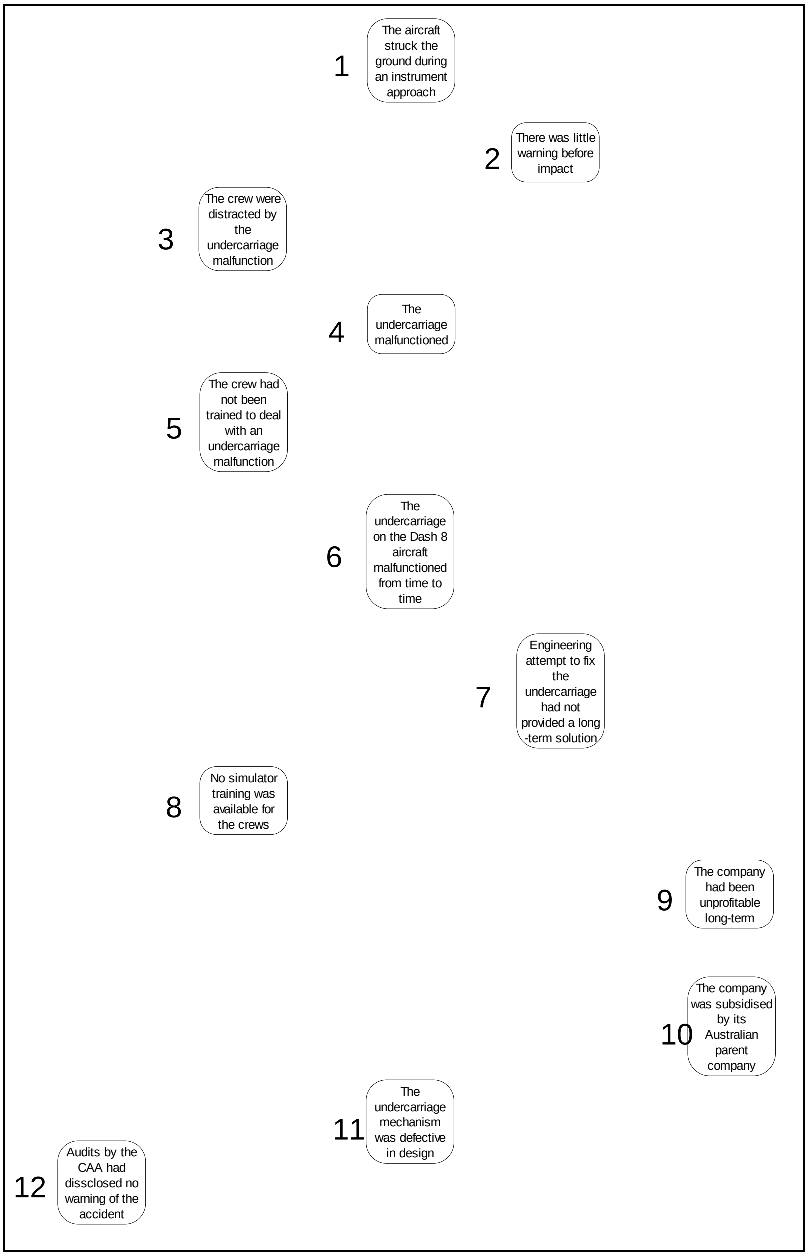

Figure 56. Undesirable effects in the Ansett Dash 8 accident.

Key:

1. The aircraft struck the ground during an instrument approach
2. There was little warning before impact
3. The crew were distracted by the undercarriage malfunction
4. The undercarriage malfunctioned
5. The crew had not been trained to deal with an undercarriage malfunction
6. The undercarriage on the Dash 8 aircraft malfunctioned from time to time
7. Engineering attempts to fix the undercarriage had not provided a long-term solution
8. No simulator training was available for the crews
9. The company had been unprofitable long-term
10. The company was subsidised by its Australian parent company
11. The undercarriage mechanism was defective in design
12. Audits by the CAA had disclosed no warning of the accident

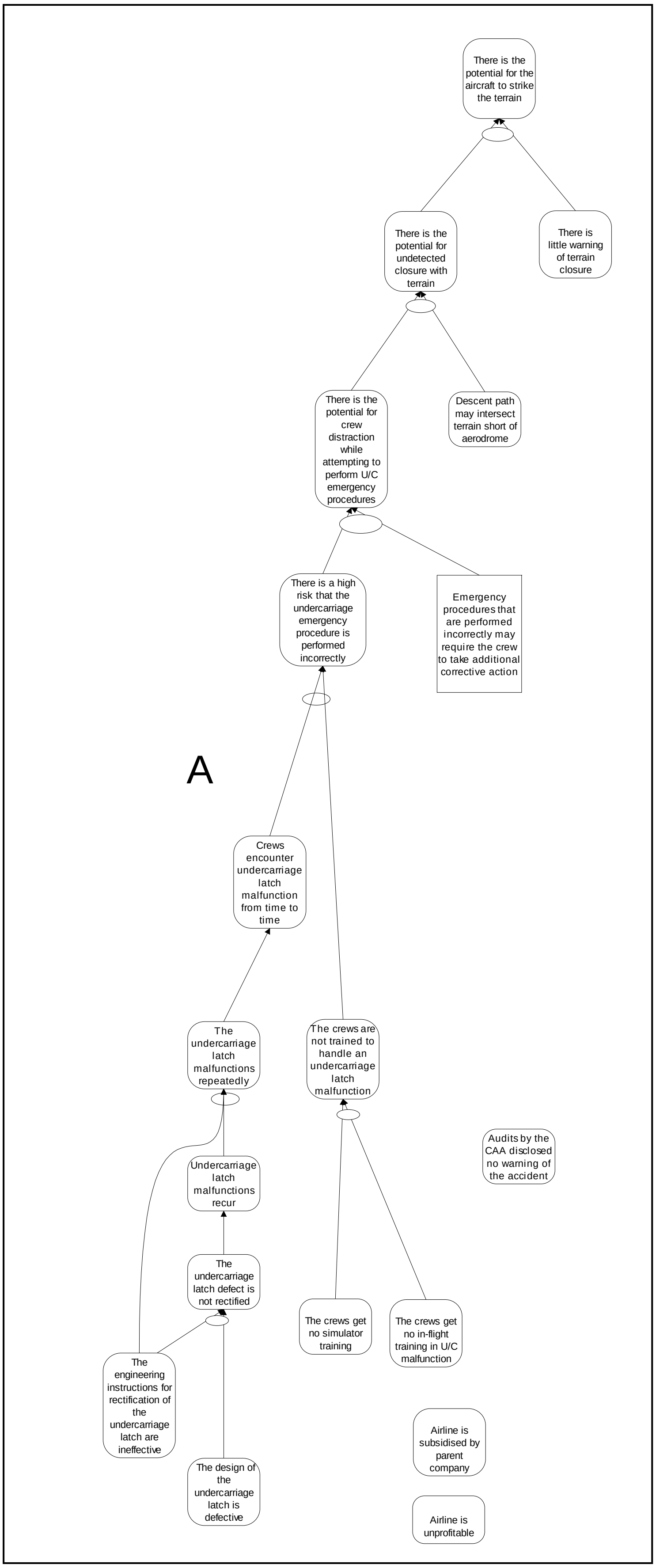

Figure 57. Connections between undercarriage latch design and potential to strike terrain.

In general, the linkages between undesirable effects will not be direct links, and additional information must be found to provide necessary and sufficient connections[2]. One stream of linkages is shown in Figure 57. This depicts the connection between the defective design of the undercarriage latch, and the potential for the aircraft to strike the terrain[3]. This stream reads:

If the design of the undercarriage latch is defective *and* the engineering instructions for the rectification of the undercarriage latch are ineffective, *then* the undercarriage latch defect is not rectified.

If the undercarriage latch defect is not rectified, *then* undercarriage latch malfunctions occur.

If undercarriage latch malfunctions occur *and* the engineering instructions for rectification of the undercarriage latch are ineffective, *then* the undercarriage latch malfunctions repeatedly.

If the undercarriage latch malfunctions repeatedly, *then* crews encounter undercarriage malfunctions from time to time.

Turning now to the crew training stream:

If the crews receive no simulator training *and* the crews receive no in-flight training in undercarriage malfunction, *then* the crews are not trained to manage an undercarriage malfunction.

Combining these two streams:

If crews encounter undercarriage malfunctions from time to time *and* the crews are not trained to handle an undercarriage malfunction, *then* there is a high risk that the undercarriage emergency procedure will be performed incorrectly[4].

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[2] In depicting necessary and sufficient conditions, an ellipse represents a logical 'and'. Where arrows enter an entity without passing through an ellipse, there is an additive effect.
[3] The diagrams are available from the authors, in Windows Metafile (.wmf) format. These can be opened in any Windows application, and printed to any convenient scale without loss of definition.
[4] The company relied, in effect, on the crews reading the emergency procedures from the aircraft documentation, as a substitute for training. However, in the accident sequence the co-pilot missed one

If there is a high risk that the undercarriage emergency is performed incorrectly *and* emergency procedures that are performed incorrectly may require the crew to take further corrective action, *then* there is the potential for crew distraction while attempting to perform undercarriage emergency procedures.

If there is the potential for crew distraction while attempting to perform undercarriage emergency procedures *and* the descent may intersect terrain short of the aerodrome, *then* there is the potential for undetected closure with terrain.

If there is the potential for undetected closure with terrain *and* there is little warning of terrain closure, *then* there is the potential for the aircraft to strike the terrain.

There is a common theme underlying some of the early effects. The engineers decided not to spend $20 000 to maintain the undercarriage and so avoid malfunctions (Ansett (NZ), 1994a; Bombardier, 1994), while the training of pilots to manage such emergencies was limited or non-existent, and there was no record of any recurrent training (Ansett (NZ), (n.d. a), (n.d. b)). These are indicative of financial stress, and the way this stress came about is evident in Figure 58.

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step, and there was the possibility of locking the undercarriage irretrievably, with one main wheel up and one down. This got the Captain’s attention.

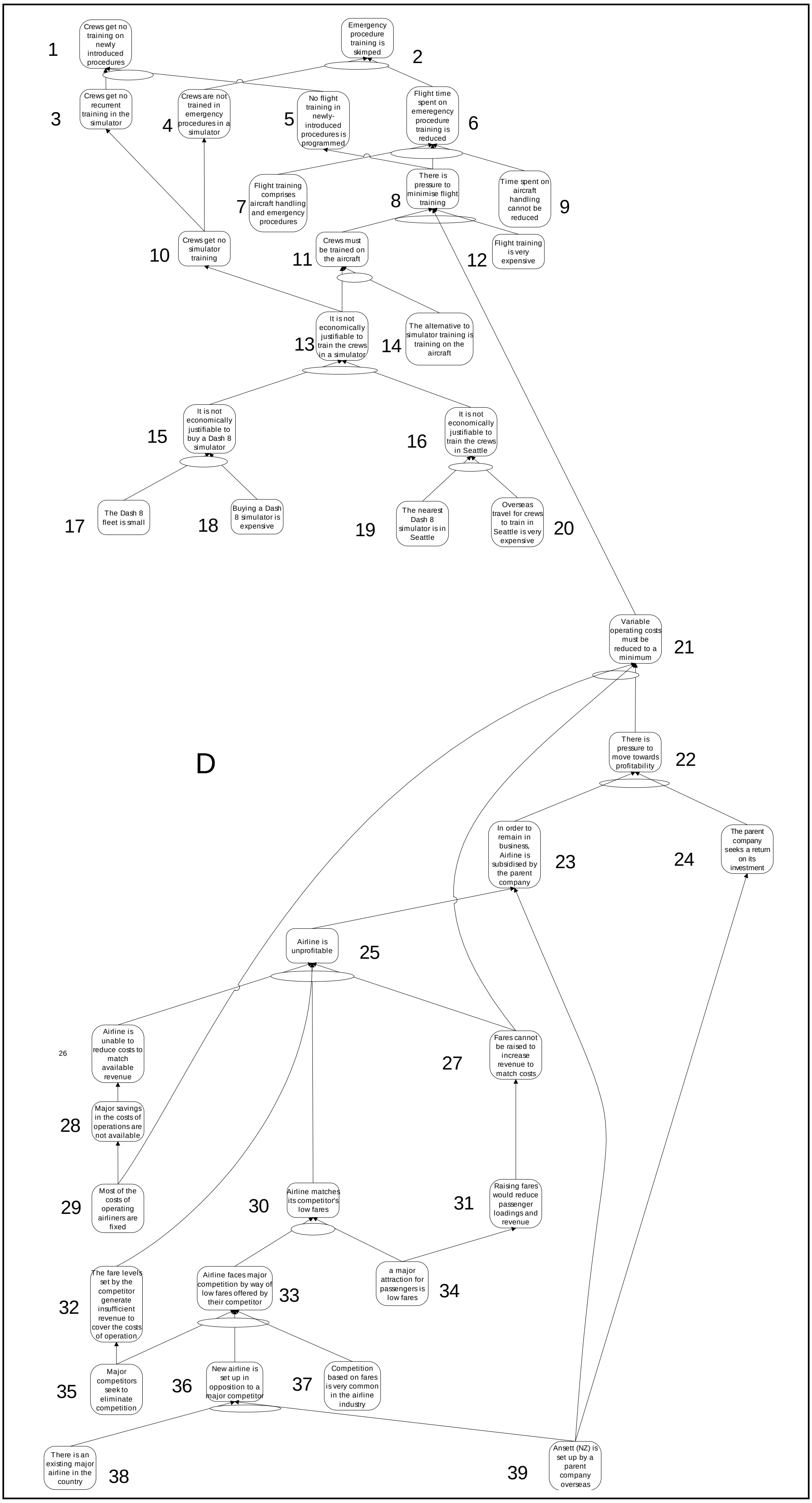


Figure 58. Financial stress and emergency training.

Key:

1. Crews get no training on newly introduced procedures
2. Emergency training is skimped
3. Crews get no recurrent training in the simulator
4. Crews are not trained in emergency procedures in a simulator
5. No flight training in newly introduced procedures is programmed
6. Flight time spent on emergency procedures is reduced
7. Flight training comprises aircraft handling and emergency procedures
8. There is pressure to minimise flight training
9. Time spent on aircraft handling cannot be reduced
10. Crews get no simulator training
11. Crews must be trained on the aircraft
12. Flight training is very expensive
13. It is not economically justifiable to train the crews on a simulator
14. The alternative to simulator training is training on the aircraft
15. It is not economically justifiable to but a Dash 8 simulator
16. It is not economically justifiable to train the crews in Seattle
17. The Dash 8 fleet is small
18. Buying a Dash 8 simulator is expensive
19. The nearest Dash 8 simulator is in Seattle
20. Overseas travel for crews to train in Seattle is expensive
21. Variable operating costs must be reduced to a minimum
22. There is pressure to move towards profitability
23. In order to remain in business, Ansett (NZ) is subsidised by the parent company
24. The parent company seeks a return on its investment
25. Ansett (NZ) is unprofitable
26. Ansett is unable to reduce costs to match available revenue
27. Fares cannot be raised to increase revenue to match costs
28. Major savings in the costs of operations are not available
29. Most of the costs of operating airliners are fixed
30. Ansett matches its competitors low fares
31. Raising fares would reduce passenger loadings and revenue
32. The fare levels set by the competitor are insufficient to cover the costs of operation
33. Ansett faces major competition by way of low fares offered by their competitor
34. A major attraction for passengers is low fares
35. Major competitors seek to eliminate competition
36. Ansett is set up in opposition to a major competitor
37. Competition based on fares is very common in the airline industry
38. There is an existing major airline in New Zealand
39. Ansett (NZ) is set up by a parent company in Australia

The Government of the day had said previously that it wanted to ‘stoke up competition’ in air transport ("Safety in the Sky," 1990), and an overseas airline, Ansett Australia was encouraged to set up in opposition to the national carrier, Air New Zealand. The established airline was determined to preserve its position, and was well able to do so, because it could cross-subsidise internal flights from its international operations. The effect was that the fares that the new airline, Ansett (New Zealand) was able to charge were too low to generate a profit ("Ansett Announcement," 1994; "Ansett loss announcement," 1995).

The overseas parent company would expect a return on its investment in due course, but the avenues available for cost reduction were few. These cost reduction efforts were focussed on maintenance (see, for example, (Ansett (NZ), 1993a) and flying training, as indicated below. These may have resulted from staff perception of the company’s financial situation (see ("Ansett Announcement," 1994).

The Dash 8 fleet was small (initially two aircraft, later increased to three) and the parent company did not operate this type. The purchase of a simulator could not be justified, and the nearest simulator was in Seattle. To avoid the expense of sending crews to Seattle, it was decided that all training would be performed on the aircraft. However, air training is very expensive and, in any case, the aircraft were needed for line flying, so there was pressure to minimise crew training. It was established that the co-pilot on the accident aircraft had *never* been shown the emergency undercarriage operation, let alone practised it (Zotov, 2001). Defects in the checklist, which should have come to light if the procedure was practised, were not identified. Further, with the absence of recurrent training, new Air Traffic Control procedures were not practised in a controlled environment (see Figure 59).

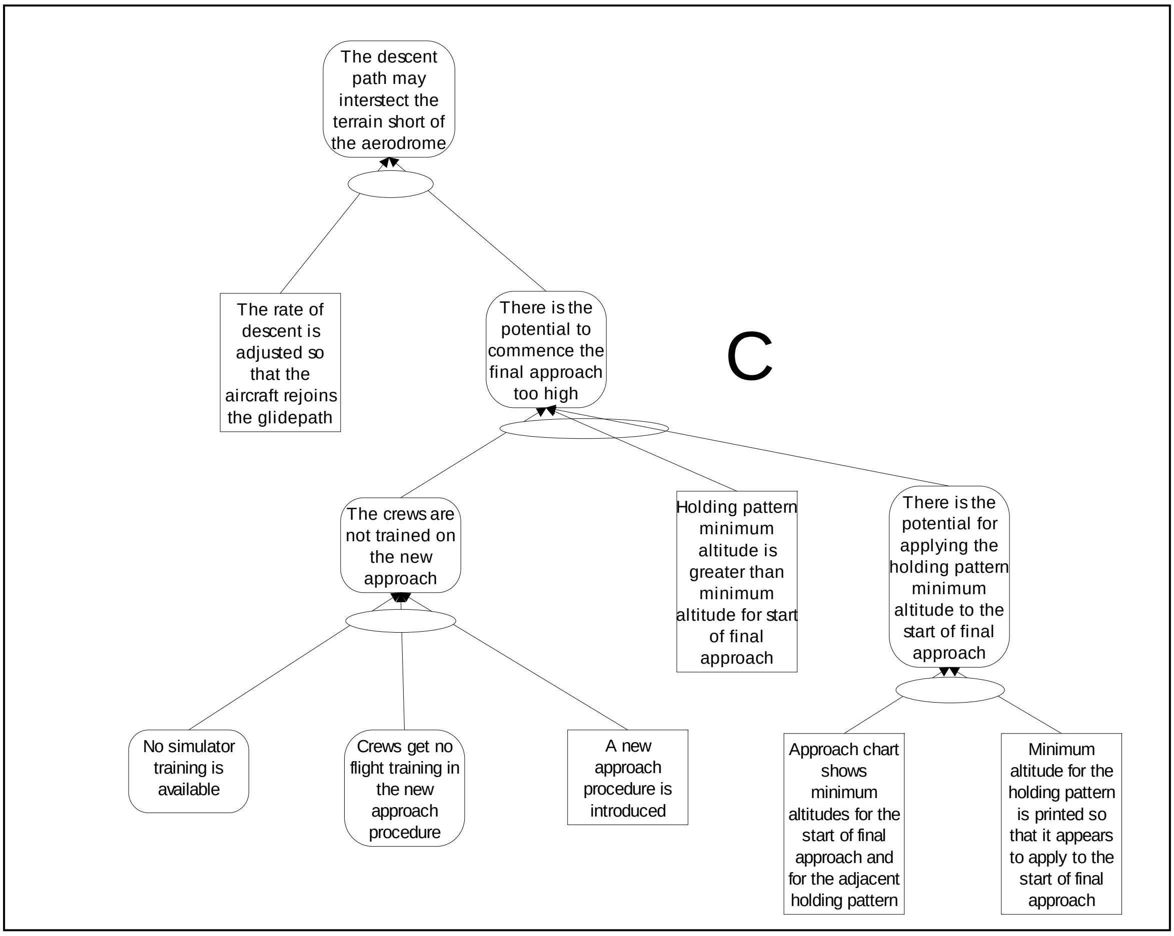


Figure 59. Lack of continuation training – approach procedure.

1. The descent path may intersect the terrain short of the aerodrome
2. The rate of descent is adjusted so that the aircraft rejoins the glidepath
3. There is the potential to join the final approach too high
4. The crews are not trained on the new approach
5. Holding pattern minimum altitude is greater than minimum altitude for start of final approach
6. There is the potential for applying the holding pattern minimum altitude to the start of final approach
7. No simulator training is available
8. Crews get no training in the new approach procedure
9. A new approach procedure is introduced
10. Approach chart shows minimum altitudes for the start of final approach and for the adjacent holding pattern
11. Minimum altitude for the holding pattern is printed so that it appears to apply to the start of the final approach

Maintenance Aspects:

The Engineering review committee decided that $20 000 was too much to spend on replacement undercarriage parts. Without consultation, they decided that an undercarriage ‘hang-up’ – that is, an undercarriage leg that was slow to descend or failed to descend when the undercarriage was selected ‘Down’ - had no safety implications, because the pilot could always use the emergency procedure (Ansett (NZ), 1993a, 1994a, 1994b, (n.d. c); Bombardier, (n.d.)) (Figure 60).

Instead of replacing the defective parts, the problem would be fixed. Unfortunately, the ‘fix’ was an instruction to ‘check [the up-lock latch] for wear’ (Ansett (NZ), 1992). The shop floor workers interpreted this as ‘run a thumbnail over it’ (Ansett (NZ), 1996), unaware that the wear they were looking for was of the order of a few thousandths of an inch, over an area perhaps a quarter of an inch wide (Messier Dowty, 1995). Not surprisingly, the wear was not detected, and hang-ups recurred. No-one in the maintenance section realised that the hang-ups were recurring more and more often (Zotov, 2001). This was a sure sign of increasing wear, but was not recognised as such. Ultimately, the nuisance value of repeated unscheduled hangar visits persuaded the engineers to order replacement parts. By this time there were insufficient parts available from the manufacturer to replace all units, and the starboard leg latch on the accident aircraft was not replaced.

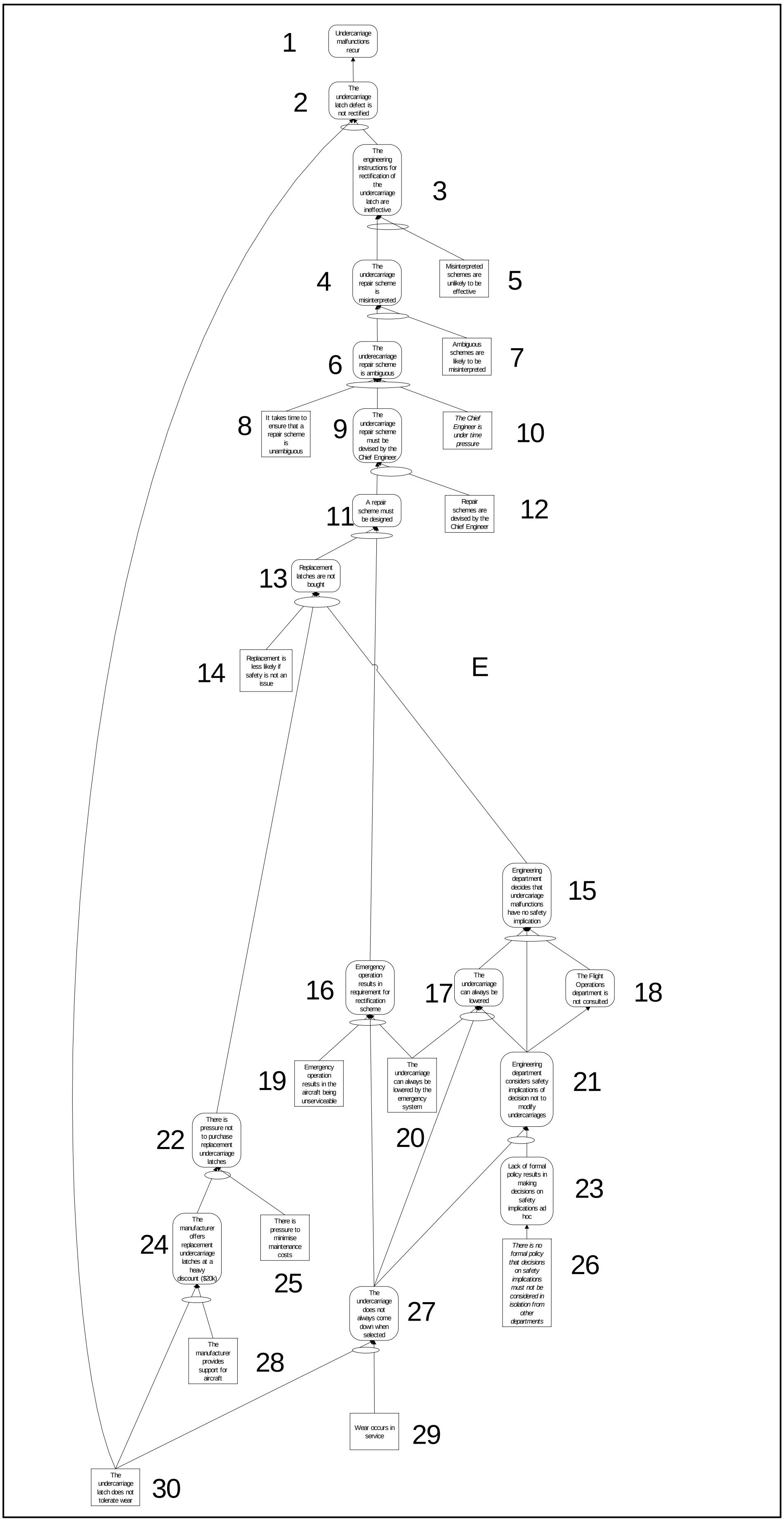


Figure 60. Maintenance aspects.

Key

1. Undercarriage malfunctions recur
2. The undercarriage latch defect is not rectified
3. The engineering instructions for rectification of the undercarriage latch are ineffective
4. The undercarriage repair scheme is misinterpreted
5. Misinterpreted schemes are unlikely to be effective
6. The undercarriage repair scheme is ambiguous
7. Ambiguous schemes are likely to be misinterpreted
8. It takes time to ensure that a repair scheme is unambiguous
9. The undercarriage repair scheme must be devised by the Chief Engineer
10. *The Chief Engineer is under time pressure*
11. A repair scheme must be devised
12. Repair schemes are devised by the Chief Engineer
13. Replacement parts are not bought
14. Replacement is less likely if safety is not an issue
15. Engineering decides that undercarriage malfunctions have no safety implication
16. Emergency operation results in a requirement for a rectification scheme
17. The undercarriage can always be lowered
18. Flight Operations are not consulted
19. Emergency operation results in the aircraft being unserviceable
20. The undercarriage can always be lowered by the emergency system
21. Engineering considers safety implications of decision not to modify undercarriages
22. There is pressure not to purchase replacement undercarriage latches
23. Lack of formal policy results in making decisions on safety implications ad hoc
24. The manufacturer offers replacement undercarriage latches at a heavy discount ($20k)
25. There is pressure to minimise maintenance costs
26. There is no formal policy that decisions on safety implications must not be considered in isolation from other departments
27. The undercarriage does not always come down when selected
28. The manufacturer provides support for the aircraft
29. Wear occurs in service
30. The undercarriage latch does not tolerate wear

The Safety Department

Various matters should have come to the notice of the Safety Department. The repeated hang-ups, and their increasing frequency, were readily apparent using standard methods (ICAO, 1984). Risk management would suggest that, as a minimum, the crews should have been given recurrent training in handling undercarriage emergencies. Internal audit should have brought to light the lack of recurrent training.

However, the repeated hang-ups and increasing frequency were not noticed, no recurrent training in undercarriage emergencies was provided, and no internal audit detected this omission, because the Safety Department had been abolished (Figure 6). No individual was responsible for safety management. Rather than a dedicated Safety Department, it was announced that ‘safety was everybody’s responsibility’ (Ansett (NZ), 1993b).The implication is that this was done to reduce costs, but evidence on this point is not available[5]. A part-time Safety Coordinator was appointed, who perceived his function as developing Crew Resource Management training, to enable crews to make the most of the resources at their disposal.

