DEPARTMENT FOR BUSINESS
ENTERPRISE & REGULATORY REFORM

WATCHMAN PRIMARY SURVEILLANCE RADAR IN THE PRESENCE OF WIND TURBINE INTERFERENCE

Part 1 - Generic Safety Case

CONTRACT NUMBER: W/45/00665/00/00

URN Number: URN 07/1441

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Contractor

HVR Consulting Services Ltd

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Executive Summary

1. This document presents the Part 1 Safety Case: Safety Requirements for the Baseline Watchman PSR (as installed at the hypothetical aerodrome RAF Clatter) in the presence of wind turbine interference. There are four annexes to this document; annexes A and B present a set of Safety Requirements for each of the two candidate mitigating technologies and annex C presents the outline safety argument for the Baseline Watchman PSR. Annex D presents the revisited event tree diagrams.

2. The safety analysis performed in support of this document followed a quantitative approach as agreed against the original proposal submitted by HVR-CSL and following the guidance and notes given in CAA CAP670 and CAP760. However the corresponding qualitative definitions have been given to aid the readers understanding.

3. Through the analysis in sections 7 and 8, the Baseline Watchman PSR has been demonstrated as safe for provision of a radar service in the absence of wind turbine interference. The event trees have shown that there are no mitigations within the system itself to counteract the effects of turbine interference and the risks that are associated with the wind farm related hazards (primarily H8 and H9) rely heavily on factors within the external operational environment to provide mitigation. In order to apply this analysis to any aerodrome specific safety cases the operational environment of the aerodrome MUST be analysed to ensure that similar external mitigating factors exist.

4. The quantitative values used throughout this safety case are based upon assumptions made by SME with a collective 50 years of ATC experience between them and on estimated failure rates provided by the radar manufacturer. Various external factors meant that HVR-CSL were not furnished with the empirical data that they had hoped for; the value of this report is as a robust generic safety argument on which to base a safety case for the provision of Air Traffic Services in areas affected by wind turbine interference. If the results of Trial Celtic Storm were made available in the future it may be possible to make a better quantitative argument for the safety of the affected radar service. For an aerodrome specific safety case all of the SME assumptions should be substantiated with real data provided by the subject ATS providers.

5. The decision on whether to provide technological mitigation against wind turbine interference should remain an aerodrome-specific concern. In the long term a technological solution across the fleet of Watchman radars would be an effective type of mitigation given the government targets for wind energy. A number of other areas that could provide mitigation were discussed during this analysis but ultimately the ability to distinguish real targets from 'false' targets generated by the turbines is desired (Section 11).

6. The overarching recommendation is that wind turbines are not erected in areas that will adversely affect the safe provision of Air Traffic Services unless acceptable mitigation can be assured.

7. In summary those areas significant to safe operations at an aerodrome where the Watchman