[5] Shortly after the Board minutes dealing with the abolition were demanded by Counsel for the passengers, in litigation against Ansett, the Company settled out of court

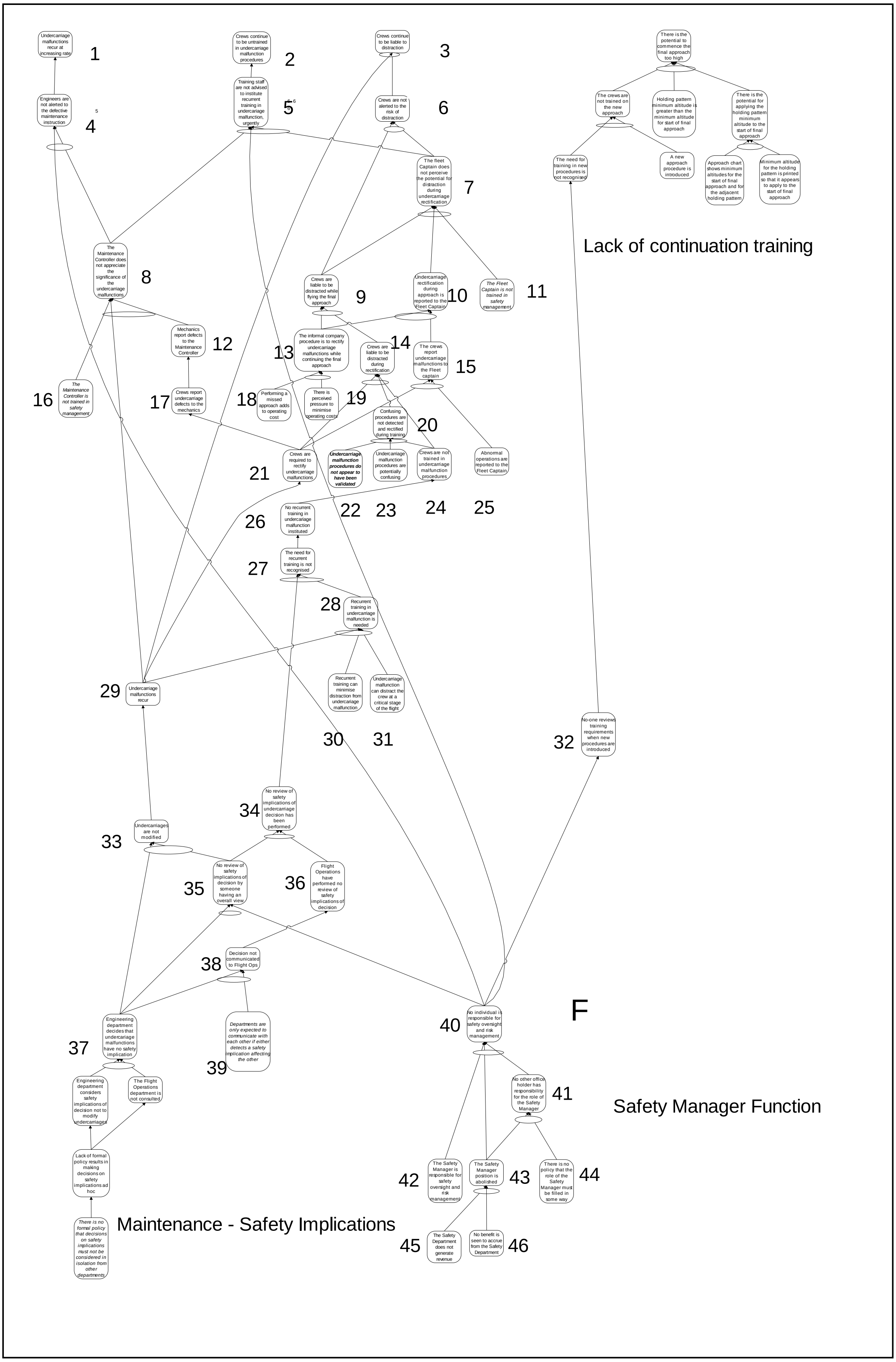


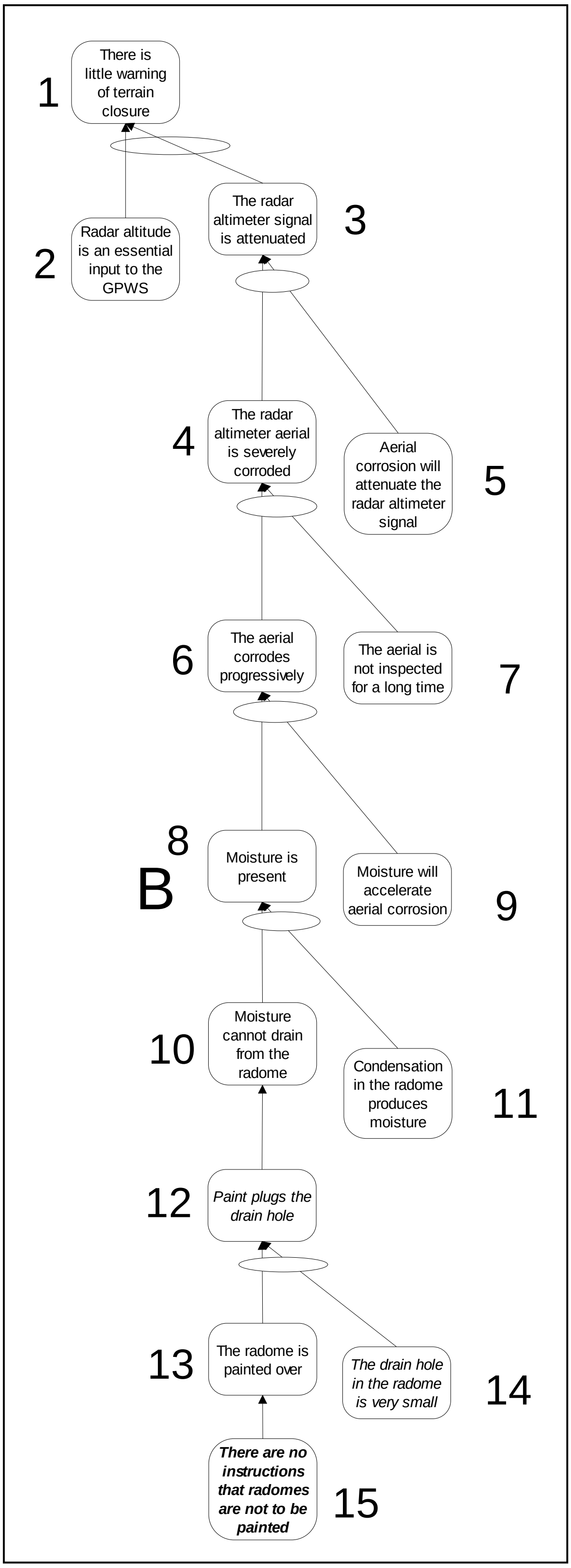
Figure 61. Absence of a Safety Manager.

1. Undercarriage malfunctions occur at increasing rate
2. Crews continue to be untrained in undercarriage malfunction procedures
3. Crews continue to be liable to distraction
4. Engineers are not alerted to the defective maintenance instruction
5. Training staff are not advised to institute recurrent training in undercarriage malfunction procedures, urgently
6. Crews are not alerted to the risk of distraction
7. The Fleet Captain does not perceive the risk of distraction during undercarriage rectification
8. The Maintenance Controller does not appreciate the significance of the undercarriage malfunctions
9. Crews are liable to be distracted while flying the final approach
10. Undercarriage rectification during approach is reported to the Fleet Captain
11. *The Fleet Captain is not trained in safety management*
12. Mechanics report defects to the Maintenance Controller
13. The informal Company procedure is to rectify undercarriage malfunctions while continuing the final approach
14. Crews are liable to be distracted during rectification
15. Crews report undercarriage malfunctions to the Fleet Captain
16. *The Maintenance Controller is not trained in safety management*
17. Crews report undercarriage defects to the mechanics
18. Performing a missed approach adds to the operating costs
19. There is perceived pressure to minimise operating costs
20. Confusing procedures are not detected and rectified during training
21. Crews are required to rectify undercarriage malfunctions
22. *Undercarriage malfunction procedures do not appear to have been validated*
23. Undercarriage malfunction procedures are potentially confusing
24. Crews are not trained in undercarriage malfunction procedures
25. Abnormal procedures are reported to the Fleet Captain
26. No recurrent training in undercarriage malfunction procedures is instituted
27. The need for recurrent training is not recognised
28. Recurrent training in undercarriage malfunction is needed
29. Undercarriage malfunctions recur
30. Recurrent training can minimise distraction from undercarriage malfunction
31. Undercarriage malfunction can distract the crew at a critical stage of flight
32. No-one reviews training requirements when new procedures are introduced
33. Undercarriages are not modified
34. No review of safety implications of undercarriage decision has been performed
35. No review of safety implications of decision, by someone having an overall view
36. Flight Operations have performed no review of safety implications of decision
37. Engineering department decides that undercariage malfunctions have no safety implication
38. Decision not communicated to Flight Operations
39. *Departments are only expected to communicate with each other if either detects a safety implication affecting the other*
40. No individual is responsible for safety oversight and risk management
41. No other office holder has responsibility for the role of Safety Manager
42. The Safety Manager is responsible for safety oversight and risk management
43. The Safety Manager position is abolished
44. There is no policy that the role of Safety Manager must be filled in some way
45. The safety Department does not generate revenue
46. No benefit is seen to accrue from the Safety Department

Ground Proximity Warning System

Other factors did not help the crew of the accident aircraft, not least the shortness of warning from the Ground Proximity Warning System (GPWS). The deficiencies underlying the brief warning (about four seconds, when 17 seconds' warning should have been available) are shown in Figure 62.

It can be deduced that the aerial corrosion which resulted in deficient GPWS performance (Morgan, 2001)was a consequence of the radome being painted (it should not have been). How the radome came to be painted over is not known, but it does not reflect favourably on the airline's maintenance procedures.



1. There is little warning of terrain closure

2. The radar altimeter signal is attenuated

3. Radar altitude is an essential input to the GPWS

4. The radar altimeter aerial is severely corroded

5. Aerial corrosion will attenuate the radar altimeter signal

6. The aerial corrodes progressively

7. The aerial is not inspected for a long time

8. Moisture is present

9. Moisture will accelerate aerial corrosion

10. Moisture cannot drain from the radome

11. Condensation in the radome produces moisture

12. Paint plugs the drain hole

13. The radome is painted over

14. The drain hole in the radome is very small

15. There are no instructions that radomes are not to be painted

Figure 62. Shortness of GPWS warning.

Current Reality Tree

These various clusters of conditions can be joined to form the Current Reality Tree (Figure 63).

The CRT has a definite origin, and it should be no surprise that this shows a fundamental conflict between profitability and safety. The Theory of Constraints argues that, if one can address such fundamental problems, then – since *all* the undesirable effects stemmed from them, the entire problem is resolved. However, this core conflict arose from fundamental Government policy that air travel should be opened up to competition, and was thus likely to prove intractable.

In practice, a CRT will often disclose a number of ‘core problems’ (perhaps three or four) from which a significant number of effects stem (Dettmer, 1997)[6]. Eliminating one of these ‘core problems’ will eliminate all of the effects downstream of that core problem. These core problems can be identified by the large number of downstream effects they generate, and a simple indicator of this is the number of effect lines radiating from a single entity. In the Ansett CRT, the maximum number of outgoing effect lines from a single entity was four (prior to inserting linkages to the CRT for the NZ Civil Aviation Authority (CAA), discussed later). Accordingly, for the present study, core problems were defined as those from which stemmed four or more effects. There were four such entities. These, emphasised in Figure 63, should be fruitful points to address:

- The need to minimise costs in all departments
- The Engineering department decision that undercarriage failure had no safety implications
- There was no individual responsible for safety oversight
- Undercarriage malfunctions recurred.

[6] It may be that this happens where there is a ‘system of systems’: potentially, there might be a core problem in each system. However, this has not yet been established.

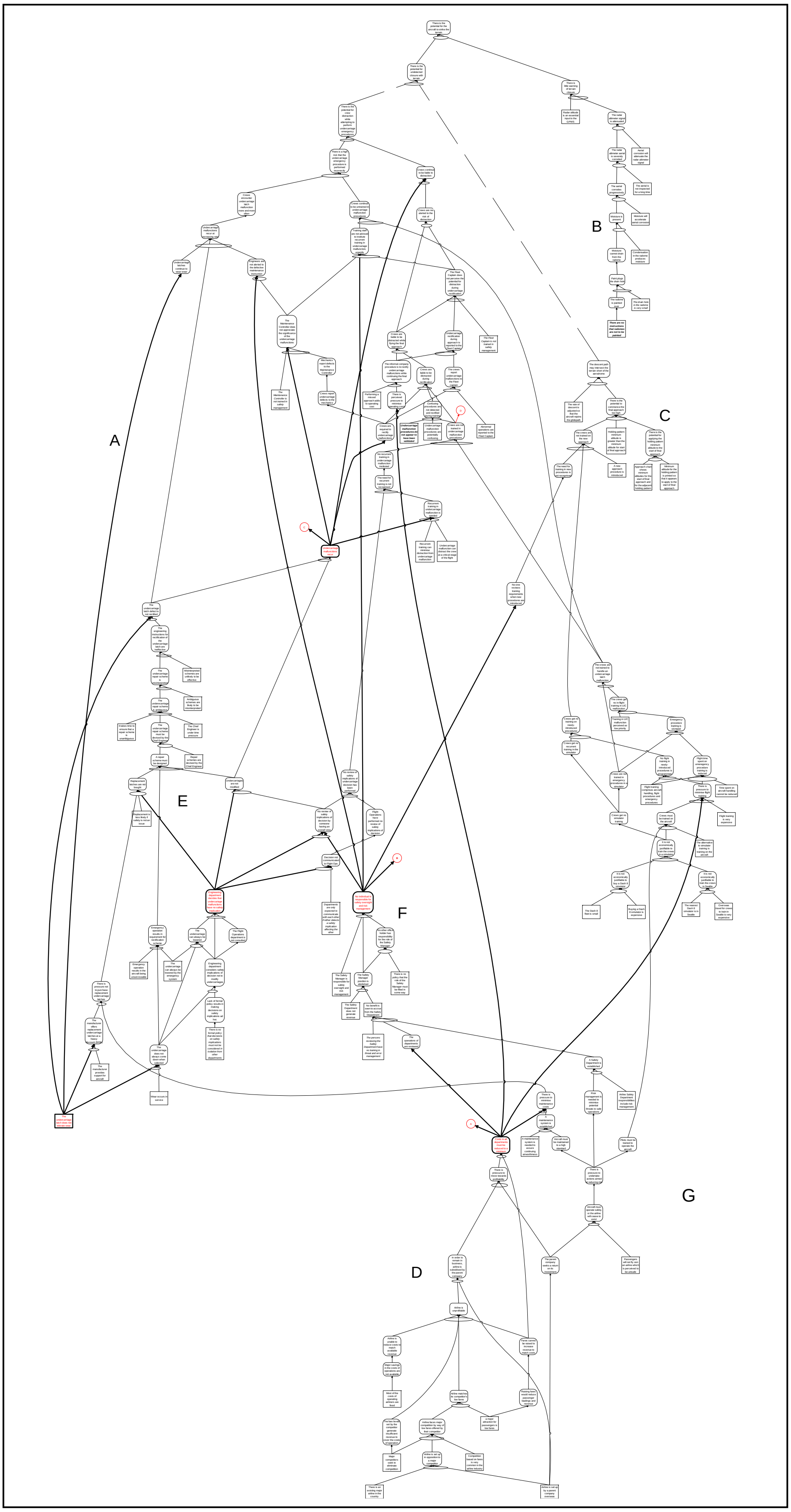


Figure 63. Ansett Dash 8 Current Reality Tree.

A number of points are evident:

1. The structure of this accident does not lend itself readily to the use of the ‘Swiss Cheese’ analogy (Reason, 1997). The defective GPWS was a failed defence, but that, of itself, is of little value in averting future accidents. The absence of a Safety Department could be also be termed an absent defence, since there was no mechanism for cross-functional synchronisation – ‘one hand couldn’t know what the other hand was doing’. However, the concept of layers of defences is certainly not there.

2. An alternative analogy, suggested by Harris, is the comparison with a fail-safe engineering structure (Harris, D. 2003, personal communication). In a fail-safe structure, the load is taken by a primary path, and there is a redundant path available to take the load should the primary structure fail. There must also be some means of alerting to show that the primary structure has failed, so that it can be rectified. Here, the engineering department, which should have produced serviceable aircraft, was the primary load-path. This path failed. The redundant load-path was the aircrew, who should have been able to manage the aircraft when the primary undercarriage system failed. The alerting system should have been defect monitoring, by the safety department or another responsible group. There was no alerting system, so the failed primary path was not rectified in sufficient time to avert the accident. Due to the lack of training, the redundant path supposedly provided by the aircrew also failed. The second redundant path, the GPWS, had already failed, although it was not known at the time.

3. Reason (1990) has likened latent failures to pathogens within a body. Perhaps a more useful analogy might be that the core problems are tumours. They spread their tendrils throughout the body, and trigger further tumours. Like tumours, core problems need to be excised if the body is to survive. How this could be done will be examined in the second study depicting the Future Reality Tree, to be reported separately.

4. The dashed lines near the top of the tree indicate potentiation. While the solid connecting lines show necessary and sufficient linkages, the

dashed lines indicate that something more is needed before the next stage follows. That ‘something’ is a random event or condition. There were two such variables which affected the accident flight, and which (as far as can be determined) did not affect its precursors:

- The aircraft was in cloud which extended down to the terrain, and it appears that previous flights on which the undercarriage malfunctioned were in visual meteorological conditions (Ansett Captain, 1988, 1993, 1994, 1995), and
- The undercarriage warning was perceived just as the aircraft crossed the glidepath from above (Zotov, 2001).

The *potential* for the accident was there before. However, the circumstances meant that this potential was tipped over into actuality.

The base of the CRT suggests that, given the state of commercial law, which had no prohibition on predatory pricing practices, there was limited likelihood that Ansett (NZ) could ever operate profitably. It need not have taken an accident to make this point, and it is an argument for the construction of a Future Reality Tree as a means of decision-making. However, the corollary is that there might have been little point in the investigating authority making safety recommendations to the airline. The implementation of safety recommendations almost invariably costs money, and there was a limited prospect of Ansett (NZ) generating the necessary revenue. Only if Ansett Australia was prepared to continue subsidising New Zealand travellers indefinitely could the airline find the funds to make safety improvements. Alternatively, the Government could have used taxpayers’ funds to assure travellers’ safety, but the Government was adamant that it would not do so ("AIA Conference Report," 1994).

The alternative to making recommendations to Ansett (NZ) was for the investigating authority to demonstrate the latent failures at Ansett (that is, the policy and management decisions giving rise to unsafe conditions) to the Civil Aviation Authority (CAA). It would then have been open to the CAA to direct that Ansett address these failures. If Ansett was unable to do so, that would have provided grounds for suspension of the airline’s Operating Certificate. Further, the knowledge that such latent failures had occurred should have been grounds for increased safety oversight by the CAA.

While the purpose of constructing the CRT is to make the first step towards constructing a Future Reality Tree (FRT) in which the undesirable effects no longer arise, inspection of the CRT has already given clues to how improvements should be made.

The five effect lines from the condition ‘No individual is responsible for safety oversight and risk management’ categorise it as a core problem, and highlight the unwisdom of the decision to abolish the position of Safety Manager. It is perhaps not surprising that the Ansett Board should seek to save money on an apparently unproductive area such as the Safety Department. The position of Safety Manager might, therefore, be an area in which prescriptive regulation is appropriate, since the raison d’etre of the CAA is risk management on behalf of the public.

The condition ‘undercarriage malfunctions recur’ also has five effect lines radiating from it. This indicates that the decision not to modify the undercarriage was flawed. However, this was a matter of ordinary company operation. Erroneous decisions are to be expected from time to time. What is essential is that the effects arising from faulty decisions should be recognised before they can do harm. There were many precursor events before the accident resulted, and thus, there were many opportunities to recognise that there was a problem and, thereby, intervene. Ordinarily, the Safety Department would be the department responsible for risk management. However, having abolished the position of Safety Manager, the company had deprived itself of an important source of what Weick and Sutcliffe refer to as ‘mindfulness’, or the ability to detect the unexpected and react to it before serious harm can result (Weick & Sutcliffe, 2001). The CAA, on behalf of the public, also had a duty to detect that all was not well, and intervene to prevent an accident. Given that there were many precursor events, how did it happen that the CAA was unaware of the impending disaster?

Were there features of the CRT which would have justified action by the CAA, had it been aware of them?

The Current Reality Tree: Civil Aviation Authority

There was, at the time, no statutory requirement for an airline to have a safety management system. Nevertheless, the action of abolishing the safety department ought to have caused disquiet, at the very least. The CAA had been informed of this action, but made no inquiry as to the reason, or how the deficiency in safety oversight was to be made good (NZCAA, 1995). The CAA auditors were unaware that the safety department had been abolished.

The recurring undercarriage defects, requiring regular use of the emergency system, were known to the airworthiness department of the CAA, but the implications as to the quality of maintenance were overlooked, and it appears that no-one saw fit to advise the operations section of the CAA. The auditors were not, therefore, alerted to look at what emergency procedures training the pilots might be receiving.

The co-pilot's training records certified that he had been trained in undercarriage malfunction procedures (Ansett (NZ), (n.d. a)), but this was incorrect (Zotov, 2001). The erroneous entry in the co-pilot's training records was clearly a serious matter. It was discoverable on audit, but some prompt would have been needed for the auditors to review the records in sufficient depth to identify it.

The lack of simulator training was self-evident, and it would have been appropriate for the auditors to ask how the deficiency in training was being made good, particularly in regard to emergency and continuation training. Evidently they did not, and this raises questions about their background experience in airline operations (though there could have been other reasons for the oversight).

With the exception of the original undercarriage design defect which set the accident sequence in motion, the core problems are all amenable to regulatory action. Compelling the company to perform appropriate maintenance, train crews in emergency procedures, and re-instate its safety department, might have imposed costs beyond Ansett (NZ)'s resources. Such action might then have resulted in the suspension of the Operating Certificate but, in that case, it would none-the-less have averted the deaths of passengers. This, therefore, raises the question of what the problems were in the CAA, that prevented it from taking effective action.

To consider why CAA oversight did not identify the weaknesses in Ansett which led to the accident, it is necessary to look at the CRT from the CAA perspective[7].

Prior to the formation of the CAA in 1990, its predecessor, the Civil Aviation Division (CAD) of the Ministry of Transport[8], had performed its function of the safety oversight of air transport by conducting surveillance in accordance with the ICAO Standards and Recommended Procedures (ICAO, 1995). However, the CAD was significantly understaffed for the work that it was required to do, largely as a result of a Government policy of 'downsizing' ("Safety in the Sky," 1990). This resulted in severe criticism of the CAD by two Courts of Inquiry, convened to inquire into two air transport accidents (Carruthers, 1988, 1989). The amount and quality of surveillance performed was found to have fallen short of that required. Additionally, a review of documentation by Division staff, prior to the accidents, would have had the potential to alert the airline inspectors to the shortcomings that led to those accidents. In 1990, the CAA sought an alternative to surveillance, which it recognised that it had not the staff to perform.

Following the Skyferry Court of Inquiry (Carruthers, 1988), an independent review of civil aviation regulation and monitoring (the Swedavia Review) recommended that the regulatory authority needed a suite of monitoring tools, particularly surveillance of operations and auditing of documentation (Swedavia AB & McGregor and Company, 1988). The Swedavia Review argued that operators would act responsibly because it was in their interests to do so, so that a primary function of the CAA should be to ensure that operators had satisfactory systems in place which would ensure safe operation. The CAA decided to discard the surveillance role, and confine itself to auditing (NZCAA, 1994). Further, such audits would be largely confined to a review of safety system documentation (ibid, 'Audit Tools'). Therefore, the examination of outputs would be a minor function, since this would be 'surveillance' (see, for example, ("CAA Audits," 1995)). There was little surveillance of Ansett prior to the Dash 8 accident.

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[7] For convenience in presentation, the activities of the CAA will be shown in a separate diagram, the linkages between the CAA and Ansett parts of the CRT being indicated by key letters in circles.

[8] There was a transient stage when the CAD was known as the Air Transport Division of the Ministry of Transport, but this is unimportant for the present study.

A further complication, introduced at about this time, was a Government philosophy of ‘user pays’. Government bodies would not be funded from general taxation, but as far as possible, by those who benefited from the activities of those bodies. In the case of the CAA, aircraft operators were perceived to be the ‘users’, and were charged for CAA ‘services’ at a rate which was required to cover the costs of those services ("AIA Conference Report," 1994).

One consequence of the ‘user pays’ approach was that time spent on monitoring airline activities was charged at an hourly rate, and that rate was far in excess of the market rate for such activities. For example, clerical time was charged at $133 per hour ("CAA Funding," 1995). The aviation industry protested at the level of charges. In response to criticism, the CAA sought ways to minimise the time spent on auditing. In particular, since a significant proportion of audit costs was time spent on preparation such as review of documents, the preliminary reviews were minimised.

The decision to (largely) confine audits to a review of documentation had a number of effects. Abnormal events were not covered by the review, so events which might have been precursors to more serious trouble were unknown to auditors. An audit which does not examine the actuality of operations by looking at the end-product cannot detect such abnormal events. Further, not all the actions required for safe operation are capable of being documented. The flexible reactions characterised by Weick and Sutcliffe as part of ‘mindfulness’ are essential to any high reliability organisation (Weick & Sutcliffe, 2001) but, by their nature, they cannot be documented: they are a part of the organisational culture. Also, an airline may not necessarily operate in accordance with its documentation: as Clausewitz said, the map is not the terrain (Clausewitz, 1874). An audit which does not examine the actuality of operations by looking at the end-product cannot detect such non-conformance with the documentation (Arbon, Homer, & Feeler, 1998).

The consequences of a lack of knowledge of the ‘real’ operations at Ansett were two-fold. Firstly, the auditors were unaware that, in the period before the accident, Ansett had abolished the position of Safety Manager. Had they been aware of this, they would have been aware of the lack of conformity with the documentation as they believed it to be. Ansett stated that they had advised the CAA of the change, but the auditors were unaware of it (NZCAA, 1995). Had they been aware of the change, they would have been prompted to review risk management at Ansett, since a prime function of the Safety Department is risk management.

Secondly, the auditors were unaware of the history of undercarriage malfunctions in the Dash 8 fleet. (Ansett had advised the Airworthiness section at CAA, who were ‘monitoring’ the situation but had not advised the auditors). Since the auditors were unaware of the undercarriage malfunctions, they could not be expected to query the management of the associated risks, which might have led them to discover the absence of the Safety Manager. Such awareness could also have led them to query the ineffectiveness of engineering rectification of the failures, and the absence of the effective training of pilots in what had become a recurring emergency.

The undesirable effects at the CAA are shown in Figure 64.

The undesirable effect ‘Audits are ineffective in averting accidents’ is the end-point of a sequence of undesirable effects relating to auditing. Those relating to this particular accident include:

- Auditors were unaware of the absence of a Safety Manager
- Auditors were unaware of deficient crew training
- Auditors were unaware of recurring malfunctions

And, arguably,

- CAA did not perform surveillance of airline operations.

These undesirable effects are shown in Figure 64; they are written in the present tense, which by convention is used in the Current Reality Tree.

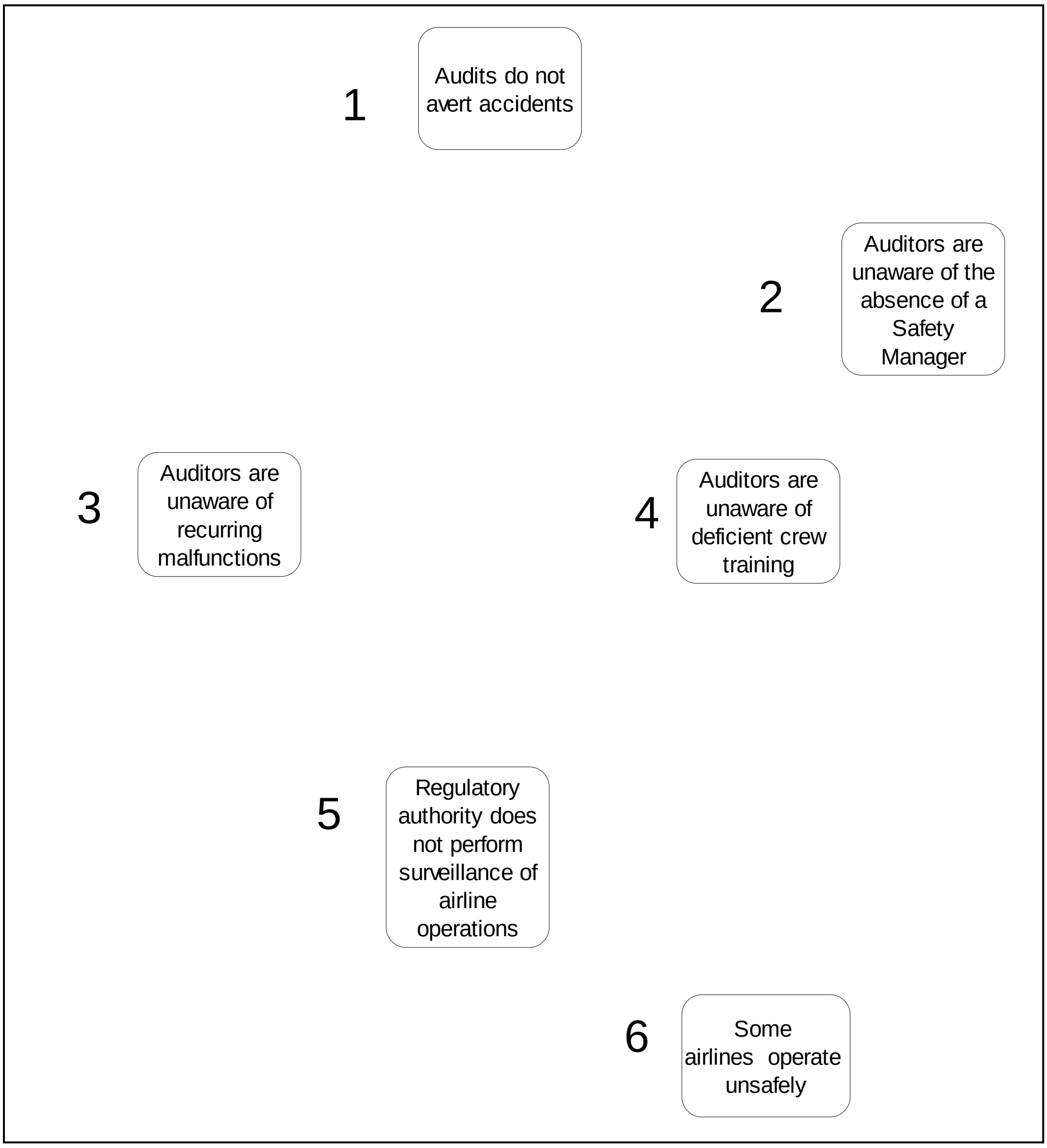


Figure 64. Undesirable effects at the CAA.

Key

1. Audits do not avert accidents
2. Auditors are unaware of the absence of a Safety Manager
3. Auditors are unaware of recurring malfunctions
4. Auditors are unaware of deficient crew training
5. Regulatory authority does not perform surveillance of airline operations
6. Some airlines operate unsafely

CAA auditing of airlines is one of the ways by which the regulatory authority can achieve safety oversight. Other components of oversight include surveillance (ICAO, 1995) and monitoring the effectiveness of an airline's Safety Management System. Audits alone are unlikely to be effective in informing the CAA of the safety health of an airline (Swedavia AB & McGregor and Company, 1988). The undesirable effects shown in Figure TOC24 stem from the decision to confine oversight activities to auditing alone, exacerbated by defining 'auditing' as 'determining that an organisation has a management system in place which will ensure compliance with relevant standards...' (TAIC, 1995). In practice, audits were largely confined to review of documentation (see, e.g., ("CAA Audits," 1995; "Safety in the Sky," 1990). The CRT traces the linkages which demonstrates why this policy had adverse consequences.

Crew Training.

Consider, first, the deficient training of the crew in emergency procedures. Emergency training was not performed in accordance with the documentation, but auditing of the documentation, alone, could not detect the deficient training. The auditors were not prompted to review the training in undercarriage emergencies, even though these were a recurring problem (as discussed in the next section) and so the absence of training to handle a recurring emergency was not detected. (See Figure 65). (The numbers on the following diagrams refer to the key for Figure 71, 'CAA Performance').

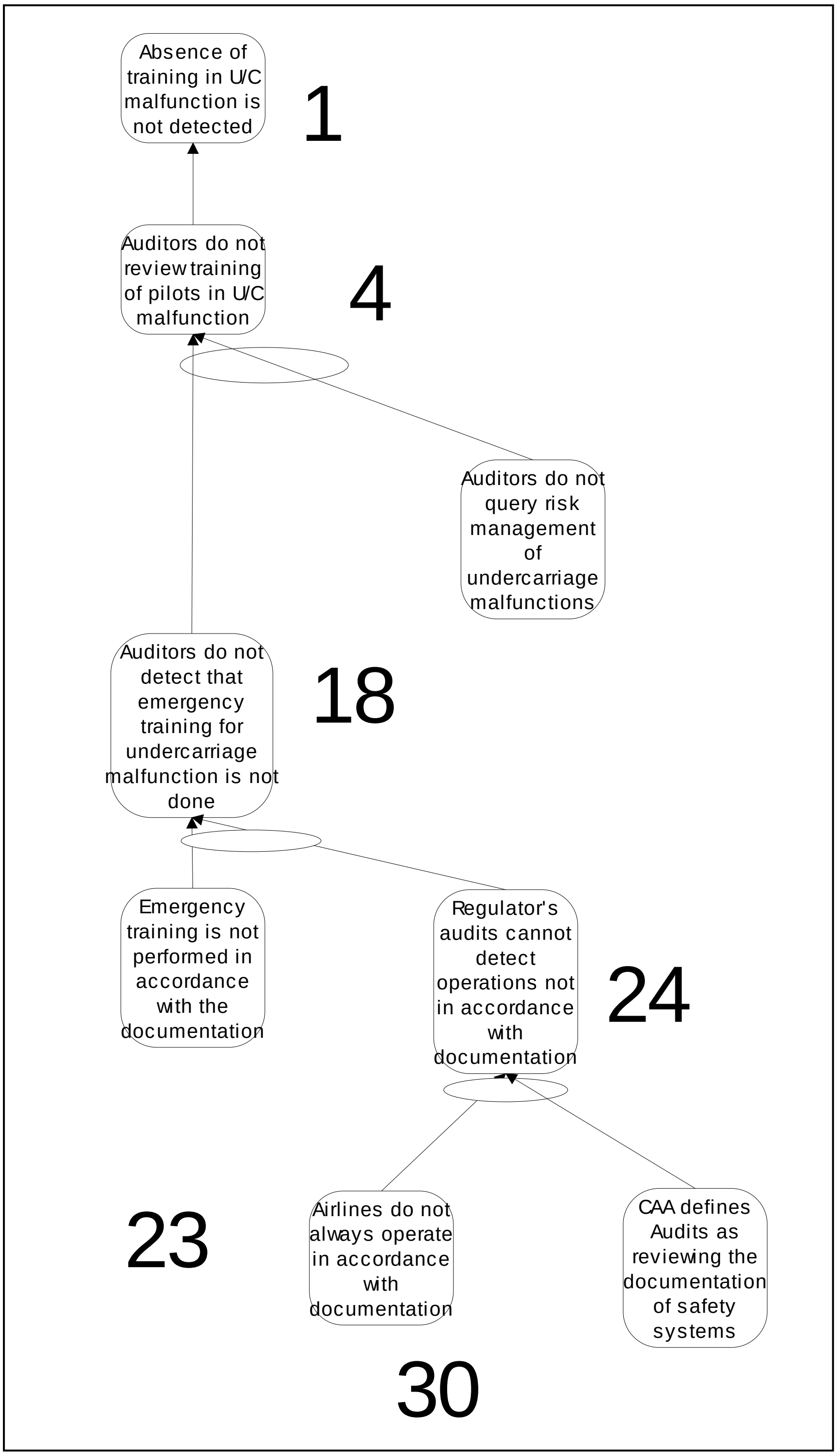


Figure 65. Knowledge of Crew Training.

Recurring events.

Abnormal events which occur in flight are noted in crew reports, not in the airline's procedural documentation available to the auditors before they commence an audit. The auditors are therefore unaware of such events if they do not also review crew reports. Likewise, review of maintenance procedural documentation would not have alerted the auditors, since there were no applicable airworthiness directives referring to the engineering problem. The auditors did not examine physical reality by performing surveillance, which would have had at least some chance of observing defects recurring or being rectified. Absence of either review of crew or defect reports, or surveillance, meant that the auditors were unaware of the recurring undercarriage defects. Had they been aware, they might have inquired into the risk management of these events, e.g. what training the aircrew had received to deal with them. Inquiry as to why the events recurred should have led the auditors to the deficient maintenance instruction which did not detail the required inspection. (See Figure 66).

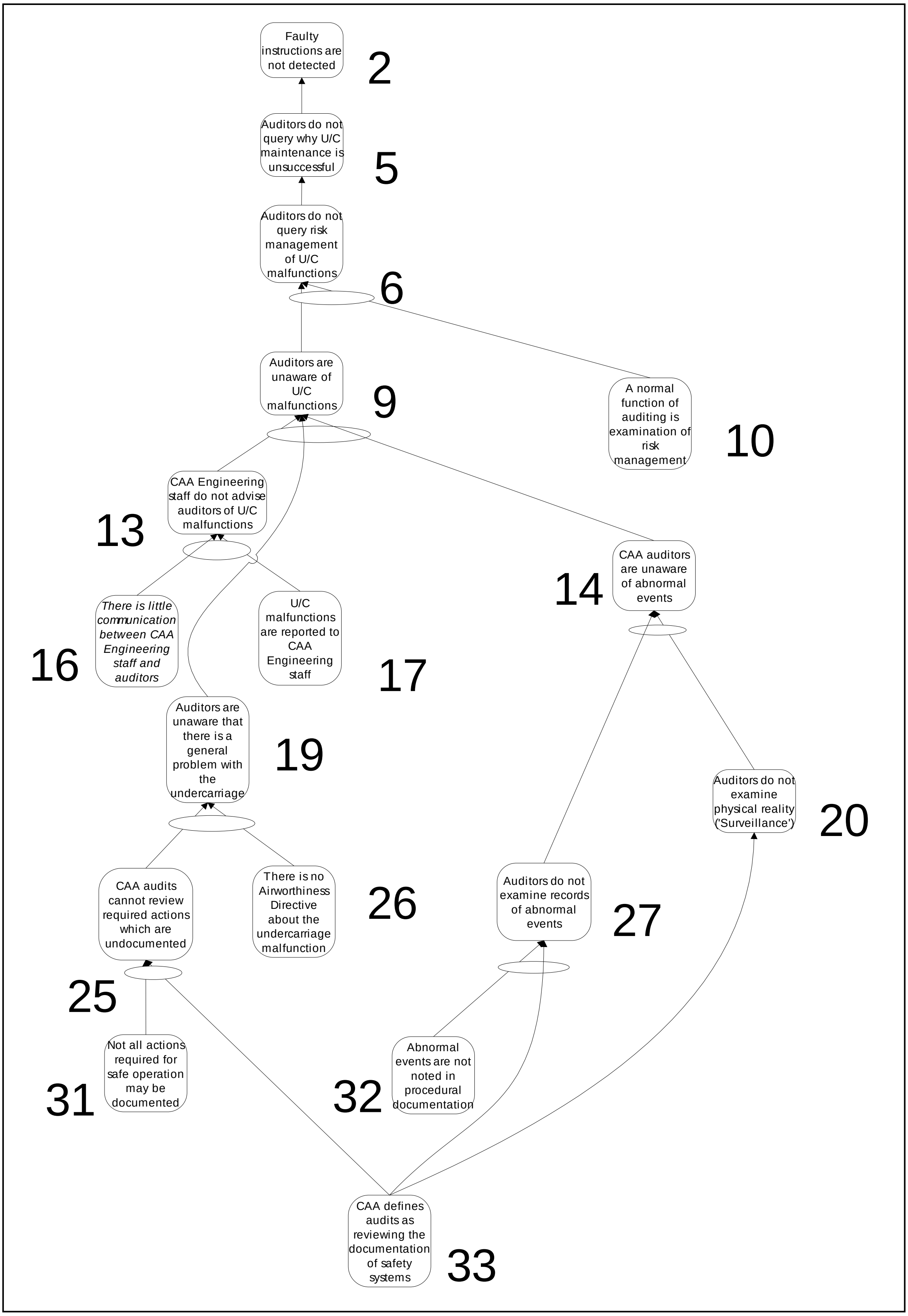
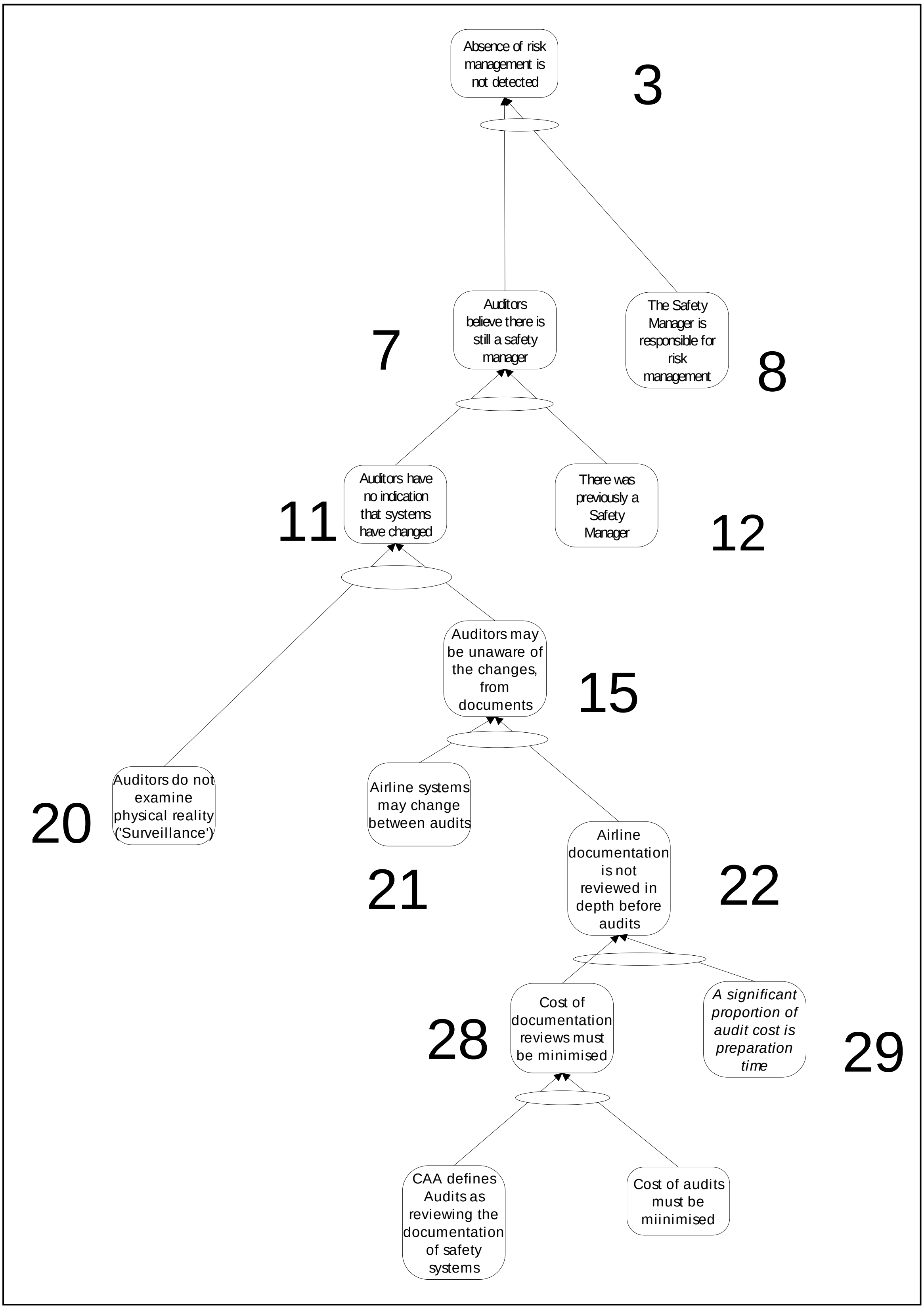


Figure 66. Knowledge of Recurring Events.

Risk Management.

Risk management is one function of the Safety Department. However, although the CAA had been advised that Ansett no longer had a Safety Manager, the CAA auditors did not know this (TAIC, 1995). Audit preparation should have alerted the auditors to the change, but pressure to minimise cost, and therefore time for such preparation (ibid., p. 56), led to deficient preparation, and the change went unnoticed. Surveillance should have brought the absence of the Safety Manager to the auditors' notice. In the event, the auditors were unaware of the change, and so of the absence of risk management. (See Figure 67).



.Figure 67. Knowledge of risk management.

The combined diagram (Figure 68) illustrates why audits alone could not keep the CAA informed as to the true state of the airline. Had the CAA been aware, possible corrective actions included

- Insisting that emergency training be performed
- Requiring correction of the defective maintenance instruction
- Requiring the Safety Manager position to be reinstated.

Collectively, these actions would have made the accident unlikely.

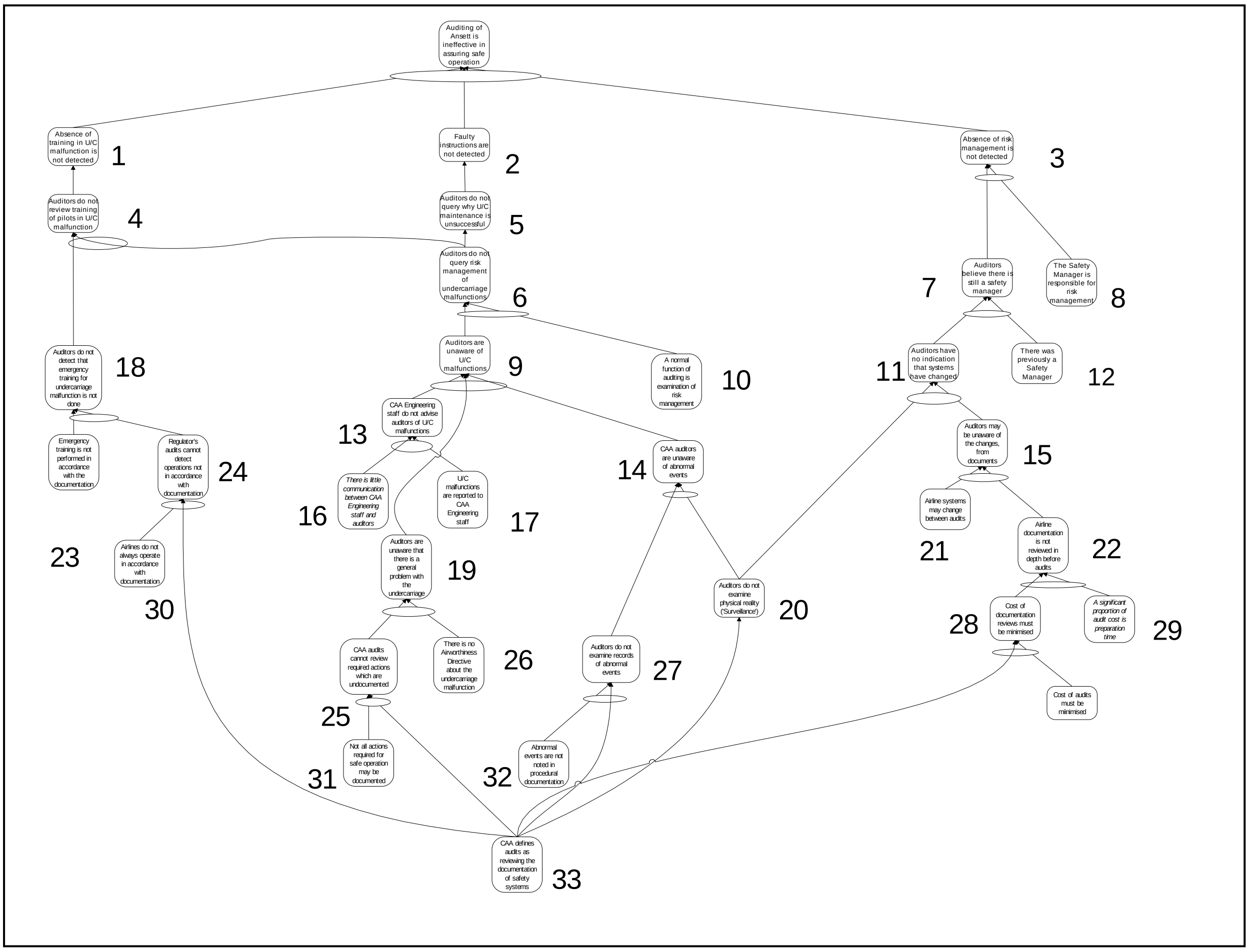


Figure 68. Combination of Figures 65, 66 and 67.

There are two common themes so far:

- The policy of not conducting surveillance, and
- Restricting 'audits' to examination of the airline's documentation to ensure that systems were in place.

Both of these stemmed from the need to minimise costs. The relationship is shown in Figure 69. Surveillance to the level required by (ICAO, 1995) is resource intensive, and the CAA had insufficient staff who were suitably qualified and trained to conduct surveillance. The CAA and its predecessors had been criticised for inadequate surveillance, when a number of air transport accidents had been investigated (e.g. (Carruthers, 1988, 1989). The CAA therefore sought an alternative to surveillance. An independent review (Swedavia AB & McGregor and Company, 1988) recommended a combination of audit and surveillance, but the CAA decided to conduct audits only.

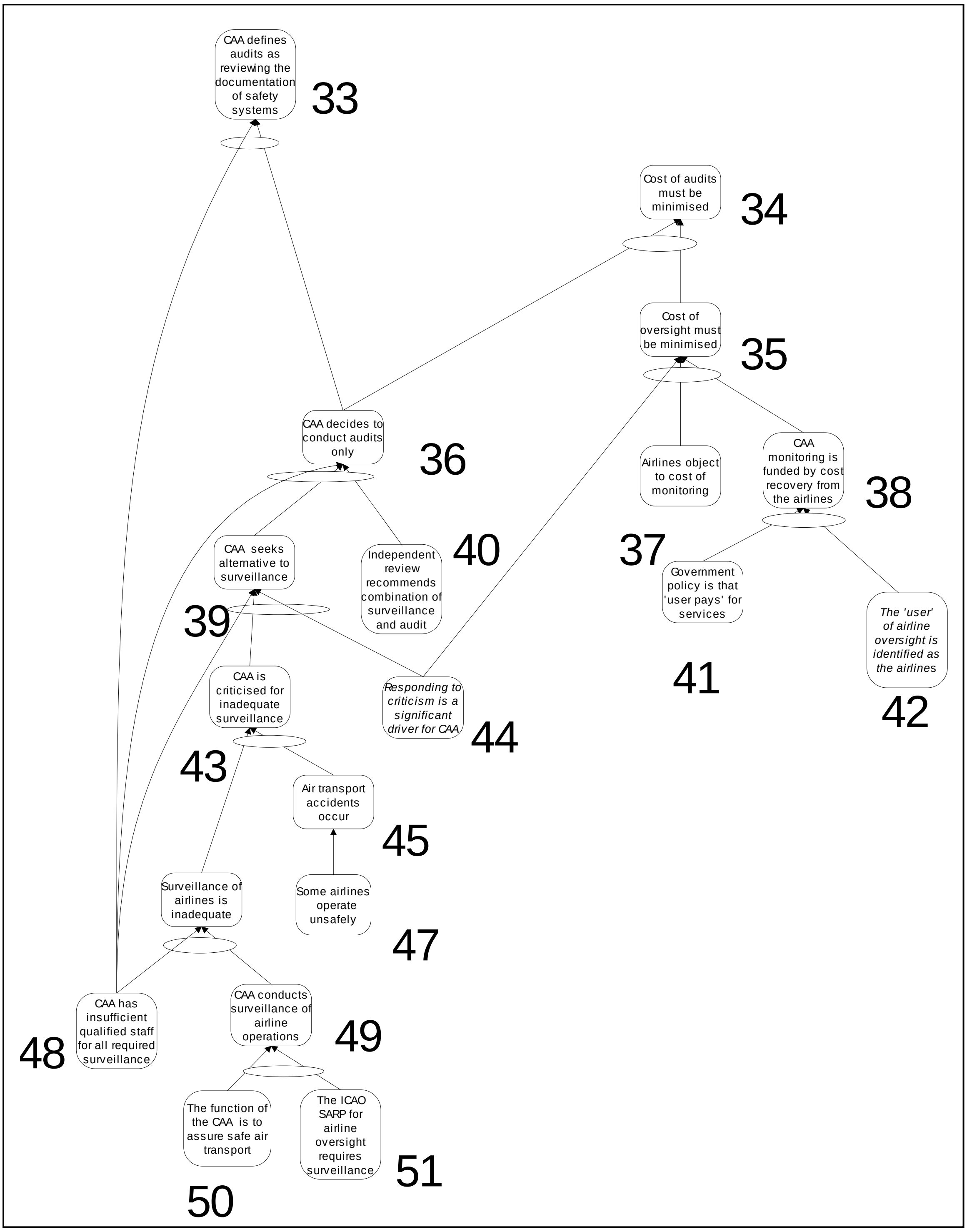


Figure 69. Audit Policy.

.The cost pressures which prevented recruitment of suitably qualified staff for surveillance also bore on the audit process. It was Government policy that the users of services were to be charged for those services. The 'users' of audits were considered to be the airlines, who were charged fees based on the time that an audit took. There was pressure to minimise fees, which resulted in reduced preparation time (TAIC, 1995)

All of the pressures leading to the CAA being unaware of the impending Ansett accident can be seen to stem from what (Mumford, 2001) has called the 'double bind' between safe performance and cost. This double bind can be depicted as a Conflict Resolution Diagram, Figure 70.

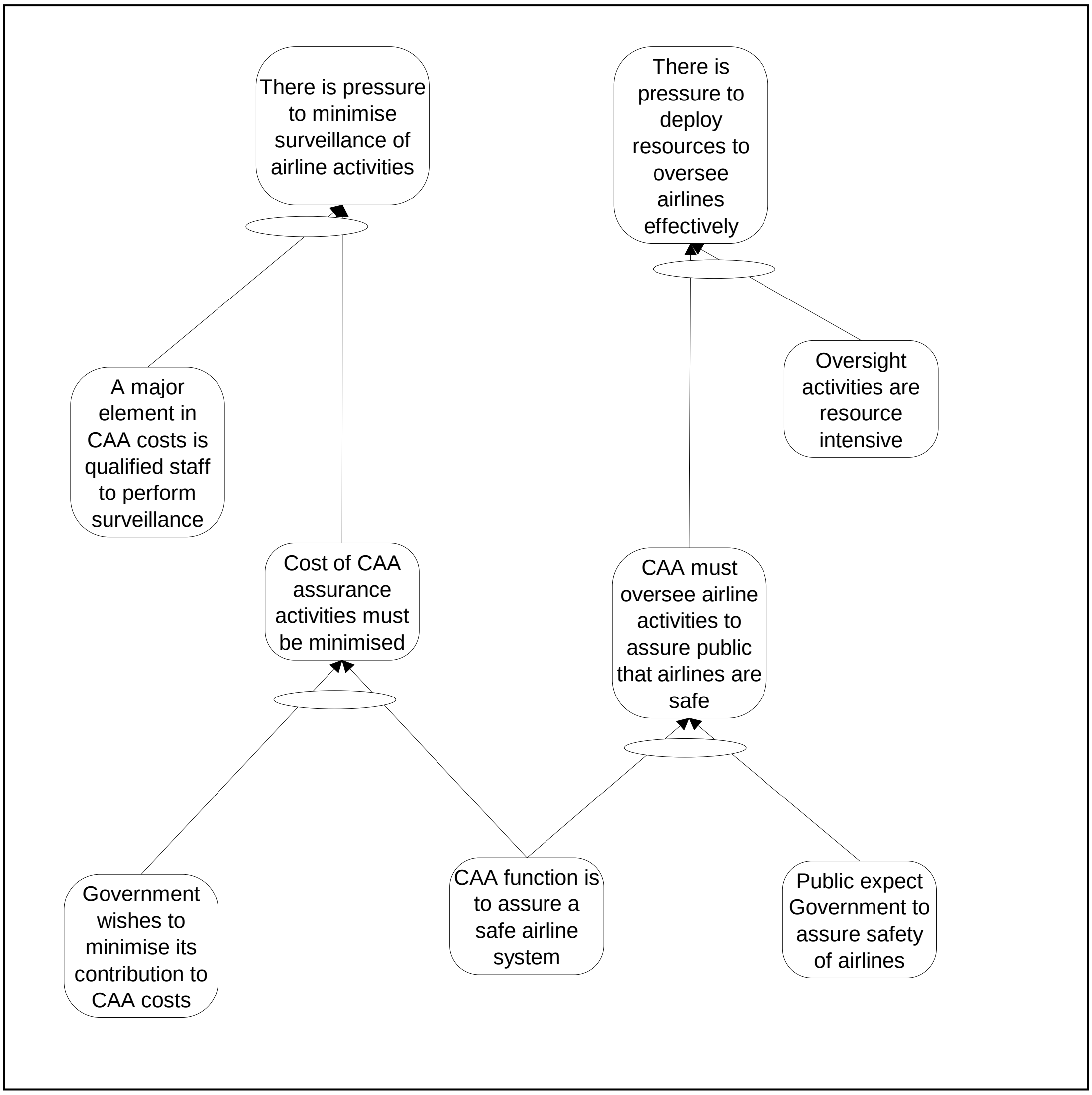


Figure 70. Safe Performance and Cost.

The diagrams relating to CAA performance can be combined, as shown in Figure 71.

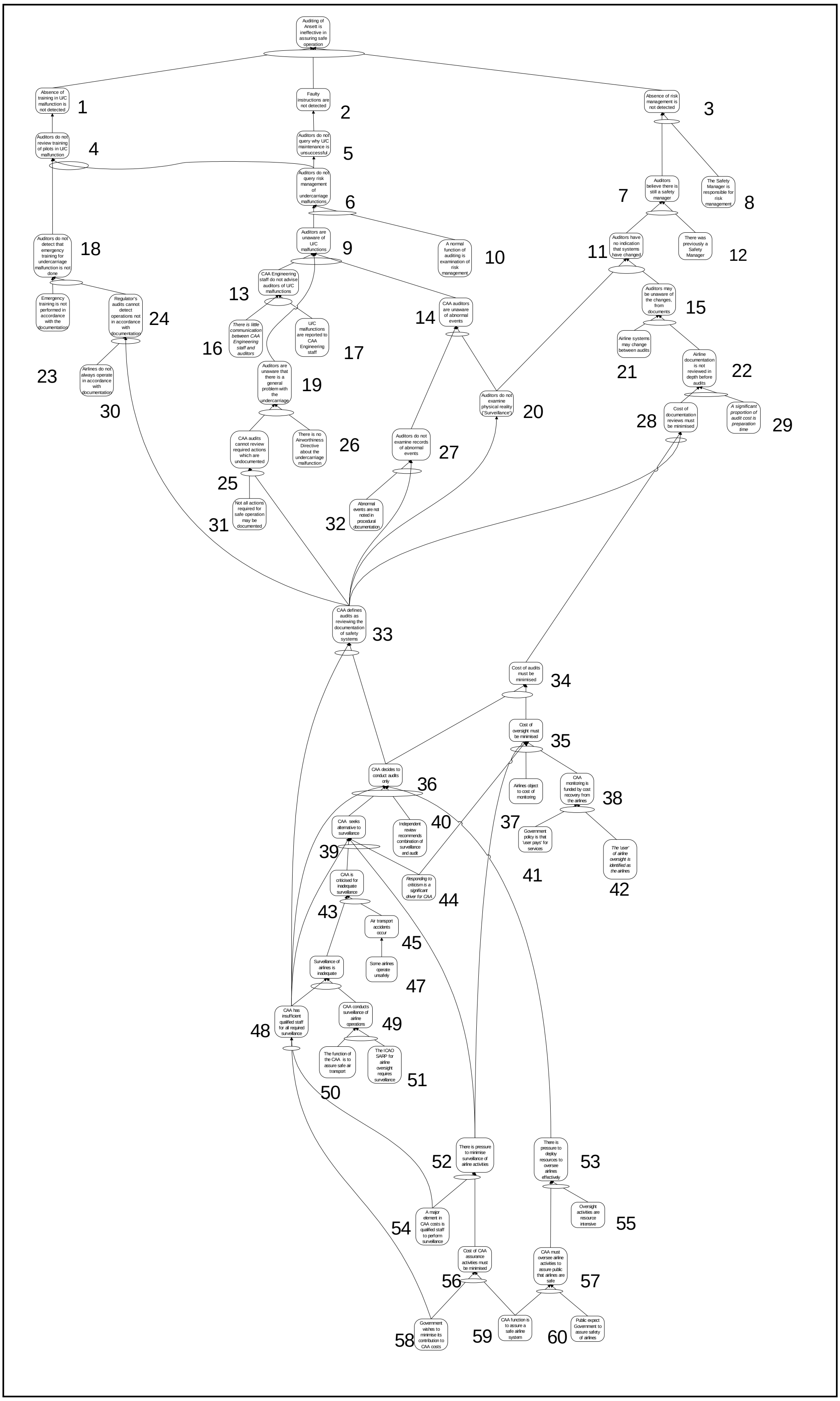


Figure 71. CAA Performance.

Key to Figure 71

1. Absence of training in undercarriage malfunction is not detected
2. Faulty instructions are not detected
3. Absence of risk management is not detected
4. Auditors do not review training of pilots in undercarriage malfunction
5. Auditors do not query why undercarriage maintenance is unsuccessful
6. Auditors do not query risk management of undercarriage malfunctions
7. Auditors believe there is still a Safety Manager
8. The Safety Manager is responsible for risk management
9. Auditors are unaware of undercarriage malfunctions
10. A normal function of auditing is examination of risk management
11. Auditors have no indication that systems have changed
12. There was previously a Safety Manager
13. CAA Engineering staff do not advise auditors of undercarriage malfunctions
14. Auditors do not examine records of abnormal events
15. Auditors may be unaware of changes, from documents
16. *There is little communication between CAA Engineering staff, and auditors*
17. Undercarriage malfunctions are reported to CAA Engineering staff
18. Auditors do not detect that emergency training for undercarriage malfunction is not done
19. Auditors are unaware that there is a general problem with the undercarriage
20. Auditors do not examine physical reality (“Surveillance” is not allowed)
21. Airline systems may change between audits
22. Airline documentation is not reviewed in depth between audits
23. Emergency training is not performed in accordance with the documentation
24. CAA Audits cannot detect operations not in accordance with documentation
25. CAA Audits cannot review required action which is undocumented
26. There is no Airworthiness Directive about the undercarriage malfunction
27. CAA Auditors are unaware of abnormal events
28. Cost of documentation reviews must be minimised
29. *A significant proportion of audit cost is preparation time*
30. Airlines do not always operate in accordance with documentation
31. Not all actions required for safe operation may be documented
32. Abnormal events are not noted in procedural documentation
33. CAA defines audits as reviewing the documentation of safety systems
34. Cost of audits must be minimised
35. Cost of oversight must be minimised
36. CAA decides to conduct audits only
37. Airlines object to the cost of CAA monitoring
38. CAA monitoring is funded by cost recovery from the airlines
39. CAA seeks alternative to surveillance
40. Independent review recommends combination of surveillance and audit
41. Government policy is that ‘user pays’ for services
42. *The ‘user’ of airline services is identified as the airlines*
43. CAA is criticised for inadequate surveillance
44. *Responding to criticism is a significant driver for the CAA*
45. Air transport accidents occur
46. Surveillance of airlines is inadequate
47. Some airlines operate unsafely
48. CAA has insufficient qualified staff for all required surveillance
49. CAA conducts surveillance of airline operations
50. The function of the CAA is to assure safe air transport
51. The ICAO SARP for airline oversight requires surveillance
52. There is pressure to minimise surveillance of airline activities
53. There is pressure to deploy resources to oversee airlines effectively
54. A major element in CAA oversight costs is qualified staff to perform surveillance
55. Oversight activities are resource intensive
56. Cost of CAA oversight activities must be minimised
57. CAA must oversee airline activities to assure the public that airlines are safe
58. Government wishes to minimise its contribution to CAA costs
59. CAA function is to assure a safe airline system
60. The public expects the Government to assure the safety of airlines

It could reasonably be expected that where an airline was under financial stress, it might attempt to minimise costs, perhaps to the detriment of safe performance. Ansett's actions in not buying replacement undercarriage parts, not training its crews in emergency procedures, and abolishing the Safety Manager position, can be construed as a response to financial pressures, as previously discussed. Therefore, it would be reasonable to increase the level of safety oversight of airlines under financial pressure. However, the CAA had been deprived of direct knowledge of airlines' financial positions. Previously, airlines had had to make regular financial returns ("Air Services Licensing Act," 1983), but this requirement was abolished as part of the reforms encompassed in ("The Civil Aviation Act," 1990). The financial viability of airlines was considered to be a matter for market forces. The effect of the removal of financial information is shown in Figure 72.

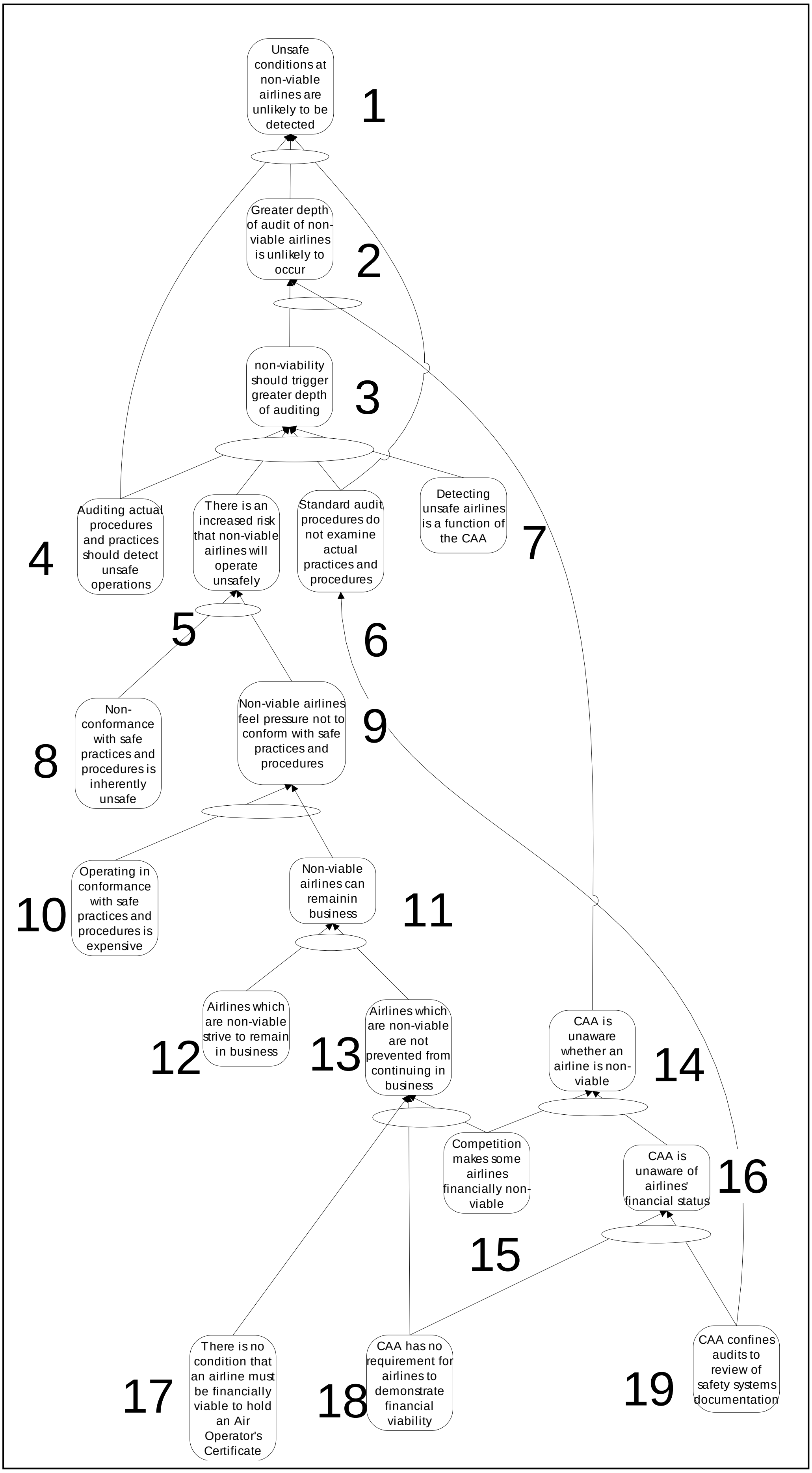


Figure 72. Lack of financial information

When Figure 72 is combined with Figure 70, the final Current Reality Tree from the perspective of the CAA is obtained (Figure 73). This CRT has been rearranged slightly (without altering the linkages) so that the core problems are evident.

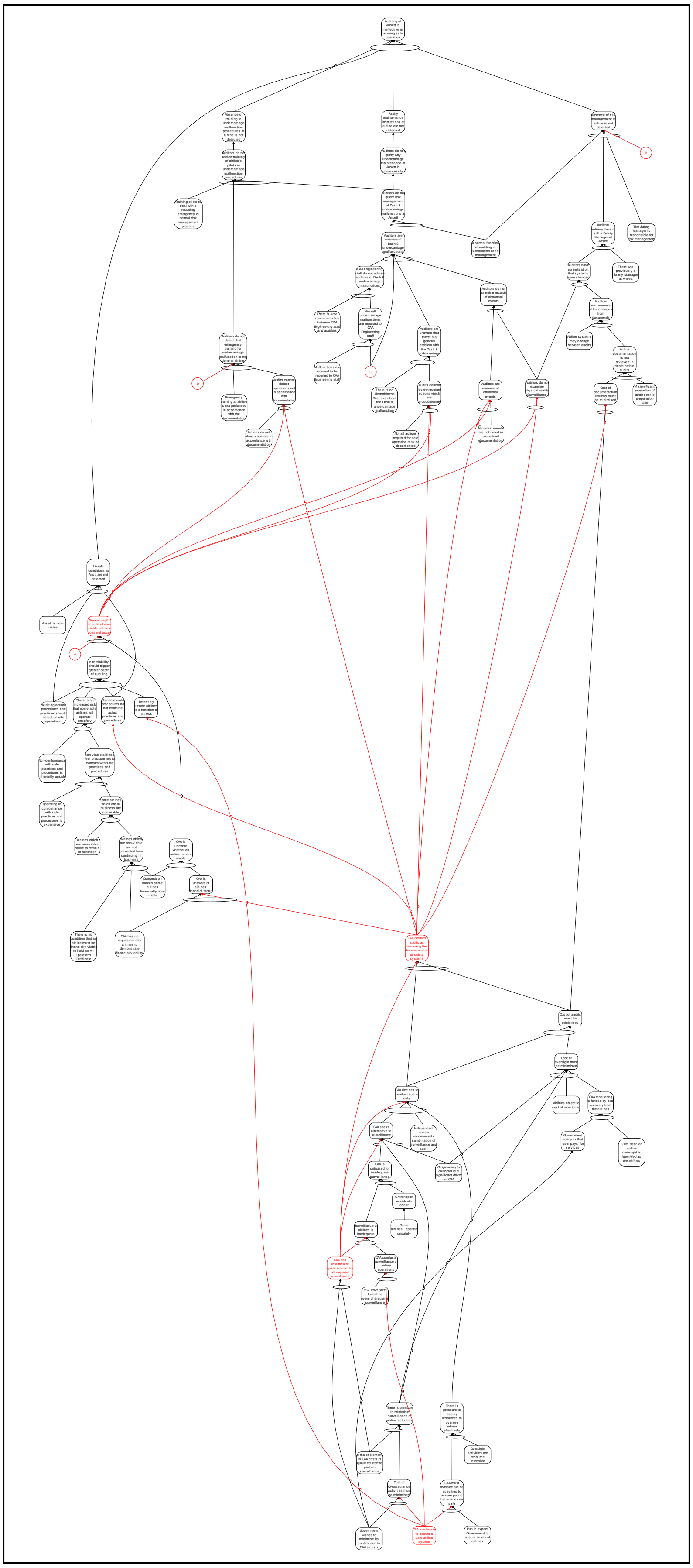


Figure 73. CRT from the CAA perspective.

As in the CRT from the Ansett perspective, core problems are highlighted:

- The CAA had insufficient qualified staff for all required surveillance;
- The CAA confined audits to review of the documentation of safety systems; and
- Non-viable airlines did not incur a greater depth of auditing.

The effects of the core problems and, in particular the decision to confine auditing to review of the documentation, are clear.

The insufficiency of staff at the CAA was a matter for appropriate funding, and getting a warning of the financial status of airlines would have required a change to the law. Neither of these was impossible, if an appropriate case had been made. However, the dominant problem was the definition of the oversight role as being confined to a review of the documentation. This was entirely a matter within the province of the CAA. It is relevant that ICAO defines this as a passive role; “The State is not in a good position to assess the adherence of industry to the regulations, other than by knowledge obtained fortuitously or in the course of accident or incident investigation. Such a system would not enable the State to exercise the necessary preventive and corrective responsibilities required by the Convention” (ICAO, 1999)(p. A2-3).

Once again, although the CRT is only the first stage in the application of the TOC, it is possible to discern corrective actions.

Discussion

Had the methods discussed in this chapter been available to those involved in the accident sequence, there is a reasonable possibility that the build-up of undesirable effects could have been foreseen by construction of a Future Reality Tree, depicting the influence of proposed actions and decisions. It is not necessary for there to have been an accident, before a Future Reality Tree could be constructed. There would then have been the opportunity to modify policies, measures and behaviours to avoid the undesirable effects, and so the accident could have been averted.

Starting right at the beginning, constructing a Future Reality Tree for airline competition would have shown the Government that, while predatory pricing was permitted, competition between a newcomer and the existing major airline was unlikely to produce lasting benefits. It would then have been possible to debar predatory pricing, as a necessary preliminary to introducing a competitive regime. It would be appropriate for the investigating authority to recommend that such a change be considered.

The effects of the various economies which Ansett proposed (particularly the abolition of the Safety Manager position) could have been examined in advance. This would not have made the airline any more viable, but would have provided a powerful argument for addressing operating strategy before the disaster, notwithstanding the sunk capital in maintenance facilities, terminal buildings and so on.

From the CAA's perspective, an analysis of the effects of constraining audits to a review of systems documentation could have illustrated the potential inability of such auditing to disclose various types of problems. Other methods of oversight could have been added to the auditors' toolbox, so that weaknesses in airlines could be detected and addressed before a major accident occurred.

The accident investigators would have benefited by the use of this formal analytical technique during the investigation, since their attention would have been drawn to information which might, otherwise, have been overlooked. Further, the generation of safety recommendations would have been focussed by the need to generate a Future Reality Tree in which the existing undesirable effects did not occur. For example, the need to ensure that an airline could not abolish the Safety Manager position, without managing the impact, could lead to the requirement for a new regulation making such a position mandatory.

The construction of the logic trees proved straightforward; the method of forming individual segments and aggregating them was successful. The work in completing each Current Reality Tree probably required about a week of full-time work, though additional time was required for retrospective amendment of the diagrams, as mentioned below. The process of finding additional information, where gaps in the logic tree showed the need, proved time-consuming, as it is in an investigation of any sort, but this is not additional to the time ordinarily required by a sound investigation.. The construction of the CRTs was an iterative process, with retrospective amendments to the individual segments being required, as the developing CRT showed the need for changes – generally the need for additional sufficiency, but sometimes also, testing showed that the original linkages were not logically sound. It would be highly desirable to be able to link diagrams so that changes in one were reflected in changes to others as appropriate. Such linkage was not a function of the graphics programs available to the author, and retrospective amendment proved time-consuming. (The need for updating the earlier stages comes from the need to present the tree to the reader in stages, rather than the somewhat bewildering apparent complexity of the final product).

Overall, the construction of a CRT and the ensuing FRT is, potentially, a powerful analytical tool, both in averting accidents *ab initio*, and in making recommendations to avoid recurrence.

Conclusion

One purpose of this case study was to determine whether it was possible to input the information from an accident into the form required for analysis by the methods used in the Theory of Constraints. If so, then it should be possible to use that change mechanism to remove the undesirable effects from aviation operations. This first stage in the analysis is known as the Current Reality Tree, because it describes the existing situation at the time of the accident.

Using this accident as a case study, it was found possible to take the information from lower levels of analysis, namely Multilinear Events Sequencing and Why-Because Analysis, and put it into the appropriate format for analysis by the Theory of Constraints methodology. The only modifications to the usual format that were found necessary were the use of an explicit chronological order in constructing the Current Reality Tree, and the concept of potentiation.

The Future Reality tree will be presented in the next section.

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The Future Reality Tree

Whereas the CRT shows undesirable effects in the present system, the Future Reality Tree (FRT) shows the system as we would like it to be. The FRT serves a number of purposes:

1. It provides a means of testing ideas for improvement, to see whether they will indeed do what is hoped, and whether there are unforeseen effects that would not be wanted. It acts as a simulator in which these ideas can be tried, before the expense of putting them into practice in reality (Dettmer, 1997).
2. It provides a safety net. The CRT or Conflict Resolution Diagrams (CRD)s may be imperfect: ‘As Goldratt has said, “It’s better to be approximately correct than precisely incorrect”’ (Dettmer, 1997), p. 195). If there are imperfections in the CRT or CRD(s), it is still possible to have an effective FRT, because the imperfections will come to light as ‘negative branches’, that is, undesirable outcomes from changes that may be introduced. These can be identified and removed.
3. The various injections needed to construct the FRT form the basis for subsequent Safety Recommendations.

One primary difference between the CRT and FRT, in this application of the Theory of Constraints methodology as an accident investigation tool, is the level of specificity. In the CRT, the action is traced from ‘this particular accident’ to the specific factors which caused it, tracing back to the more general problems which gave rise to those factors. For example, the undercarriage malfunction was one of a series of repeated undercarriage malfunctions, which arose from a particular faulty instruction by the Chief Engineer, which may have arisen from excessive workload. The FRT, by contrast, must deal with more generic terms. It is totally improbable that this particular faulty instruction would recur at this particular company. However, it is virtually certain that problems of some sort will recur in some company. Their immediate cause is irrelevant for the purpose of considering what to do about them: what is necessary is that crews are trained to deal with foreseeable problems, so that the aircraft will not be jeopardised, and that the recurrence is spotted so that the underlying problem (such as the faulty instruction) can be identified and fixed. It is for this reason that it is necessary to be able to express effects in general terms, such as ‘problems recur’.

There are various ways to move from the CRT to the FRT:

- It may be possible to discover a core conflict at the very base of the CRT. Either it may be evident on inspection, or it may be possible to discover a common factor underlying several core problems. In this case it could be possible to find a solution to the core conflict, using a Conflict Resolution Diagram (CRD), and if this can be done, the FRT is generated by linkages from the injection which broke the basic assumption, to the various desirable effects we wish to achieve (Goldratt, 1998). The FRT, in this instance, may bear little resemblance to the CRT, because the CRT itself is no longer valid. This reflects reality: resolution of a fundamental conflict may require a complete restructuring of the business in order to take advantage of the new opportunities available.
- It may be possible to address a number of core problems, using CRDs to generate ideas for solving the underlying problems, and then construct a FRT, similar in layout to the CRT, but achieving desirable effects. In this instance the FRT may be rather similar in layout to the CRT, because the underlying structure of the business may not change very much (Dettmer, 1997). For example, an airline is likely to have maintenance, flight operations and training departments, regardless of improvements in financial management.
- A third approach is to attempt to transform the CRT, by rewriting the various undesirable effects as desirable effects, adding appropriate injections required to bring the changes about (Dettmer, 1997). Like the previous approach, this is based on the idea that the underlying structure is unlikely to change much.

The first two methods were tried, for the purpose of generating a FRT from the Ansett CRT. They were unsuccessful, for a reason that is obvious in hindsight. The usual objective in applying the Theory of Constraints is to bring about an improvement in the company which is experiencing undesirable effects. In the case of Ansett, all the undesirable effects stemmed from financial constraints, and in particular the impossibility of competing head-on with the established airline, Air New Zealand. In trying to use conventional methods to construct the FRT, solutions generated were aimed at solving Ansett's financial problems. For example, while start-up full service airlines have been almost universally unsuccessful, the history of low-cost start-ups contains its share of successes (Williams, 2002). A reasonable solution for Ansett could have been to seek a low-cost niche market in which Air New Zealand, as an established full-service airline, might have been unable or unwilling to compete.

However, while this might have resolved Ansett's financial woes (and could well have been a useful exercise for Ansett to perform), it does not meet the requirements of a system intended to generate safety recommendations, for two reasons:

- Both the investigative and regulatory authorities are Government bodies, and it would be improper for them to act in a way intended to give one airline a competitive advantage. Besides, such advice might not be well-received by the airline.
- The solution is not generic. It is highly unlikely that Ansett would have another CFIT accident resulting from undercarriage malfunction, but it is quite possible that some airline would suffer a CFIT accident as a result of crew distraction. It is to the general problem that recommendations are best directed.

Accordingly, the third method was adopted for the construction of the Ansett FRT, and the earlier attempts will not be discussed further.

The FRT for the CAA, by contrast, could be constructed in the classical fashion of seeking to address a core conflict at the base of the CRT. In the first place, there is no inhibition about seeking to improve a Government body. Secondly, there is no need to seek a generic solution, because there is only one such body in the country. And thirdly, inspection of the CRT shows that there is indeed such a core conflict evident in the way in which the CAA is funded.

Using these two different approaches, it will be shown that useful recommendations can be derived from the injections needed to construct the two FRTs.

Construction of the Ansett Future Reality Tree

The method adopted was to replace each of the non-commercial undesirable effects in the Ansett CRT with the opposing desirable effect. For example,

“Crews get no training on newly-introduced procedures” is replaced with

“Crews are trained on newly-introduced procedures”.

1. Flight Crew Training

In order to illustrate the transformation process, the question of crew training can be examined. In the CRT, the undesirable effects are:

- Crews are not trained to handle an undercarriage latch malfunction
- Crews are not trained on the new approach
- Crews get no simulator training.

These statements are transformed, in the FRT, to:

- Crews are trained to handle foreseeable emergencies
- Crews are trained on newly-introduced procedures
- Crews get emergency, CRM and recurrent training on the simulator, despite the cost involved.

The first iteration of this implementation is shown in Figure 1. (For clarity, the entity ‘pilots must be trained to operate the aircraft’, entity number 12, has been moved onto this diagram).

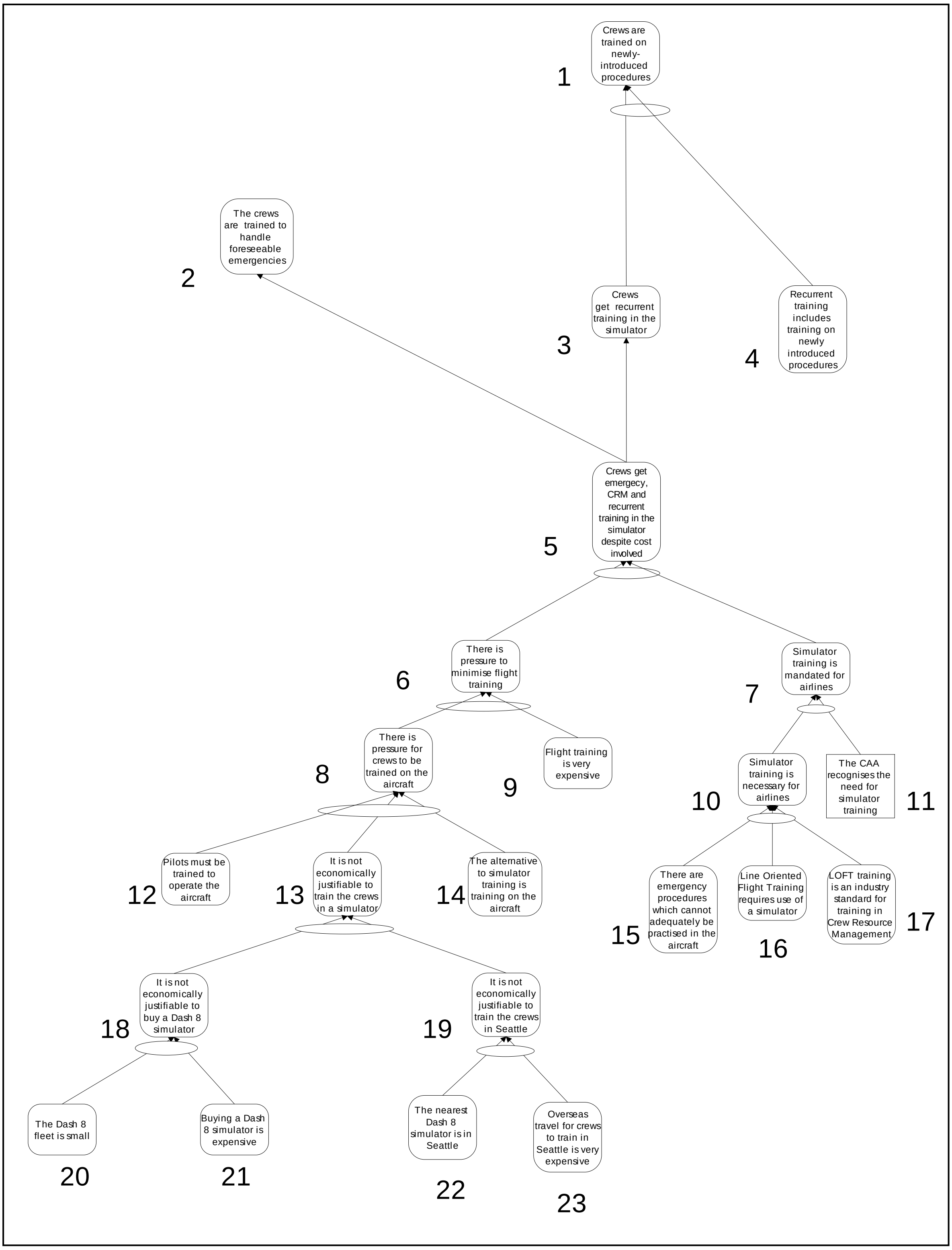

Figure 1. Crew training.

Key

1. Crews are trained on newly-introduced procedures
2. The crews are trained to handle foreseeable emergencies
3. Crews get recurrent training in the simulator
4. Recurrent training includes training on newly introduced procedures
5. Crews get emergecy, CRM and recurrent training in the simulator despite cost involved
6. There is pressure to minimise flight training
7. Simulator training is mandated for airlines
8. There is pressure for crews to be trained on the aircraft
9. Flight training is very expensive
10. Simulator training is necessary for airlines
11. The CAA recognises the need for simulator training
12. Pilots must be trained to operate the aircraft
13. It is not economically justifiable to train the crews in a simulator
14. The alternative to simulator training is training on the aircraft
15. There are emergency procedures which cannot adequately be practised in the aircraft
16. Line Oriented Flight Training requires use of a simulator
17. LOFT training is an industry standard for training in Crew Resource Management
18. It is not economically justifiable to buy a Dash 8 simulator
19. It is not economically justifiable to train the crews in Seattle
20. The Dash 8 fleet is small
21. Buying a Dash 8 simulator is expensive
22. The nearest Dash 8 simulator is in Seattle
23. Overseas travel for crews to train in Seattle is very expensive

Merely because it would be very nice were these conditions so, does not necessarily make them so. Injections[9] are needed to ensure that these desirable effects will come about in reality. The group leading to ‘There is pressure to minimise flight training’ is unchanged. All of these statements are, and will continue to be, valid. How, then, is proper crew training to be achieved? Ansett’s response, after the accident, that training on the aircraft is satisfactory (Ansett (NZ), 1995) demonstrates the need for prescriptive action by the CAA. The group at the lower right demonstrates the need for simulator training of airline crews. The injection (in the square box) is that the CAA recognises the need for simulator training. Detailed scrutiny of Figure 1 leads to a second iteration, shown at Figure 2. This forms Sector 1 of the FRT.

[9] The term ‘injection’ is particular to the Theory of Constraints. In psychological literature, an ‘injection’ is referred to as an ‘intervention’.

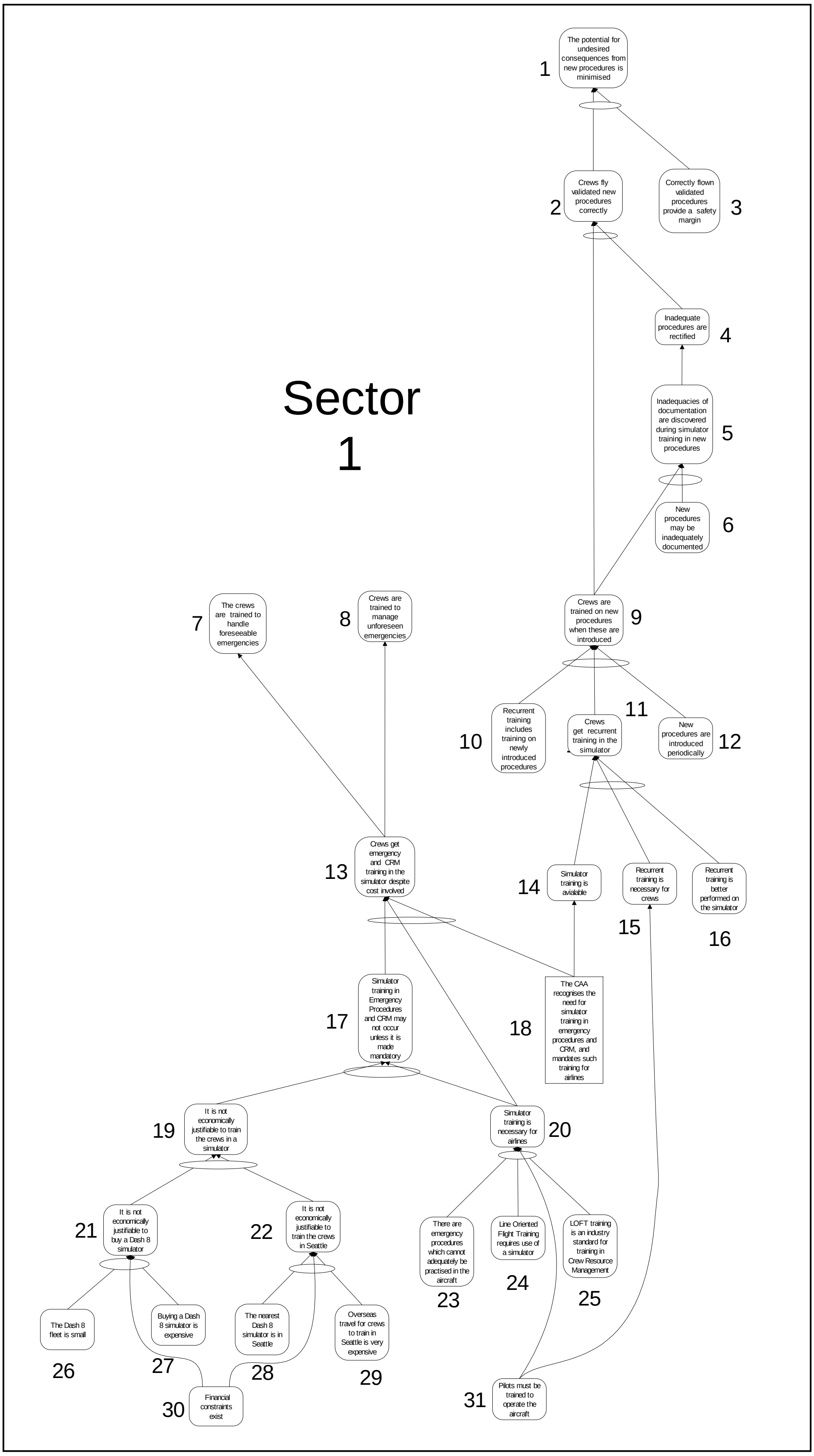

Figure 2. FRT: Training, sector 1.

Key

1. The potential for undesired consequences from new procedures is minimised
2. Crews fly validated new procedures correctly
3. Correctly flown validated procedures provide a safety margin
4. Inadequate procedures are rectified
5. Inadequacies of documentation are discovered during simulator training in new procedures
6. New procedures may be inadequately documented
7. The crews are trained to handle foreseeable emergencies
8. Crews are trained to manage unforeseen emergencies
9. Crews are trained on new procedures when these are introduced
10. Recurrent training includes training on newly introduced procedures
11. Crews get recurrent training in the simulator
12. New procedures are introduced preiodically
13. Crews get emergency and CRM training in the simulator despite cost involved
14. Simulator training is available
15. Recurrent training is necessary for crews
16. Recurrent training is better performed on the simulator
17. Simulator training in Emergency Procedures and CRM may not occur unless it is made mandatory
18. The CAA recognises the need for simulator training in emergency procedures and CRM and mandates such training for airlines
19. It is not economically justifiable to train the crews in a simulator
20. Simulator training is necessary for airlines
21. It is not economically justifiable to buy a Dash 8 simulator
22. It is not economically justifiable to train the crews in Seattle
23. There are emergency procedures which cannot adequately be practised in the airc
24. Line Oriented Flight Training requires use of a simulator
25. LOFT training is an industry standard for training in Crew Resource Management
26. The Dash 8 fleet is small
27. Buying a Dash 8 simulator is expensive
28. The nearest Dash 8 simulator is in Seattle
29. Overseas travel for crews to train in Seattle is very expensive
30. Financial constraints exist
31. Pilots must be trained to operate the aircraft

2. Safety management

The absence of a Safety Manager was central to several of the core problems in the Ansett CRT. There are five identified core problems in the CRT[10]:

[10] The criterion used in defining a core problem was that it should have the maximum number of effect lines radiating from it; the maximum number of effect lines found in the Ansett CRT was four, and there were five such core problems. Subsequently, on combining the Ansett and CAA CRTs, linkages

1. Costs in all departments must be reduced to a minimum
2. The undercarriage latch does not tolerate wear
3. The Engineering department decides that undercarriage malfunctions have no safety implication
4. Undercarriage malfunctions recur
5. No individual is responsible for safety oversight and risk management.

1. <u>Cost Reduction</u>

Cost reduction is a particular aspect of the question ‘How can Ansett move towards profitability?’ As already discussed, such commercial matters are beyond the purview of either the investigators or the regulatory authority, and will not be considered further here.

2. <u>Undercarriage Latch Design.</u>

The design deficiency in the undercarriage latch was at the root of this accident, because had it not existed, the accident would not have occurred. However, one cannot legislate against design deficiencies: like gravity, they are always with us. Naturally, had the Engineering department decided to accept the manufacturer’s offer of replacement components at a heavily discounted price, the problem would have disappeared, but the Engineers believed that they were complying with Company policy in saving money where possible and they made an internal policy decision, not subject to outside review, that such an economy had no safety effects. This policy decision will be considered next. The problem of the design defect, per se, needs no further consideration.

3. <u>Engineering Safety Review.</u>

In deciding not to purchase the replacement parts, the Engineers held a review in their department to consider whether there were any safety implications. They concluded that there were not, because the pilots could always lower the undercarriage using the emergency mechanism (Ansett (NZ), 1993a). The procedure

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between the CRTs were found to increase the maximum to five, in three cases. However, all of the effects with four or five effect lines radiating from them were used in this analysis of core problems.

to do this involved depressurising the undercarriage hydraulic system by opening a flap in the cockpit roof, withdrawing the undercarriage latch by pulling a cable accessed by the flap (allowing the undercarriage to fall down under gravity) then raising a flap beside the co-pilot's seat, inserting a lever and moving the lever to reapply hydraulic pressure. (This last action was irreversible in flight).

Requiring the crews to use the emergency system to perform a routine operation removed one stage of the safety system. Also, this requirement assumed that the pilots were trained in this somewhat lengthy procedure, and would seldom if ever make a mistake in using it.

There was no external review of this decision, either by Flight Operations, whose crews were directly affected by it, or by any other department. Nor was there any requirement that it should be reviewed outside the Engineering department.

4. Recurrent malfunctions.

Recurring problems will inevitably occur from time to time; what is necessary is that the recurrence should be noted, and the cause found. Detecting the recurrence of problems is a specific function of a Safety Manager (ICAO, 1984). Once the recurrence has been noted, it should be brought to the attention of the responsible manager (in this case the Chief Engineer) for diagnosis and correction.

Since the Chief Engineer was aware of exactly what the mechanical problem was, the fault lay in the implementation of his instructions, and simple inquiry would have brought to light the ambiguity of those instructions. This ambiguity could have been corrected with ease. If mechanical rectification had then proved too difficult (and manual grinding of a hard chromed surface, attempted at one time (Ansett (NZ), 1993c) would have been a somewhat dubious procedure) then purchase of replacement parts would have been seen to have been a priority. Thus, the proper performance of the Safety Manager's function would have removed a core problem in the potentiation of this accident.

5. Safety oversight and risk management.

Ansett had previously had a Safety Manager, but as already discussed, the position had been abolished 2 years before the accident (TAIC, 1995), p. 49.). The inference is that the position was abolished to save money. Other explanations are possible, such as personal conflict, but the abolition of the position was in line with the requirement to save money in all departments. The effect of abolishing the position was that no individual was responsible for safety oversight and risk management. In theory, this was one of the duties of the CEO, under the general duty of care. In practice, safety oversight and risk management are specialised functions which require both experience and training (see for example the outline of training suggested by ICAO: Accident Prevention Manual (ICAO, 1984) pp. 72-79) and it is general practice to have a Safety Department, headed by a Safety Manager. While there could be other alternatives, such as a high level committee from all departments headed by the CEO, none of these were implemented by Ansett. In any case, ICAO advises that there should be an independent company safety officer, reporting directly to the highest level of management (ICAO, 1984). This view is reflected in guidance to airline operators by the UK Civil Aviation Authority (UKCAA, 2002), who consider this best practice, and in pending Australian legislation (Civil Aviation Safety Regulation 119 (in draft)). A Conflict Resolution Diagram (CRD) can be used to surface the assumptions behind Ansett’s action in abolishing the Safety Manager position.

Conflict Resolution Diagram Formation

A CRD is a ‘necessity’ diagram, as opposed to the CRT and FRT, which are ‘sufficiency’ diagrams. That is, it shows things which are necessary, but not necessarily of themselves sufficient to bring about the effects shown. One way of forming it is by writing an undesirable effect, and below it the preferred opposite, on the right hand side of the diagram (by convention). Then the CRD is formed from the right-hand side. (Figure 3).

Then the important need which give rise to the undesirable effect is sought, and also the need which would be satisfied by the desired opposite effect. Finally, the common goal which gives rise to each of the needs is sought. The conflict (‘lightning’) arrow indicates that ‘we can’t have both’, either because resources are limited, or because of mutual exclusivity.

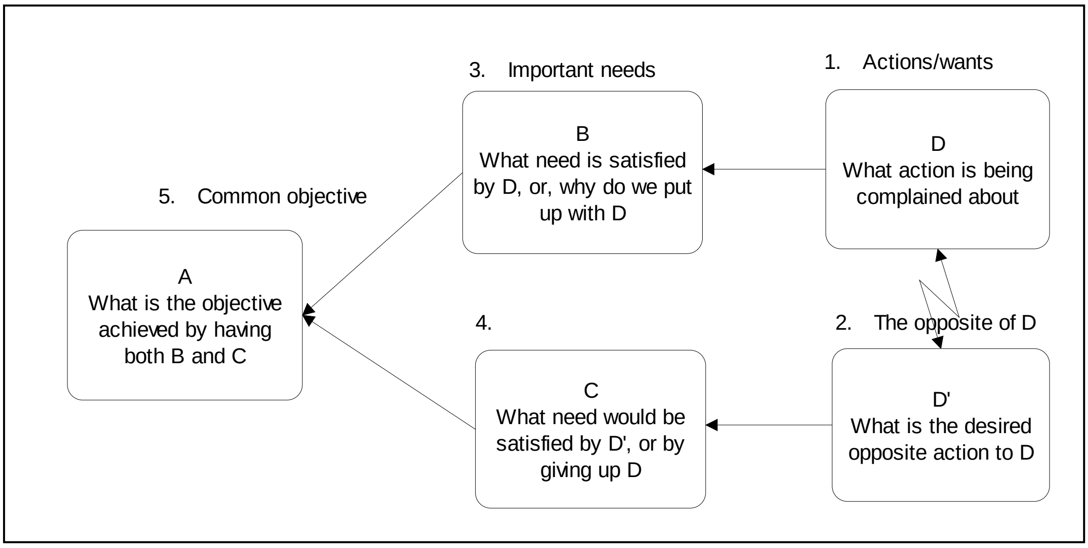

Figure3. Forming the CRD from an undesirable effect. (Source: The Jonah Programme (Goldratt, 1998)).

The CRD is read from the left hand side:

“In order to have A we need B, and in order to have B we must have D”

“In order to have A we need C, and in order to have C we must have D’. And we can’t have both D and D’.”

The rationale for ‘we must’ or ‘in direct conflict with’ comes from underlying assumptions. “The presence of an arrow in [any TOC] diagram indicates the existence of hidden, underlying assumptions about the relationship between elements... of the diagram” (Dettmer, 1997) p. 131). Such assumptions, which may be untested, need to be challenged. They may never have been valid, or may have become invalid in a changed environment. (There is a parallel with *latent failure* (Johnson, 1980), where policies that were once valid may have become inadequate because of changed circumstances). The object of the CRD is to surface underlying assumptions, so that those which are invalid can be identified.

An injection is a change initiated for the purpose of breaking a conflict or solving a problem. It may be either an action, or a desired condition (the necessary actions to achieve the desired condition being developed later). Even valid assumptions, which are impeding the conflict resolution, can be invalidated by an injection.

While not all conflicts are bi-polar – there may be three or more interacting elements – the CRD permits partitioning into manageable pieces, dealing with complexity two elements at a time.

This procedure can be applied to the abolition of the Safety Manager position (Figure 4).

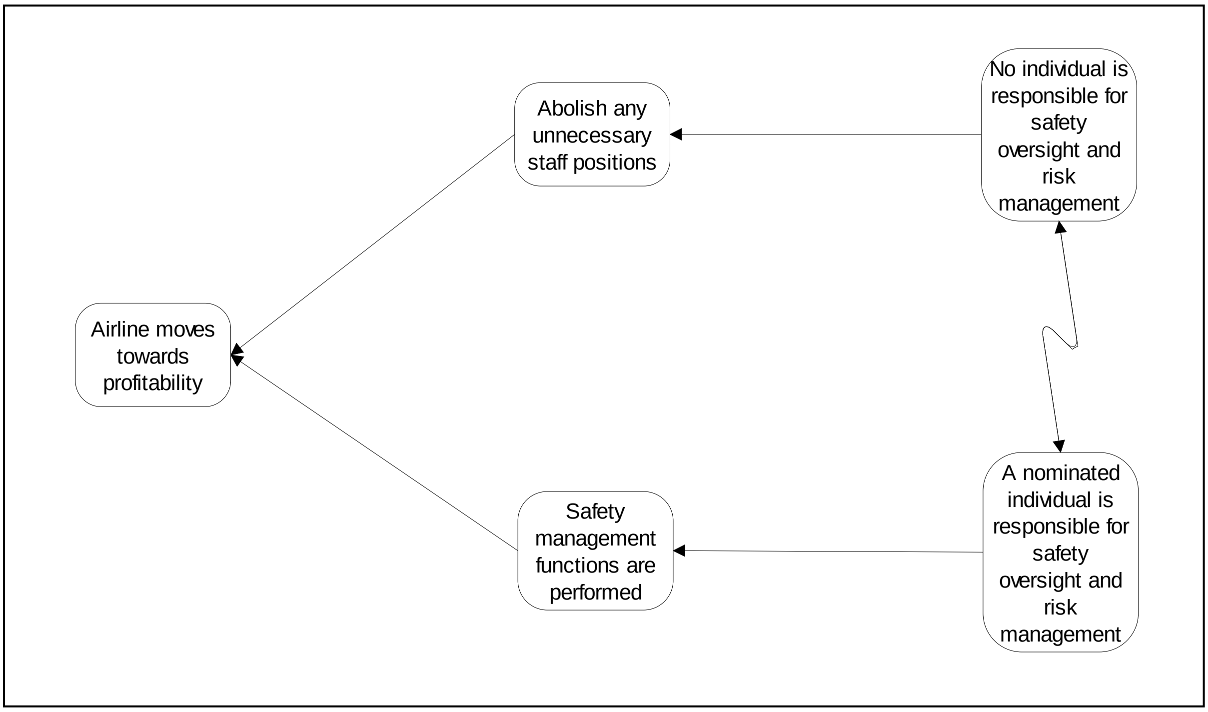

Figure 4. Conflict Resolution Diagram: Safety Manager position.

The absence of an individual responsible for safety oversight and risk management has been shown (in the CRT) to lead to a variety of undesirable effects, including unawareness by the Engineers that the undercarriage malfunctions were recurring more and more frequently, the lack of perception by the Engineers that there was a safety connotation to undercarriage malfunctions, and the absence of risk mitigation by the Training and Flight Operations Departments in the face of recurring undercarriage malfunctions. The need which gave rise to the undesirable effect appears to have been the desire to eliminate unnecessary positions, so that the goal of moving towards profitability could be achieved. The need which would have been satisfied by having a safety manager was the need to perform safety management functions, in order to operate safely and maintain public confidence. The common goal was to move towards profitability.

Each of the arrows in the CRD conceals assumptions, which may now be surfaced for examination.

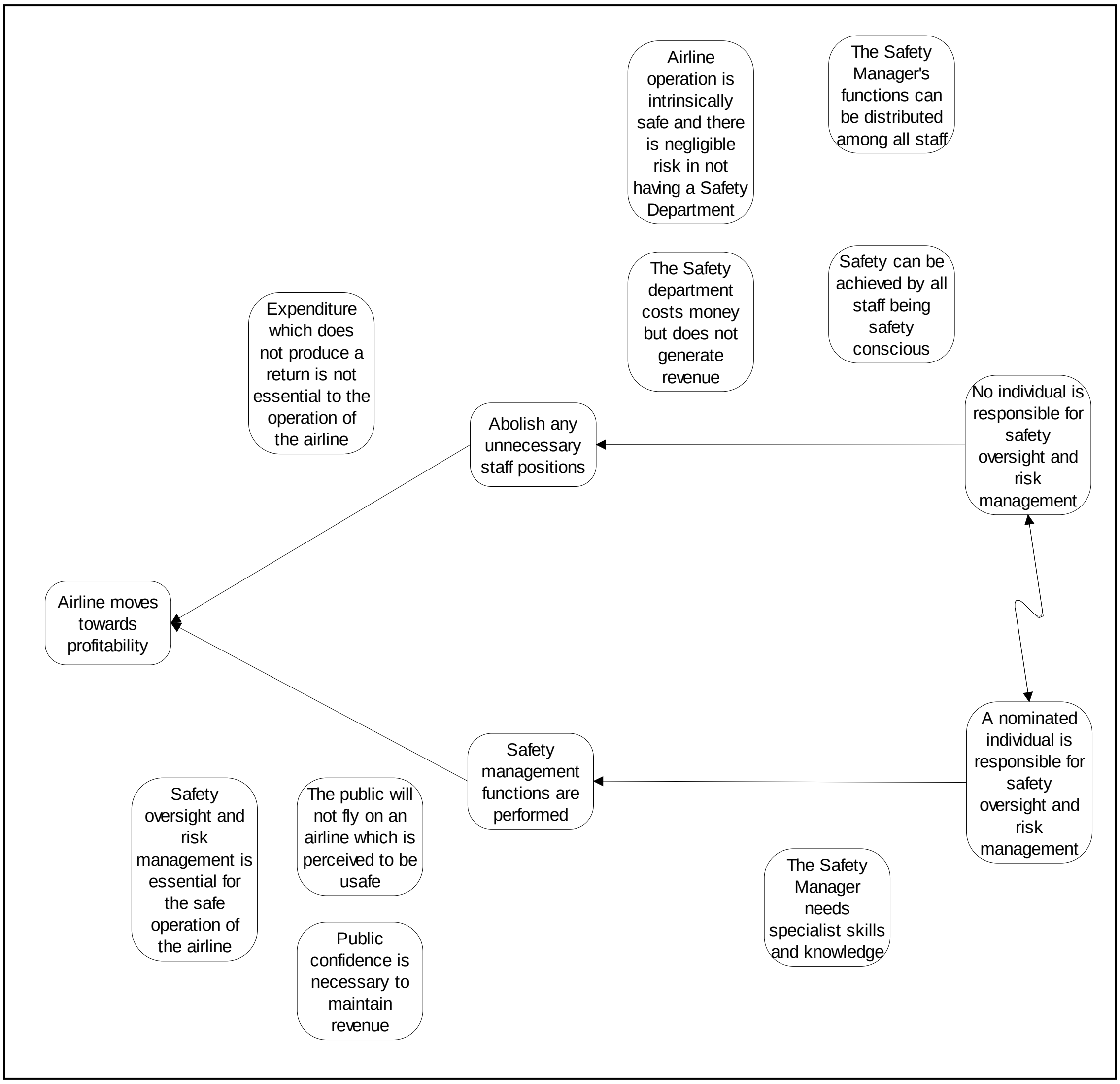

Figure 5. Assumptions in the Safety Manager CRD.

Some of the assumptions indicated by the arrows in Figure 4 have been inserted in Figure 5[11]. For example, in order to eliminate expenditure which does not

[11] These assumptions are those likely to have been made at the time. Some are inferred from actions (such as abolishing the Safety Manager position), others are generally true (such as the relation between public confidence and revenue), and where possible they are supported by evidence (e.g. the Chairman’s requirement to cut costs). Where such an analysis is performed a priori, or in the course of an accident investigation, the assumptions would be validated as part of the analysis.

produce a return, we must abolish all unnecessary positions; the Safety Manager position is unnecessary because its functions can be spread over other functions.

When the assumptions are set out in this way, their validity can be examined.

Considering first the lower part of the diagram, the need for the Safety Manager to have specialist skills and knowledge has already been established. The more general proposition, that safety oversight and risk management is essential for safe operation, might seem self-evident, were it not that Ansett (a major airline of long standing) did not consider it so. However, the fact that ICAO had published its Accident Prevention Manual in 1984 (ICAO, 1984) some 10 years before the accident, stipulating the need for safety management, indicates that the idea was not novel. The weight of authority in favour of safety management is now overwhelming (ante) but, even before the accident, the idea should not have been a matter of serious dispute.

Is it valid to say that expenditure which does not produce a return is not essential to the operation of the airline? That depends, in part, on the timeframe being considered. If the proposition was reworded ‘expenditure which *never* produces...’ it might well be considered valid. However, some expenditure generally considered essential produces a return only in the long term, and then if successful, the only return may be that nothing untoward happens. An example of this is simulator training for aircrew. In the simulator it is possible to train for emergencies which cannot safely be practised in the aircraft, and the return is that when confronted by such an emergency during operations, the aircrew is more likely to handle it effectively. Such benefits are difficult to quantify in accounting terms, but they are nonetheless real. Suppose, in this example, the aircrew do not handle the emergency successfully and an accident results. The loss of public confidence following an accident can result in the demise of the airline (e.g. the ValuJet accident (NTSB, 1997; Sakata, 2003)). The assumption that expenditure which does not produce a return is not essential to the operation of the airline would only be valid if the term ‘return’ was appropriately qualified.

It is undoubtedly true that an airline whose aircraft have mishaps[12] is likely to be perceived as unsafe, especially if fatalities occur, and that the public will not fly with an airline perceived to be unsafe – the example of the ValuJet disaster makes this point (NTSB, 1997; Sakata, 2003)[13].

The assumption that the Safety Manager functions can be achieved by all staff being safety conscious does not stand up to examination, since it is most unlikely that the staff would have the specialist skills required. Besides, some of the functions, such as confidential reporting of incidents, require that the Safety Department be seen to be separate from operational departments.

Considering now the proposition that safety can be achieved by all staff being safety conscious (‘safety is everybody’s concern’), there is no dispute that everyone being safety conscious is highly desirable. But this is not the same thing as proper safety management. Individuals, without guidance, could not be expected to take on such extra roles as ensuring that there was independent evaluation of cost-saving proposals, and establishing communication between departments when independent evaluation showed that a proposal by one department might have safety implications for another. And it would be most unlikely to find, within an airline, individuals with the necessary skills in, say, incident investigation to take on a part of the Safety Manager role. The assumptions that either general safety consciousness could make the position redundant, or that the various functions could be shared out among airline staff without specialist training (Ansett (NZ), 1993b) are therefore invalid.

The idea that airline operations are intrinsically safe is part of air transport mythology. While such operations have a generally good safety record, this has been achieved primarily by attention to all the things that might go wrong, and providing training or other assurance against them. The Safety Department, which provides

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[12] The term ‘accident’ has defined meanings in aviation, but some incidents coming within these official definitions might not fall within what the public means by an accident. In this paper, the term ‘defect’ refers to some mechanical malfunction, while an ‘incident’ is something less than a mishap because it is correctly handled by the crew. An undercarriage latch that sticks is a defect; an undercarriage leg which does not extend on command is an incident. A mishap encompasses anything likely to attract the attention of the news media: the Qantas overrun at Bangkok (ATSB, 2001) would be termed a mishap, even though no-one was injured thereby.

[13] ValuJet’s load factor declined from 60% in April 1996 to 39% in June, after the crash.

oversight of such safety operations, justifies its existence by the things that do not go wrong: difficult to quantify, but no more to be abandoned than a fire insurance policy.

While the assumptions across the lower half of the conflict diagram are valid, those across the top are unequivocally invalid. Action is therefore required to ensure that the Safety Manager position is filled, and that the Safety Manager functions effectively.

A first iteration of the section of the FRT dealing with Safety Management is shown in Figure 6.

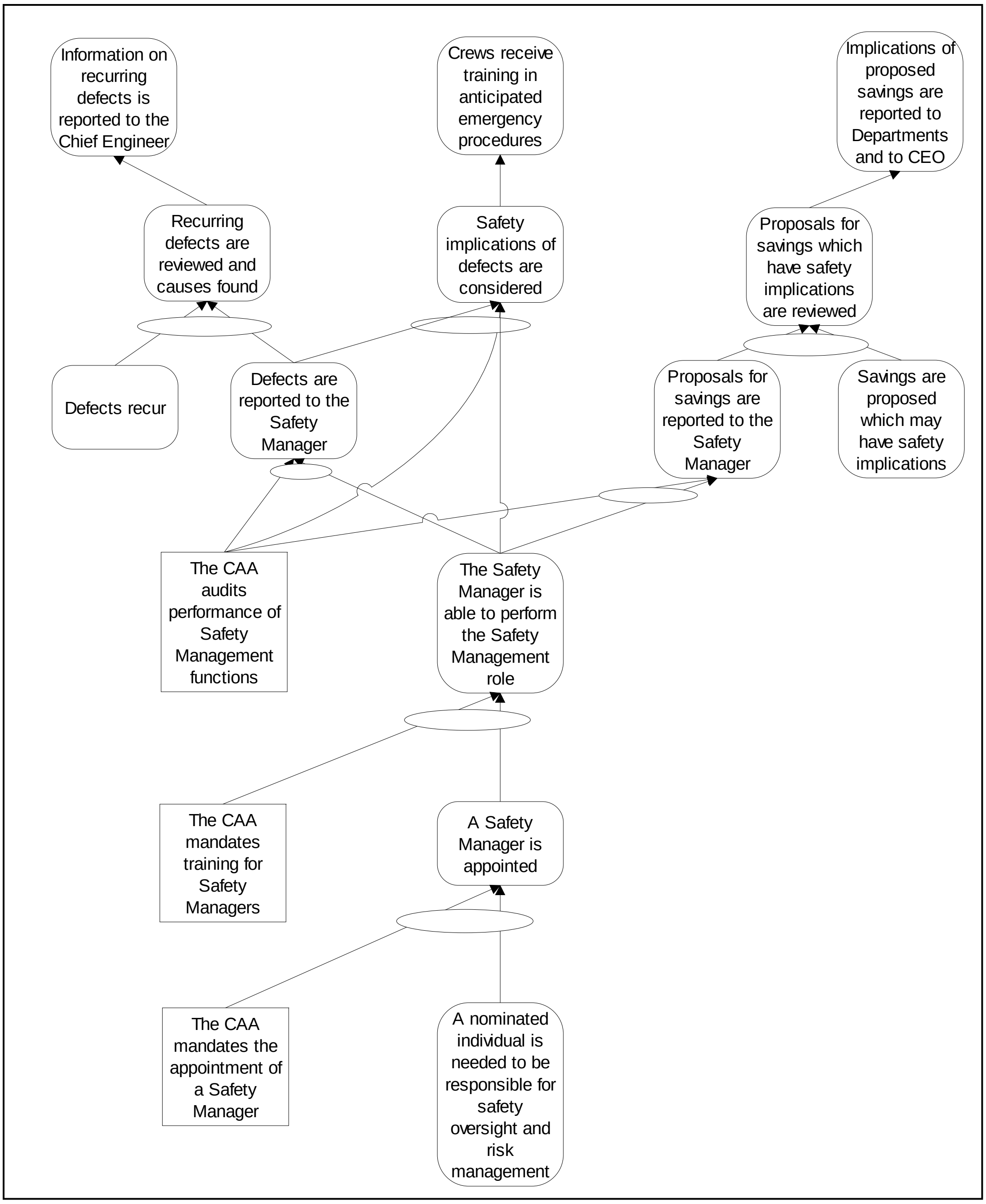

Figure 6. Future Reality Tree: Safety Manager functions.

While it would be unlikely that Ansett would have been tempted to abolish its Safety Department again, there could be no guarantee that another airline might not be tempted to do so. In the long term, education and publicity as to the need for a Safety Department might be the answer, but the immediate solution should come from the CAA in the form of a Regulation. Likewise, proper training for the Safety Manager should be mandated.

Where the Safety Manager is properly trained, normal performance of the Safety Manager's functions should have detected the factors which led to the Dash 8 accident, before it occurred. Detection of recurring problems is one such function (ICAO, 1984). Consideration of the implications of not purchasing the modified undercarriage parts should have led to their purchase (with trivial extra expenditure). Review of the performance of these functions, by CAA Auditors, should assure their proper performance (see Figure 6).

Furthermore, if there was some delay in rectifying the undercarriages, ensuring that crews were trained in the emergency procedure, and enforcing a requirement for a climb to a safe altitude in the event of malfunction on approach to land – both perfectly normal procedures, and within the purview of the Safety Manager – would have avoided any possibility of closure with terrain while the emergency was being sorted out. More generally, the safety implications of any defect not yet rectified should be considered, and appropriate emergency procedure training put in place.

Detailed scrutiny of Figure 6 led to a second iteration shown at Figure 7, which forms Sector 2 of the completed FRT.

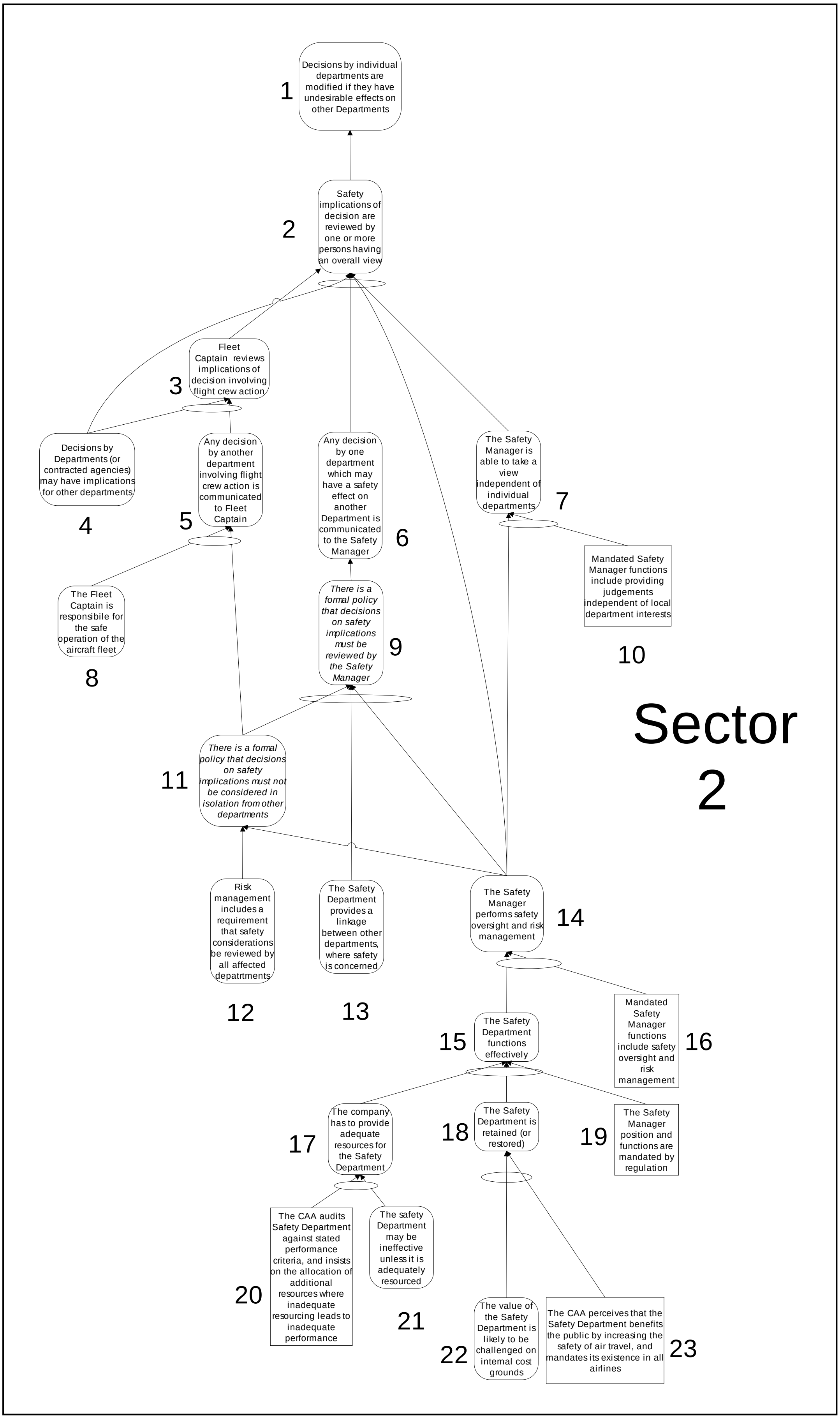

Figure 7. FRT: Safety Management System (Sector 2).

Key

1. Decisions by individual departments are modified if they have undesirable effects on other Departments
2. Safety implications of decision are reviewed by one or more persons having an overall view
3. Fleet Captain reviews implications of decision involving flight crew action
4. Decisions by Departments (or contracted agencies) may have implications for other departments
5. Any decision by another department involving flight crew action is communicated to Fleet Captain
6. Any decision by one department which may have a safety effect on another Department is communicated to the Safety Manager
7. The Safety Manager is able to take a view independent of individual departments
8. The Fleet Captain is responsible for the safe operation of the aircraft fleet
9. There is a formal policy that decisions on safety implications must be reviewed by the Safety Manager
10. Mandated Safety Manager functions include providing judgements independent of local departmental interests
11. There is a formal policy that decisions on safety implications must not be considered in isolation from other departments
12. Risk management includes a requirement that safety considerations are reviewed by all affected Departments
13. The Safety Department provides a linkage between other departments, where safety is concerned
14. The Safety Manager performs safety oversight and risk management
15. The Safety Department functions effectively
16. Mandated Safety Manager functions include safety oversight and risk management
17. The company has to provide adequate resources for the Safety Department
18. The Safety Department is retained (or restored)
19. The Safety Manager position and functions are mandated by regulation
20. The CAA audits Safety Department against stated performance criteria, and insists on the allocation of additional resources where inadequate resourcing leads to inadequate performance
21. The Safety Department will be ineffective unless it is adequately resourced
22. The value of the Safety Department is likely to be challenged on internal cost grounds
23. The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines

The remaining sectors of the CRT are transformed in a similar fashion, to generate the complete FRT:

- Figure8 shows Sector 3, Maintenance

- Figure9 shows Sector 4, Pressures
- Figure10 shows Sector 5, Distraction
- Figure 11 shows Ground Proximity Warning System.

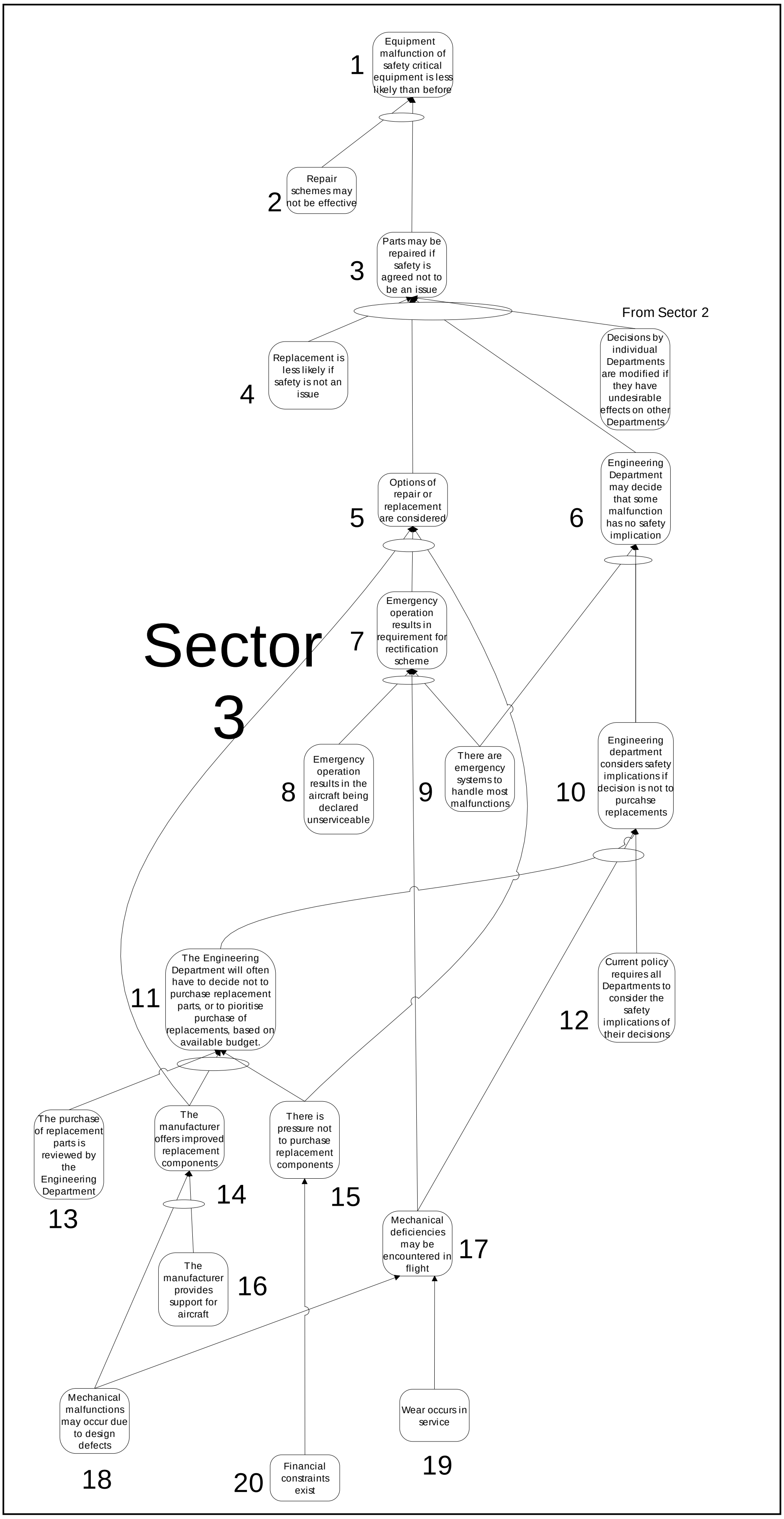

Figure 8. FRT: Maintenance (Sector 3).

Key

1. Malfunction of safety critical equipment is less likely than before
2. Repair schemes may not be effective
3. Parts may be repaired if safety is agreed not to be an issue
4. Replacement is less likely if safety is not an issue
5. Options of repair or replacement are considered
6. Engineering Department may decide that some malfunction has no safety implication
7. Emergency operation results in requirement for rectification scheme
8. Emergency operation results in the aircraft being declared unserviceable
9. There are emergency systems to handle most malfunctions
10. Engineering department considers safety implications if decision is not to purcahse replacements
11. The Engineering Department will often have to decide not to purchase replacement parts, or to prioritise purchase of replacements, based on available budget
12. Current policy requires all Departments to consider the safety implications of their decisions
13. The purchase of replacement parts is reviewed by the Engineering Department
14. The manufacturer offers improved replacement components
15. There is pressure not to purchase replacement components
16. The manufacturer provides support for aircraft
17. Mechanical deficiencies may be encountered in flight
18. Mechanical malfunctions may occur due to design defects
19. Wear occurs in service
20. Financial constraints exist

From Sector 2: Decisions by individual Departments are modified if they have undesirable effects on other Departments

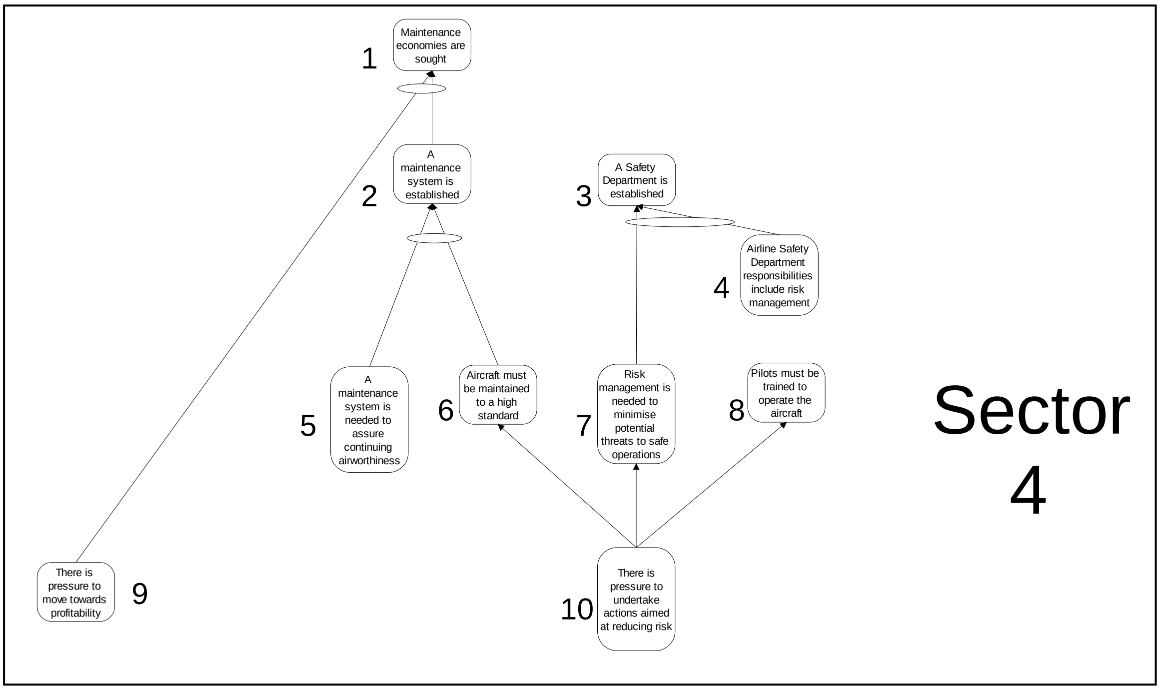

Figure 9. FRT: Pressures (Sector 4).

Key

1. Maintenance economies are sought
2. A maintenance system is established
3. A Safety Department is established
4. Airline Safety Department responsibilities include risk management
5. A maintenance system is needed to assure continuing airworthiness
6. Aircraft must be maintained to a high standard
7. Risk management is needed to minimise potential threats to safe operations
8. Pilots must be trained to operate the aircraft
9. There is pressure to move towards profitability
10. There is pressure to undertake actions aimed at reducing risk

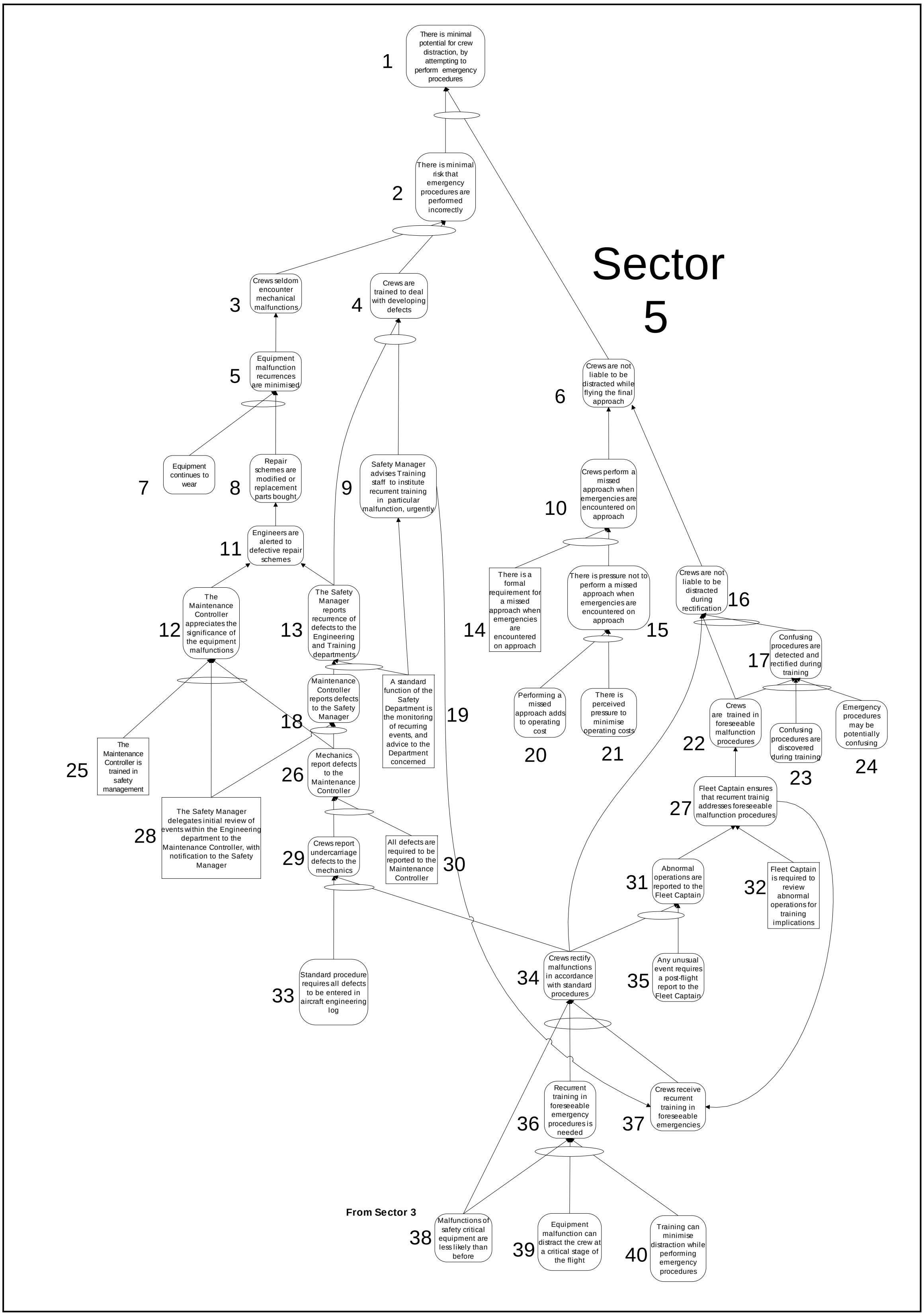

Figure 10. Distraction (Sector 5).

Key

1. There is minimal potential for crew distraction, by attempting to perform emergency procedures
2. There is minimal risk that emergency procedures are performed incorrectly
3. Crews seldom encounter mechanical malfunctions
4. Crews are trained to deal with developing defects
5. Equipment malfunctions seldom recur
6. Crews are not liable to be distracted while flying the final approach
7. Equipment continues to wear
8. Repair schemes are modified or replacement parts bought
9. Safety Manager advises Training staff to institute recurrent training in particular malfunction, urgently
10. Crews perform a missed approach when emergencies are encountered on approach
11. Engineers are alerted to defective repair schemes
12. The Maintenance Controller appreciates the significance of the equipment malfunctions
13. The Safety Manager reports recurrence of defects to the Engineering and Training Departments
14. There is a formal requirement for a missed approach when emergencies are encountered on approach
15. There is pressure not to perform a missed approach when emergencies are encountered on approach
16. Crews are not liable to be distracted during rectification
17. Confusing procedures are detected and rectified during training
18. Maintenance Controller reports defects to the Safety Manager
19. A standard function of the Safety Department is the monitoring of recurring events, and advice to the Department concerned
20. Performing a missed approach adds to operating cost
21. There is perceived pressure to minimise operating costs
22. Crews are trained in foreseeable malfunction procedures
23. Confusing procedures are discovered during training
24. Emergency procedures may be potentially confusing
25. The Maintenance Controller is trained in safety management
26. Mechanics report defects to the Maintenance Controller
27. Fleet Captain ensures that recurrent trainig addresses foreseeable malfunction procedures
28. The Safety Manager delegates initial review of events within the Engineering department to the Maintenance Controller, with notification to the Safety Manager
29. Crews report defects to the mechanics
30. All defects are required to be reported to the Maintenance Controller
31. Abnormal operations are reported to the Fleet Captain
32. Fleet Captain is required to review abnormal operations for training implications
33. Standard procedure requires all defects to be entered in aircraft engineering log
34. Crews rectify malfunctions in accordance with standard procedures
35. Any unusual event requires a post-flight report to the Fleet Captain
36. Recurrent training in foreseeable emergency procedures is needed
37. Crews receive recurrent training in foreseeable emergencies
38. Malfunctions of aety critical equipment are less likely than before
39. Equipment malfunction can distract the crew at a critical stage of the flight
40. Training can minimise distraction while performing emergency procedures

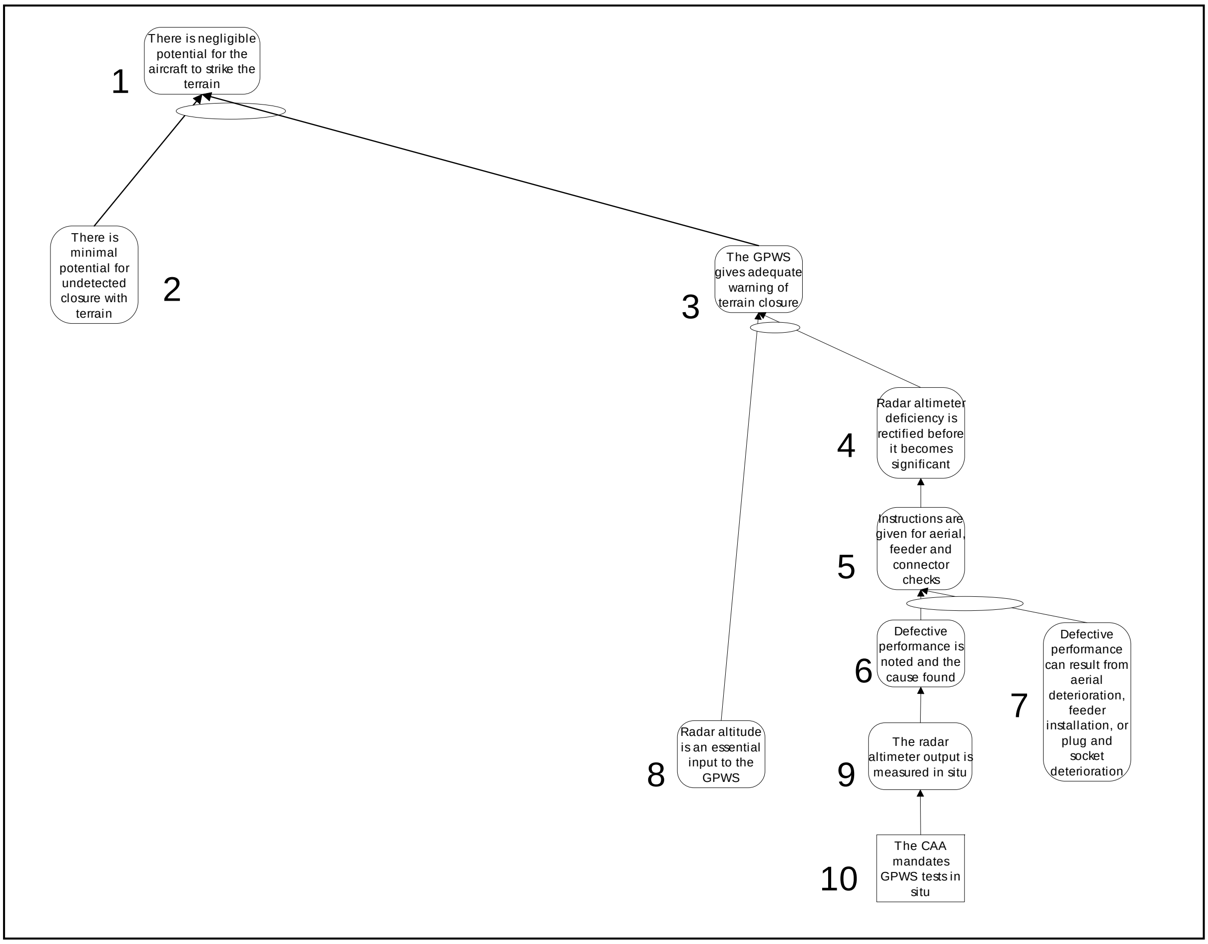

Figure 11. FRT: Ground Proximity Warning System.

Key

1. There is no potential for the aircraft to strike the terrain
2. There is minimal potential for undetected closure with terrain
3. The GPWS gives adequate warning of terrain closure
4. Radar altimeter deficiency is rectified before it becomes significant
5. nstructions are given for aerial, feeder and connector checks
6. Defective performance is noted and the cause found
7. Defective performance can result from aerial deterioration, feeder installation, or plug and socket deterioration
8. Radar altitude is an essential input to the GPWS
9. The radar altimeter output is measured in situ
10. The CAA mandates GPWS tests in situ

The complete Ansett FRT is shown at Figure 12. The contents of the individual sectors are unchanged; the diagram is intended to show the way in which the sectors link together to form the complete FRT.

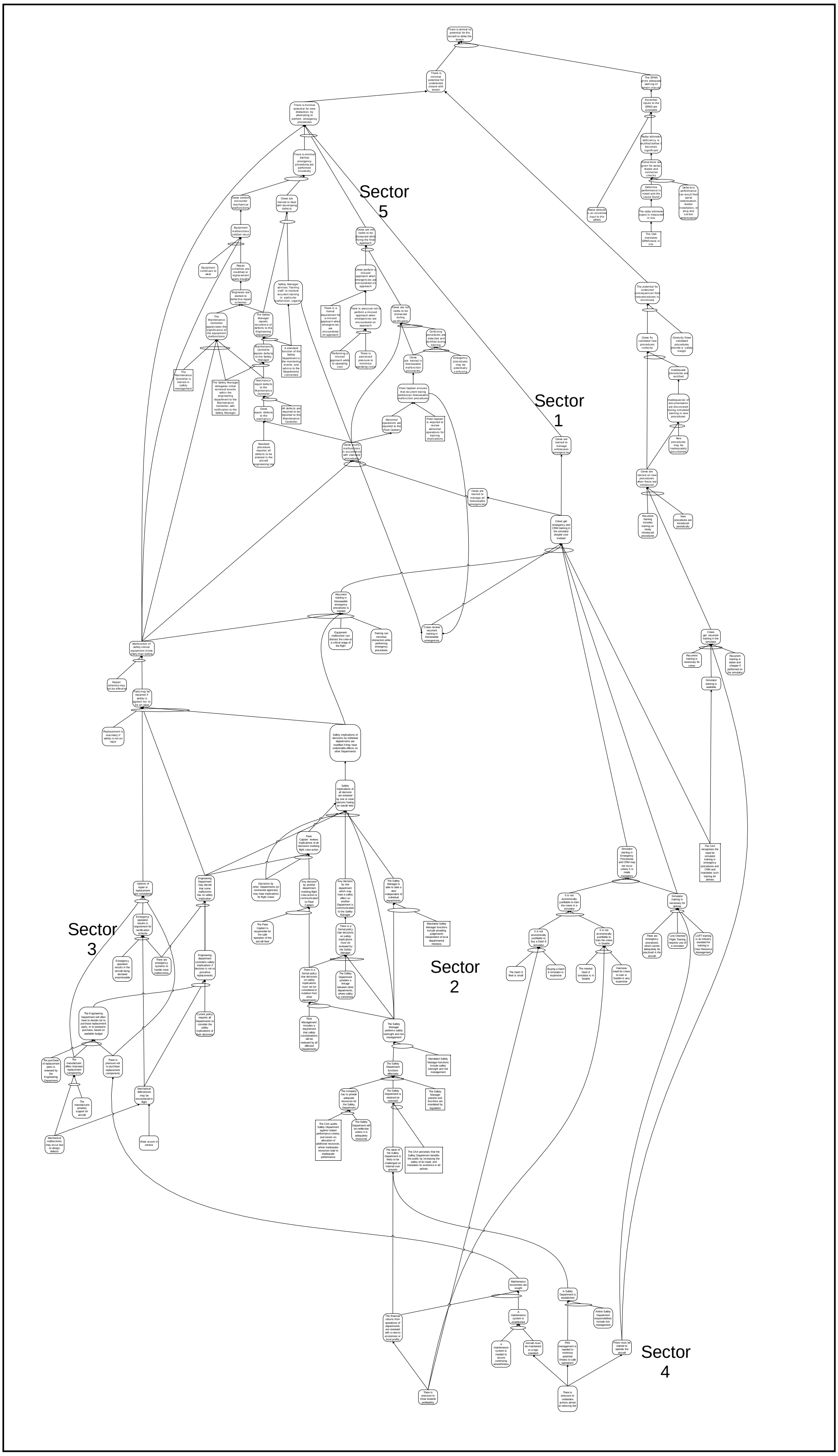

Figure 12. Ansett FRT

Additive Effects

The conjunction of two effect lines without a logical **and** denotes an additive effect. For example, in Sector 5 the entity

"Engineers are alerted to the defective repair scheme"

is fed by both

"The Safety Manager reports recurring defects to the Engineering department", and by

"The Maintenance Controller appreciates the significance of equipment malfunctions".

Either on its own would suffice. The double linkage indicates a back-up system – a highly desirable state of affairs whereby, if one system fails for some reason, the alternative system ensures that overall performance is unaffected. Here, both the reporting system through the Maintenance Controller, and the occurrence monitoring by the Safety Department, should detect a recurring defect. As both would notify the Engineering Department, an omission by either alone would have no adverse effect.

Positive reinforcement

Finally, it is desirable to generate feedback loops to provide positive reinforcement, to ensure that the planned changes do not 'run out of steam'. A desirable output is fed back into the FRT at an earlier (i.e. lower) stage, so that it amplifies or reinforces an earlier desirable effect (Dettmer, 1997). It may be necessary to add an injection to make this possible. Schematically, the process is shown in Figure 13.

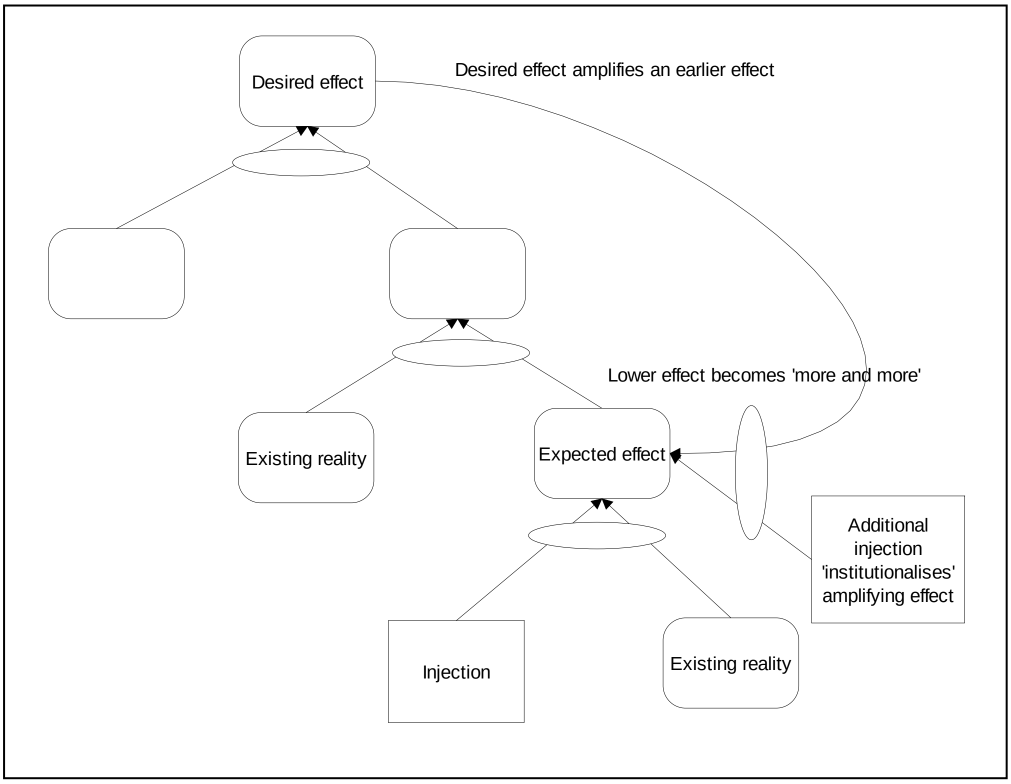

Figure 13. Positive reinforcing loop. (Source: Dettmer, 1997).

The flow in the feedback loop is against the implicit timebase, and so appears to go back in time. Strictly, the elements inside the loop should be repeated upwards ad infinitum. (This difficulty can be handled by Petri Nets, which was one of the reasons they were formerly advocated by (Johnson, Wright, & McCarthy, 1995). However, the downward loop is a convenient shorthand notation, and is standard usage in the literature of the Theory of Constraints (see, e.g.,(Dettmer, 1997). (The effects from the downward loop are not read on the first pass through that point).

Positive reinforcement loops can be drawn from the handling of incidents by maintenance and flight crews. Incidents are required to be reported to the Safety Department, so that lessons can be learnt, but in order for this to happen, personnel need to be assured that they will not be blamed for an innocent action or omission which has had an adverse outcome. This is variously referred to as a ‘no blame’ or ‘just’ culture within the company (Reason, 1997), and the required injection is “A no-blame culture is introduced”. The feedback will return to “Incidents are investigated” (by the Safety Department or Maintenance Controller, as appropriate). These positive reinforcement loops are shown in Figure12.

Negative Branch Reservations

In order to remove undesirable effects, injections – that is, changes – have been made. While the injections have been examined to see that they can bring about the removal of undesirable effects, there is the possibility that the changes may introduce new undesirable effects. The linkages which lead from injections to such new undesired effects are known as Negative Branches (Dettmer, 1997), and it is necessary to 'trim' these branches, either by choosing a different injection in the first place, or by a further injection which will nullify the undesired side effects.

The procedure is to examine each injection in turn, asking what, beside the desired effect, could also result from the injection. (It is also possible that negative branches might originate from the desired effects generated by injections).

The generation of undesirable effects by injections is a separate consideration from examination of obstacles to implementation. These are matters for the implementation process, the Prerequisite Tree and Transition Tree, should such obstacles be anticipated. However, while the injections are being reviewed, it will be convenient to note possible difficulties in implementation, for later analysis.

The Injections in the Ansett FRT

The injections in the Ansett FRT are listed in Table 2. Some, expanded in the FRT for clarity, have been grouped in Table 2. An example is the grouping of the various functions of the Safety Manager.

It is recognised that implementing some injections might have an adverse effect on Ansett's financial situation – for example, having a requirement for simulator training. However, this is not a direct concern for either the accident investigators or the CAA, whose concern is solely with the safety of operations. Deterioration of Ansett's financial position would only be relevant insofar as it put the company under even more pressure to minimise safety activities in order to attempt to survive. Where this possibility is foreseen, it will be necessary to take additional measures to ensure that no reduction in safety occurs; i.e. that the negative branches are trimmed. This could take the form of increased safety oversight by the CAA, as discussed in the next section.

In general, Safety Recommendations are directed to the CAA since, as already discussed, recommendations to Ansett might be ineffective in view of the company's financial situation.

Table 2. Injections, negative branch reservations and implementation reservations, Ansett FRT.

Injection	Negative Branch Reservation	Implementation Reservation	Remarks
The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines		The Safety Department may be ineffective if the Safety Manager lacks the right personality, experience and training	Further injections needed: The Safety Manager must be an "approved person". (Recommendation to the CAA)
The CAA audits the Safety Department against stated performance criteria, and insists on allocation of additional resources where inadequate resourcing is disclosed			
The Safety Manager position and functions are mandated by regulation	The cost of a Safety Department will put an additional financial burden on the airline, which may try to cut corners in other areas		Further monitoring by CAA will be needed to prevent short-cuts
The CAA recognises the need for simulator training in emergency procedures and Crew Resource Management, and mandates such training for all airlines	The cost of simulator training will put an additional financial burden on the airline, which may try to cut corners in other areas Simulator training may be skimped (e.g. no Line Oriented Flight Training, which is expensive in simulator time)	Current doctrine is that airlines are the proper judges of what is safe, so persuading the CAA to act may be difficult	The accident has demonstrated that airline judgement may be faulty, and prescriptive action is called for (Formal Recommendation to CAA) (See (Maurino, 1998) in (Helmreich & Merritt, 1998). Further monitoring by CAA will be needed to prevent short-cuts More detailed surveillance by CAA will be needed
The Maintenance Controller is trained in safety management	Minor adverse financial effect		Addressed by Safety Case requirement (See CAA Injections)
The Safety Manager delegates initial review of events within the Engineering Department to the Maintenance Controller, with notification to the Safety Manager			All defects are required to be reported to the Maintenance Controller
There is a formal requirement for a missed approach when emergencies are encountered on approach	Minor adverse financial effect		Addressed by Safety Case requirement (Supra)
The Fleet Captain is required to review abnormal operations for training implications			
The CAA mandates GPWS tests in situ in situ	Minor adverse financial effect		Global problem: will require regulatory action by CAA

The CAA Future Reality Tree

The classical approach to construction of a Future Reality Tree (FRT) is to seek to address the core conflict at or near the base of the Current Reality Tree (CRT). This approach was ineffective when constructing the Ansett FRT, because Ansett's problems stemmed from its financial problems. It was not open to Government bodies, such as the accident investigation authority or the CAA, to address these problems. Accordingly, the alternative approach, of transforming the CRT piecemeal, was successfully adopted to address the safety problems alone.

In the case of the CAA FRT, this restriction does not prevail. If, to address the CAA's performance problems, it was necessary to address the financial problems which gave rise to them, this would be perfectly permissible. The CRT discloses a number of core problems:

- Greater depth of audit of non-viable airlines does not occur
- CAA defines audits as reviewing the documentation of systems
- CAA has insufficient qualified staff for all required surveillance

However, it is worth attempting to address the conflict at the base of the CRT. If this can be resolved, the undesirable effects above it may disappear.

The CRT originates in a clear-cut conflict:

- There is pressure to minimise surveillance of airline activities, and
- There is pressure to deploy resources effectively, but
- The CAA cannot meet both of these requirements

And since *all* of the other undesirable effects stem from this fundamental conflict, it may be possible to clear all the difficulties which the CAA had in performing effective oversight of airline safety, by resolving this conflict. This approach is what Goldratt (Goldratt, 1987) has termed an 'evaporating cloud'.

The base of the CRT is shown in Figure 14.

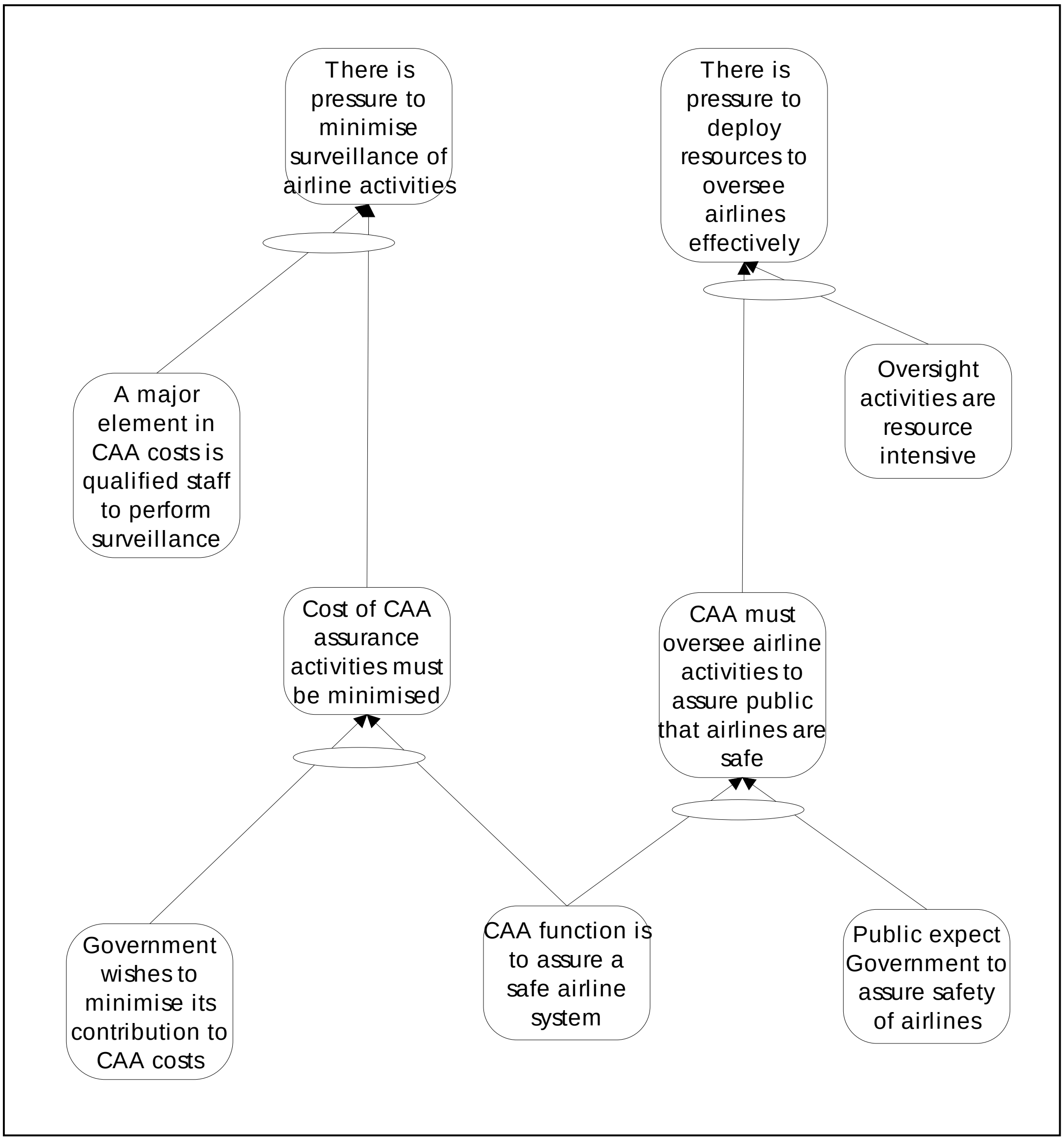

Figure 14. The core conflict at the base of the CAA CRT

(It could be argued that additional sufficiency is needed, such as '*Effective* oversight activities are resource intensive', 'There is pressure to deploy *more* resources…', but these do not affect the subsequent analysis. This illustrates Dettmer's point that the FRT acts as a safety net where there are deficiencies in the CRT (Dettmer, 1997).

The core conflict can be re-drawn as a Conflict Resolution Diagram (CRD) as shown in Figure 15. This figure also shows the assumptions which underlie the arrows (Dettmer, 1997).

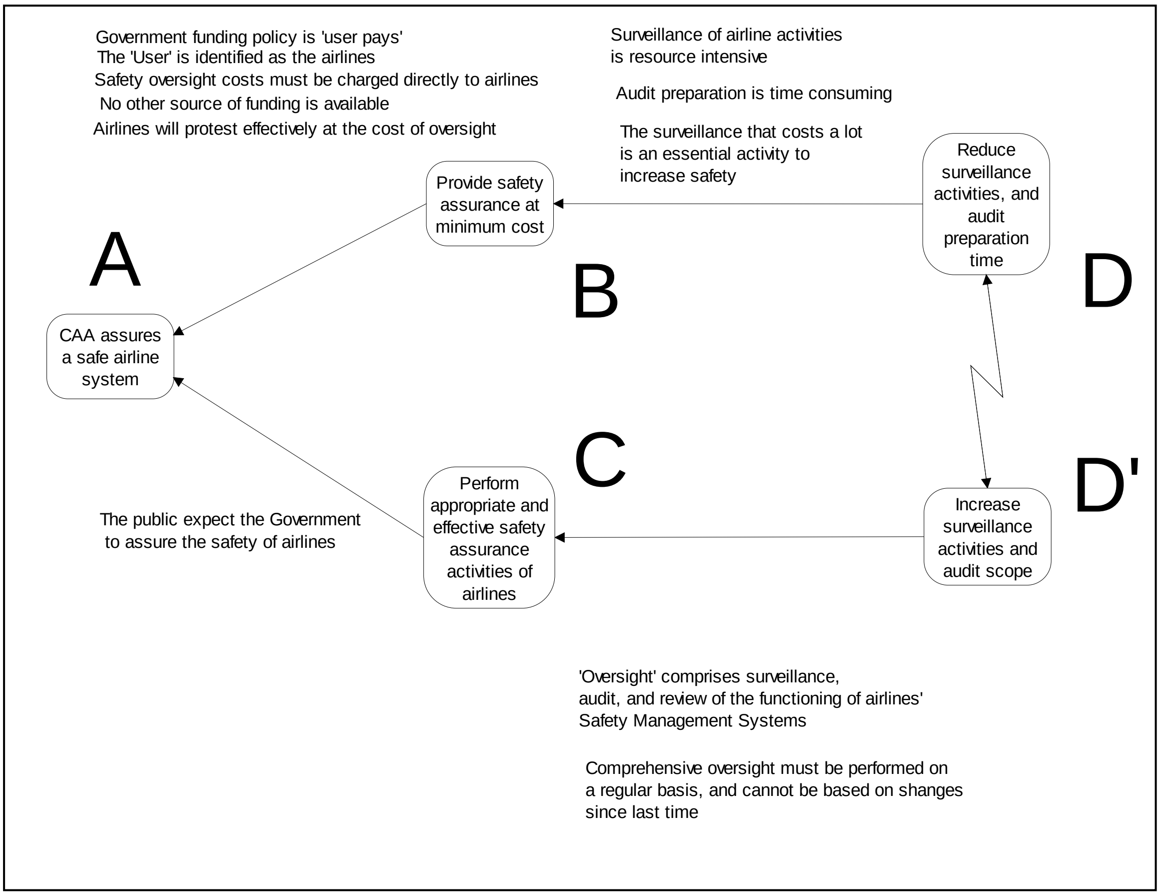

Figure 15. Conflict Resolution Diagram from CAA CRT.

Surveillance of airline activities requires a sizeable staff of highly qualified Inspectors (ICAO, 1995), and audit preparation requires a thorough review of the airline's manuals which takes appreciable time. The assumptions B-D are therefore valid. Likewise, the activities required for safety oversight (C-D) are well established (ICAO, 1999); (ICAO, 1995); (Swedavia AB & McGregor and Company, 1988); (Flight Safety Foundation, 1998). Public expectation that the Government will assure airline safety (A-C) has been demonstrated by requirements for Inquiries after a disaster (see, e.g., the Erebus Royal Commission (Mahon, 1981)). If the assumptions at A-B are valid, the CAA's dilemma is clear: it is required to do those things necessary to assure airline safety, but must remain within funding constraints dictated by airline pressure. It cannot do both effectively.

The assumptions to be addressed, therefore, are those at A-B:

- The Government's funding policy is 'user pays'

- The ‘user’ is identified as the airlines
- Safety oversight must be charged directly to airlines
- No other source of funding is available
- Airlines will protest effectively at the cost of oversight.

There is no question that the Government required CAA activities to be charged to the user of those activities, and the Government was adamant that it would not pay for the safety of airline operations ("AIA Conference Report," 1994). Where these costs were passed to airlines it is not surprising that protests should result, and given the constitution of the CAA Board which contained representatives from the aviation industry, those protests were likely to be effective (see, for example, ("CAA Board Appointments," 1994). However, the identification of the ‘user’ of CAA ‘services’ as the airlines themselves is open to challenge.

It was the public expectation, that the Government would assure the safety of air travel, that gave rise to existence of the CAA. (This expectation was a world-wide phenomenon, which led in part to the Chicago Convention (ICAO, 2000): the safety of aviation is a significant function of ICAO). The public, as travellers, were the beneficiaries of the CAA’s activities. Accordingly, the public could be seen as the ‘users’. A feasible means of payment could be a small levy per ticket, as previously used to fund the activities of the Air Services Licensing Authority ("Air Services Licensing Act," 1983). The charge would be so small, in proportion to the cost of an air ticket, as to be virtually unnoticeable, and therefore unlikely to excite protest[14].

Since there is a feasible alternative source of funding for the CAA, the assumptions at A-B that safety oversight must be charged to airlines, and no alternative funding is available, are not valid. The conflict (D-D’) is therefore broken: it is possible to deploy all resources to oversee airlines effectively, within potential alternative funding.

[14] Figures needed to determine the levy which would have been needed in 1994 are not readily available. Current figures in Australia in 2004 are 93.8 million passenger tickets (single sector); operating cost of the Civil Aviation Safety Authority (CASA) is $114 million: a charge of $2 per ticket would adequately fund the Authority’s operating costs. The costs of the NZCAA could be expected to be roughly proportional to those of the Australian CASA.

In the CRT, the core conflict feeds to the limitation in what can be done ('audit is defined as review of airlines' documentation to assure that safe systems are in place') which in turn feeds to all the factors depriving the CAA of 'mindfulness' (Weick & Sutcliffe, 2001) such as 'audits cannot detect operations which are not in accordance with the documentation'. These factors, collectively, were the reason that 'auditing Ansett is ineffective in assuring safe operation'. With the basic conflict resolved by a funding mechanism which should provide sufficient funding for the CAA to operate effectively, it should be possible to identify high-risk operations, and take action to forestall many airline accidents.

The FRT from the CAA perspective is constructed somewhat differently from the Ansett FRT, because the performance improvement sought is more generic. It is not just similar accidents at Ansett that are to be averted, but all the airline accidents which can be averted by proper safety oversight. Additionally, it is not practicable merely to reverse undesirable effects in the CAA CRT as the basis for the FRT, since the fundamental injection – that adequate funding is available – completely collapses the CRT. It is therefore necessary to build the FRT ab initio, from the basic premises that adequate funding is available, and all necessary oversight means will be used.

The FRT is constructed from a number of clusters:

A. Funding is not a constraint on safety oversight

B. Oversight comprises surveillance, auditing and safety management review

C. Non-viability of airlines triggers greater depth of auditing

D. CAA is aware of deficiencies in airline operations.

These clusters are shown separately in Figures 16-19 below, and the complete FRT is shown at Figure 20.

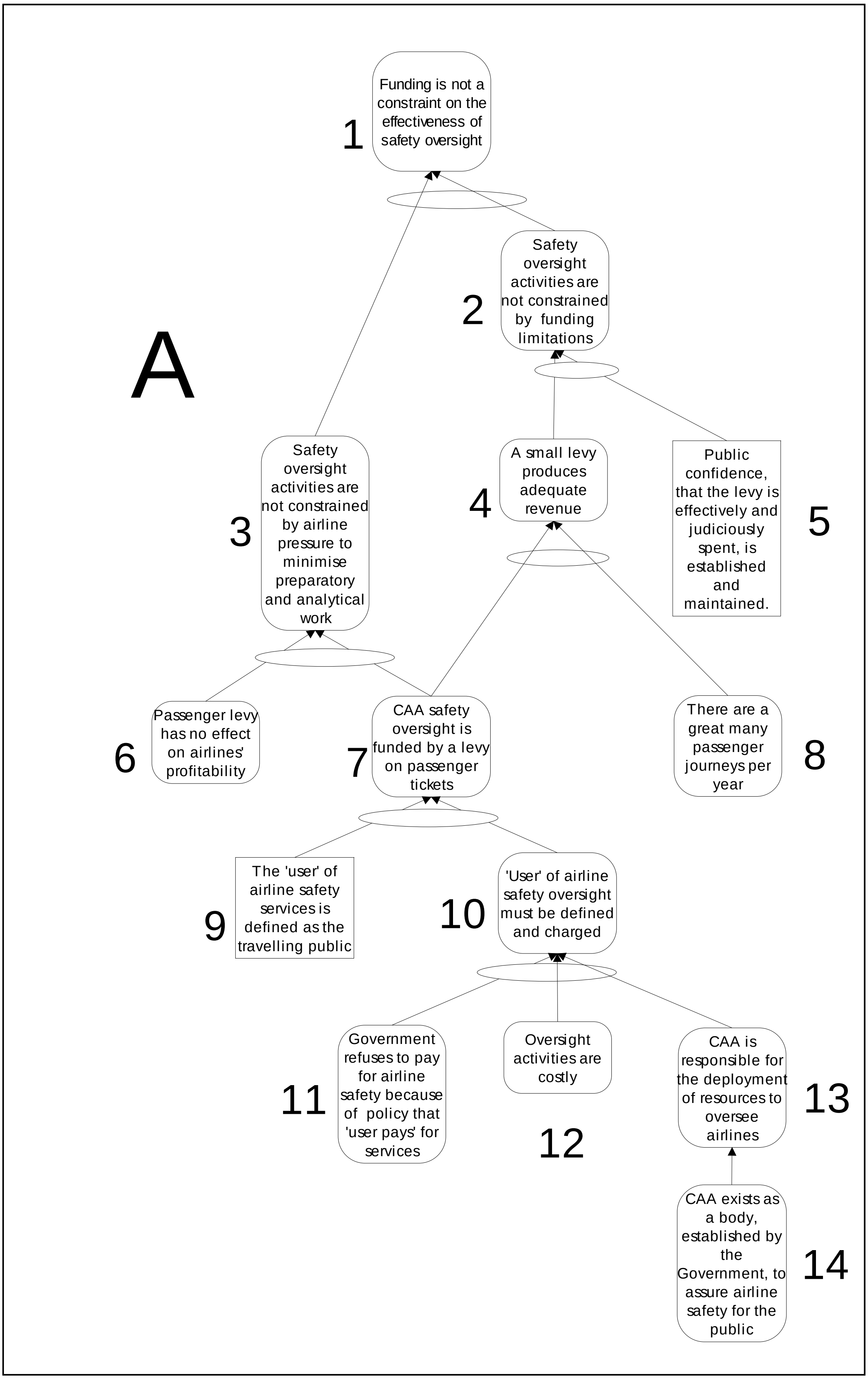

Figure 16. Funding is not a constraint on safety oversight.

Key

1. Funding is not a constraint on the effectiveness of safety oversight
2. Safety oversight activities are not constrained by funding limitations
3. Safety oversight activities are not constrained by airline pressure to minimise preparatory and analytical work
4. A small levy produces adequate revenue
5. Public confidence that the levy is effectively and judiciously spent is established and maintained.
6. Passenger levy has no effect on airlines' profitability
7. CAA safety oversight is funded by a levy on passenger tickets
8. There are a great many passenger journeys per year
9. The 'user' of airline safety services is defined as the travelling public
10. 'User' of airline safety oversight must be defined and charged
11. Government refuses to pay for safety oversight because of policy that 'user pays' for services
12. Oversight activities are costly
13. CAA is responsible for the deployment of resources to oversee airlines
14. CAA exists as a body, established by the Government, to assure airline safety for the public

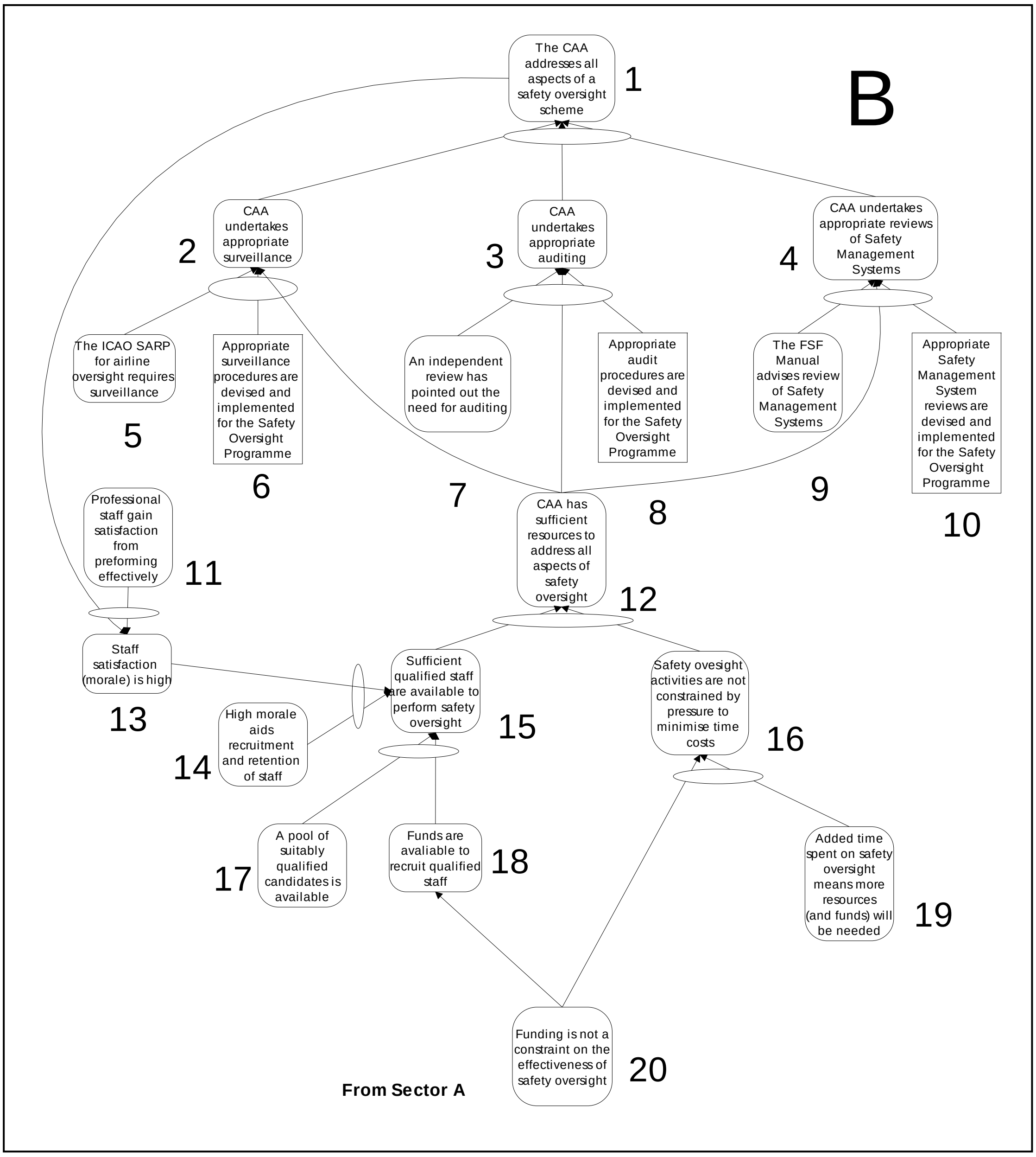

Figure 17. Oversight comprises surveillance, auditing and safety management review.

Key

1. The CAA addresses all aspects of a safety oversight scheme
2. CAA undertakes appropriate surveillance
3. CAA undertakes appropriate auditing
4. CAA undertakes appropriate reviews of Safety Management Systems
5. The ICAO SARP for airline oversight requires surveillance
6. Appropriate surveillance procedures are devised and implemented for the Safety Oversight Programme
7. An independent review has pointed out the need for auditing
8. Appropriate audit procedures are devised and implemented for the Safety Oversight Programme
9. The FSF Manual advises review of Safety Management Systems
10. Appropriate Safety Management System reviews are devised and implemented for the Safety Oversight Programme
11. Professional staff gain satisfaction from preforming effectively
12. CAA has sufficient resources to address all aspects of safety oversight
13. Staff satisfaction (morale) is hig
14. High morale aids recruitment and retention of staff
15. Sufficient qualified staff are available to perform safety oversight
16. Safety ovesight activities are not constrained by pressure to minimise time costs
17. A pool of suitably qualified candidates is available
18. Funds are avaliable to recruit qualified staff
19. Added time spent on safety oversight means more resources (and funds) will be needed
20. Funding is not a constraint on the effectiveness of safety oversight

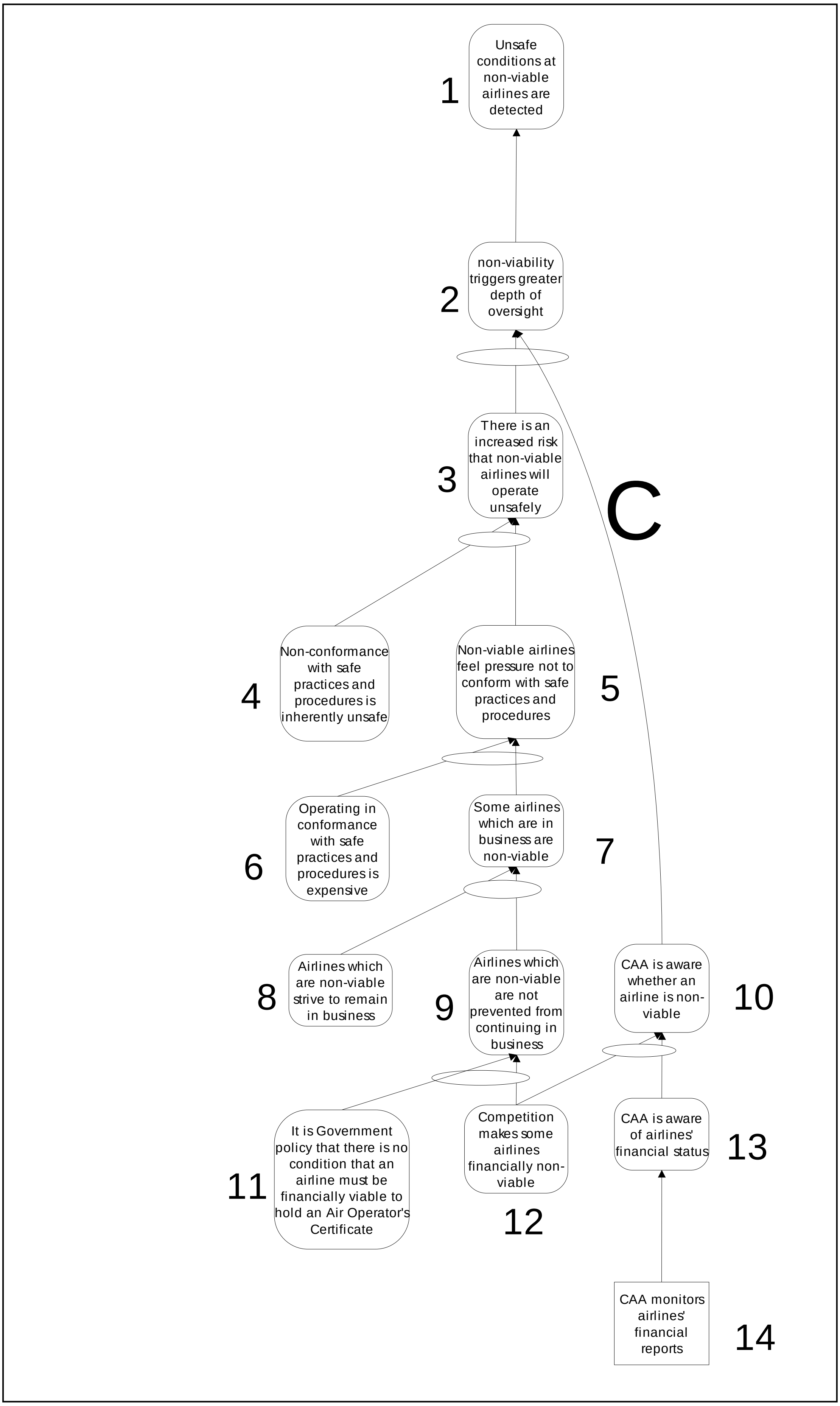

Figure 18. Non-viability of airlines triggers greater depth of oversight

Key

1. Unsafe conditions at non-viable airlines are detected
2. non-viability triggers greater depth of oversight
3. There is an increased risk that non-viable airlines will operate unsafely
4. Non-conformance with safe practices and procedures is inherently unsafe
5. Non-viable airlines feel pressure not to conform with safe practices and procedures
6. Operating in conformance with safe practices and procedures is expensive
7. Some airlines which are in business are non-viable
8. Airlines which are non-viable strive to remain in business
9. Airlines which are non-viable are not prevented from continuing in business
10. CAA is aware whether an airline is non-viable
11. It is Government policy that there is no condition that an airline must be financially viable to hold an Air Operator's Certificate
12. Competition makes some airlines financially non-viable
13. CAA is aware of airlines' financial status
14. CAA monitors airlines' financial reports

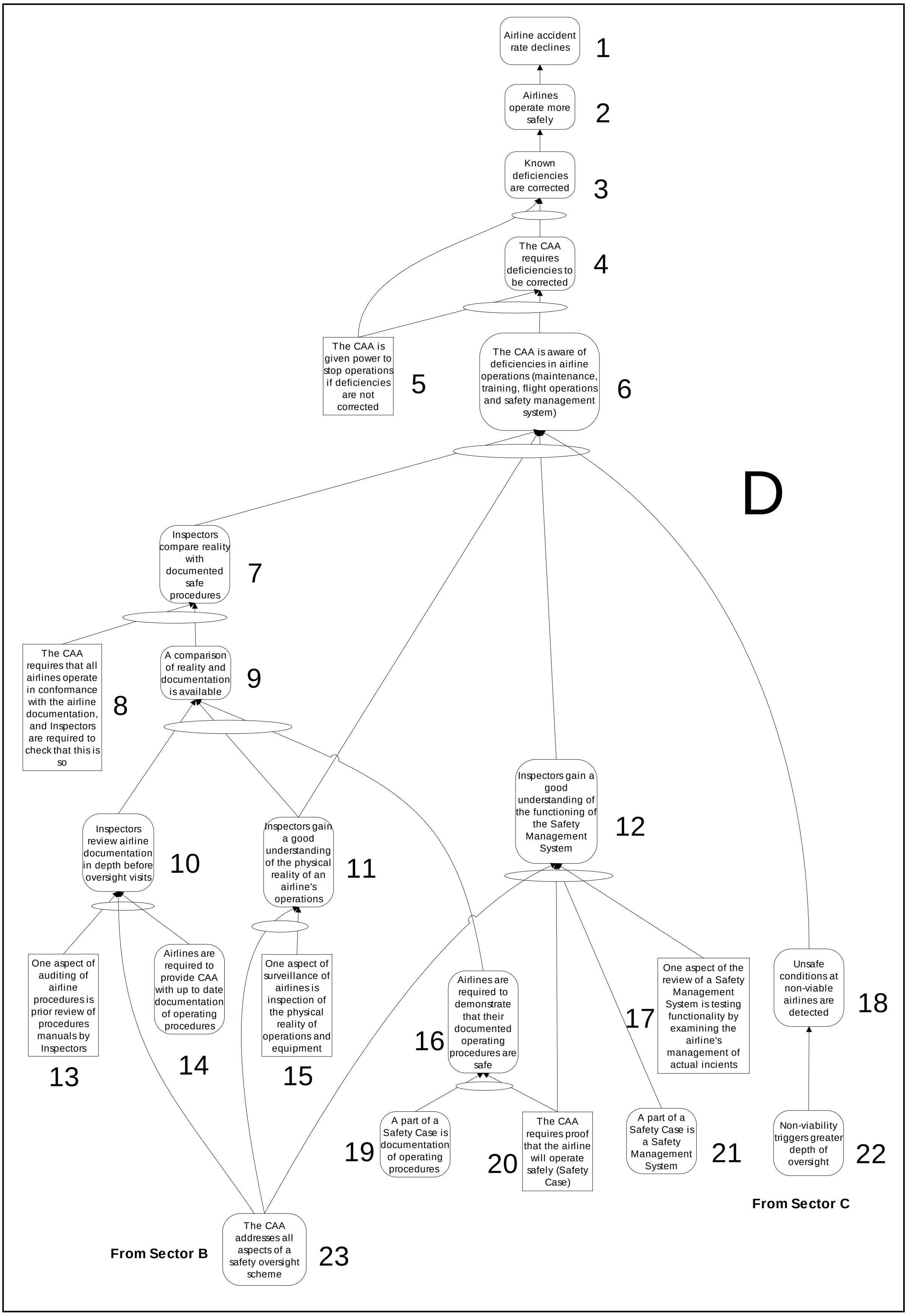

Figure 19. CAA is aware of deficiencies in airline operations.

Key

1. Airline accident rate declines
2. Airlines operate more safely
3. Known deficiencies are corrected
4. The CAA requires deficiencies to be corrected
5. The CAA is given power to stop operations if deficiencies are not corrected
6. The CAA is aware of deficiencies in airline operations (maintenance, training, flight operations and safety management system)
7. Inspectors compare reality with documented safe procedures
8. The CAA requires that all airlines operate in conformance with the airline documentation, and Inspectors are required to check that this is so
9. A comparison of reality and documentation is available
10. Inspectors review airline documentation in depth before oversight visits
11. Inspectors gain a good understanding of the physical reality of an airline's operations
12. Inspectors gain a good understanding of the functioning of the Safety Management System
13. One aspect of auditing of airline procedures is prior review of procedures manuals by Inspectors
14. Airlines are required to provide CAA with up to date documentation of operating procedures
15. One aspect of surveillance of airlines is inspection of the physical reality of operations and equipment
16. Airlines are required to demonstrate that their documented operating procedures are safe
17. One aspect of the review of a Safety Management System is testing functionality by examining the airline's management of actual incients
18. Unsafe conditions at non-viable airlines are detected
19. A part of a Safety Case is documentation of operating procedures
20. The CAA requires proof that the airline will operate safely (Safety Case)
21. A part of a Safety Case is a Safety Management System
22. Non-viability triggers greater depth of oversight
23. The CAA addresses all aspects of a safety oversight scheme

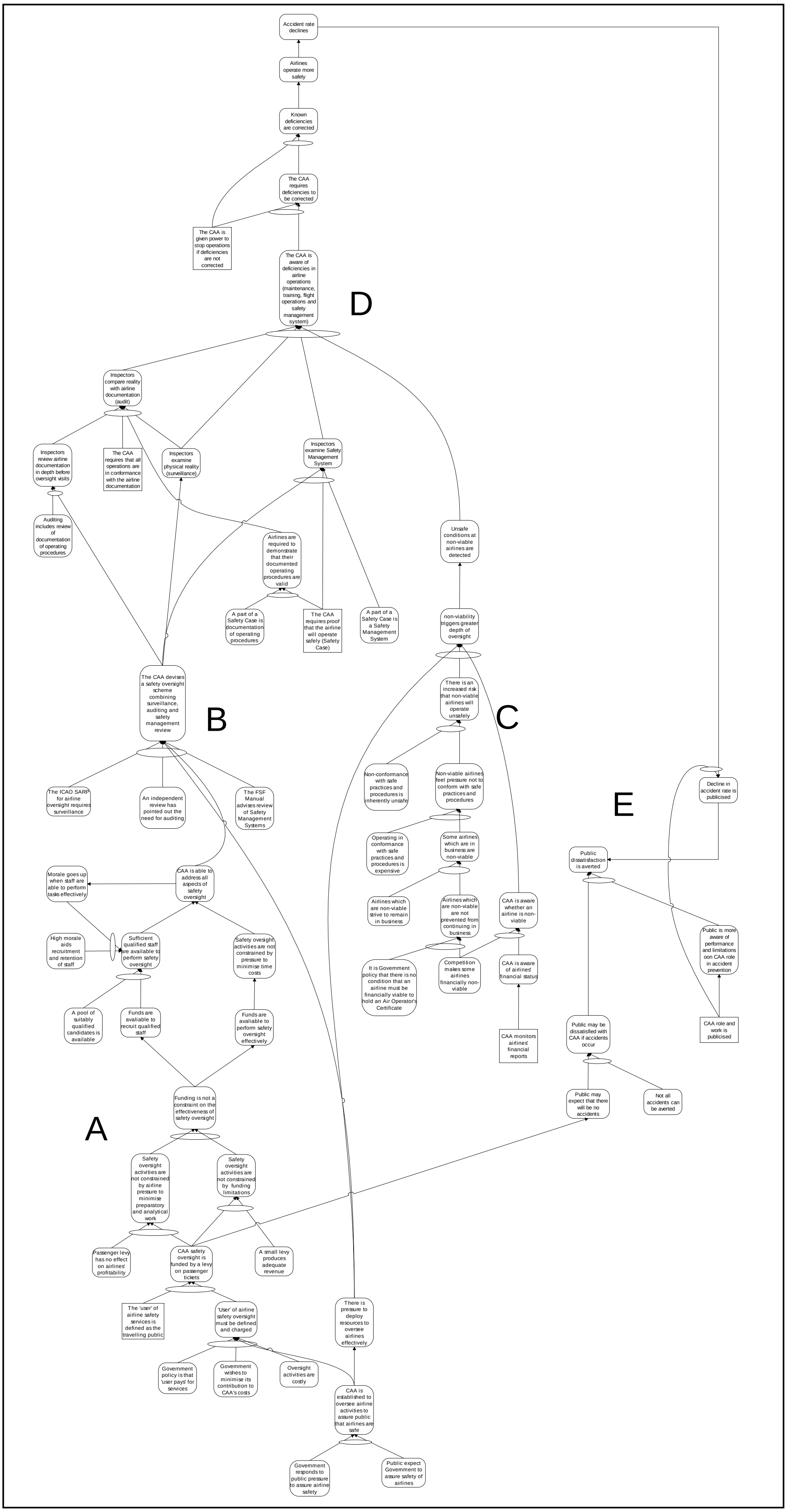

Figure 20. CAA Future Reality Tree

Figure 20 also addresses a potential ‘negative branch’, i.e. a potential undesirable effect arising from an otherwise beneficial injection. Imposing a safety charge on the public could give rise to the perception that the CAA is able to ensure that all airlines are absolutely safe. The CAA cannot do this: it can increase safety by reducing risk, but there is always the possibility that something unforeseen could lead to disaster. If an accident is not to give rise to unwarranted criticism of the CAA, it is necessary that the public understands the CAA’s function, be aware of its success (as shown by a reducing rate of accidents and incidents) and be aware of the limitations of what can be done. This negative branch and response is shown in Figure 21.

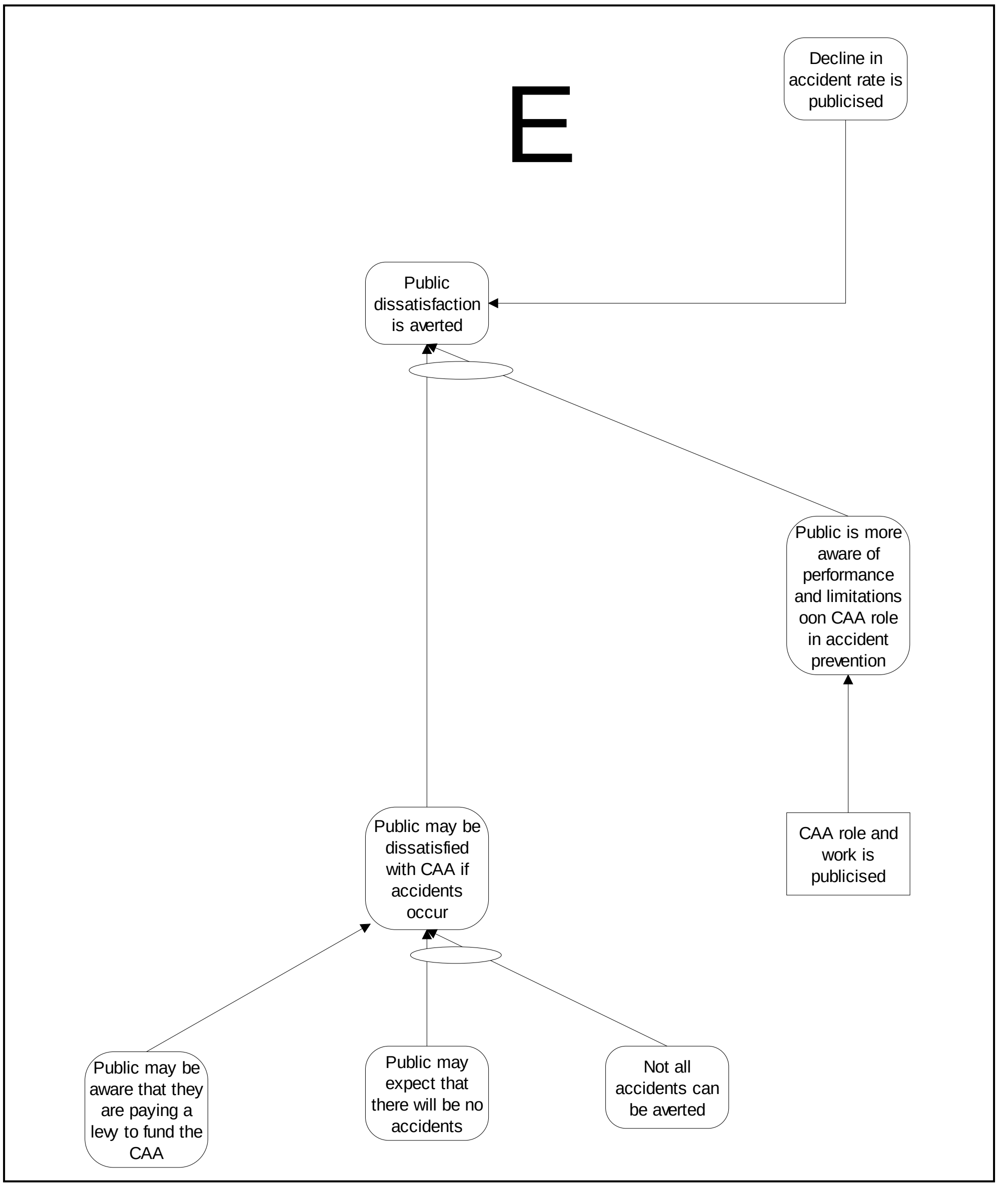

Figure 21. Negative Branch: public perception of CAA performance.

Apart from the fundamental injection that ‘The user of CAA services is defined as the travelling public’, there are a number of other required injections, as shown in Figure 21. These are:

- A Safety Case is required[15]
- The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline’s documentation
- The CAA has power to stop an airline operating, if identified deficiencies are not remedied
- The CAA monitors airlines’ financial reports, and
- The CAA’s role and work is publicised.

Negative Branch Reservations

In the same way as was done with the Ansett FRT, the injections in the CAA FRT must be scrutinised for negative branch reservations. The injections, with negative branch and implementation reservations, are listed in Table 3 below.
Only two of these injections require further comment:

- Power to stop an airline operating: This would require express legislation, since the power to suspend an Operating Certificate exists only to prevent an unsafe operation, and mere non-conformance with documentation might not be held, in Court, to demonstrate that the operation was manifestly unsafe. To demonstrate this to politicians, the CAA would need to show them that, in operating outside its documentation, the airline was in breach of its Safety Case, i.e. the airline’s own statement of how it was going to conduct its operations safely. In so doing, the airline had departed from known safe ground, and should immediately return to its documented procedures, and an effective sanction was required to ensure that this happened. The CAA might well need to consider a Prerequisite Tree, to produce a case for such legislation, but this is not a matter for the Investigating authority.

[15] A Safety Case is documentation showing how the company is going to conduct its business safely. A Safety Management System is part of a Safety Case (DITR, 2003)

- Monitoring financial reports: Current doctrine is that this should not be an interest of the CAA, as market forces would ensure that only viable airlines survived. This doctrine overlooks the known propensity for airlines under financial stress to seek economies which may reduce the margin of safety (see, for example, (Dekker, 2004). The Ansett accident indicates the value of financial information as an alerting tool, and the information is readily available. The Recommendation needs to be couched in these terms, so as to persuade the CAA to change its practice.

Table 3. CAA FRT: injections and reservations

Injection	Negative Branch reservation	Implementation reservation	Remarks
The user of CAA services is defined as the travelling public			Within CAA's purview
A Safety Case is required	Novel approach for civil aviation		Within CAA's purview. Already widely required in other hazardous industries in other countries
The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline's documentation			Amplification of existing requirement
The CAA has power to stop an airline operating, if identified deficiencies are not remedied	May require additional legislation	May need to demonstrate to politicians that additional powers are required	Departure from the Safety Case is, of itself, unsafe. CAA needs to be able to stop an operation without having to demonstrate that it is unsafe, in the particular case.
The CAA monitors airline's financial reports	Contrary to current doctrine	Could be obtained from reports to Companies Office, or through financial monitoring agencies	CAA may need to be persuaded of the need to change its doctrine: financial stress is an indicator that there may be unsafe operations
The CAA's role and work is publicised			Extension of existing role, in countering adverse comment. Implements requirement that there be public confidence that funds are effectively and judiciously spent
Appropriate safety oversight procedures are devised and implemented		Increase in staffing levels will be needed	Safety Oversight includes surveillance, auditing, and review of the airline's Safety Management System.

Discussion

The injections form the basis of the Safety Recommendations. As discussed earlier, recommendations to Ansett were seen as being ineffective, in that Ansett might not have the financial resources to implement them. Accordingly, the recommendations are directed to the CAA, and come in two forms:

- Recommendations derived from the Ansett FRT refer to changes which the CAA should make in order that airlines will operate more safely
- Recommendations derived from the CAA FRT refer to changes in the CAA's methods of operating, in order that it may conduct the safety oversight of airlines more effectively.

The purpose of the FRT is to show how improvements may be made. It can be seen as a simulator, in which proposed changes can be examined for effectiveness, and checked for adverse effects which might arise. It can also highlight implementation difficulties, requiring further analysis.

One objective of this case study was to see whether the information from an accident could be put in the form required for analysis by the methodology of the Theory of Constraints. That this could be achieved has been demonstrated by the first part, the Current Reality Tree. The Current Reality Tree showed that there were a few areas which could profitably be addressed, and gave an indication of the changes that might be needed. These areas were examined by Conflict Resolution Diagrams, which aimed to surface hidden assumptions, so that they could be investigated. Changes might then be possible to invalidate assumptions and so break the conflict; alternatively, some assumptions might be found to be already invalid.

The ideas generated by the Conflict Resolution Diagrams were then used to generate Future Reality Trees. These tested the ideas, and showed where further injections might be needed to make the ideas work.

Safety Recommendations which have been through this process are thus tested, as far as is possible before actually putting them into force, and are likely to be practicable and effective. The Safety Recommendations are:

To the CAA, in respect of airline safety:

The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines

The Safety Manager position and functions are mandated by regulation

The Safety Manager must be an “approved person”.

The CAA audits the Safety Department against stated performance criteria

The Maintenance Controller is trained in safety management, and initial review of events within the Engineering Department is delegated to him, with notification to the Safety Manager

The CAA recognises the need for simulator training in emergency procedures and Crew Resource Management, and mandates its use in airlines

Airlines have a formal policy that decisions on safety implications by one Department must not be considered in isolation from other Departments

Fleet Captains are required to review abnormal operations, for training implications

Airlines have a formal requirement for a missed approach when emergencies are encountered on approach

Radar altimeter performance is measured in situ.

To the CAA, in respect of its own operations:

The user of CAA services is defined as the travelling public

A Safety Case is required for airline operations

The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline’s documentation, and Inspectors are required to check that this is so

The CAA seeks power to stop an airline operating, if identified deficiencies are not remedied

Appropriate safety oversight procedures are designed and implemented, including surveillance, auditing, and review of Safety Management Systems

The CAA monitors airline’s financial reports

The CAA’s role and work is publicised.

There are ten recommendations, generic in nature, addressing airline operations, and seven dealing with improvements to the CAA’s safety oversight. By contrast, the official Report had 15 recommendations to Ansett, many on matters of detail (e.g. “Enhance the opportunity for the Flight Safety Coordinator to attend international flight safety conferences and seminars” (p. 94)). There are six recommendations in broad terms to the CAA (e.g. “Explore the practicability of instituting check flights to supplement the audit process on companies” (p. 99)). Many of the recommendations arising from the official report are related to ‘this accident’ and ‘this airline’. But ‘this accident’ is unlikely to happen again in any event, while the chance of Ansett (NZ) having another Controlled Flight Into Terrain accident related to undercarriage malfunction is negligibly small. More generally, the official Safety Recommendations deal largely with undesirable effects rather than the deeper core problems giving rise to those undesirable effects. For example, as mentioned above, it is recommended that the CAA consider performing surveillance, but the underlying funding problem is not addressed.

The ability to seek out and resolve core problems is a distinguishing advantage of the TOC methodology.

The recommendations from the TOC methodology are different in kind from those derived from the earlier formal analyses, performed as part of this case study, Multilinear Events Sequencing and Why-Because Analysis. MES gave rise to a recommendation on fuel tank inerting. MES is about ‘what happened’, and this is an intervention related to ‘what happened’ – an outer wing panel was blown off by a fuel-air explosion, and the ensuing inverted impact caused fatalities and injuries. WBA is about the specific causality of the accident, and WBA gave rise to recommendations relating to causality – ‘why it happened’ – on specific matters:

- The early start to the crew roster, leading to fatigue
- The confusing approach plate, leading to the high rate of descent inbound to Palmerston North
- The painted radio altimeter radome, leading to corrosion of the aerial and inadequate performance of the Ground Proximity Warning System.

The advantages of the ‘multi-framing’ approach (Mabin & Davies, 2003), using a number of analytical methodologies to achieve different perspectives, is apparent.

The recommendations arising from the Theory of Constraints analysis deal with the underlying systemic factors which gave rise to the accident, and the recommendations are generic. They relate to all airline operations, rather than to the specific accident being analysed.

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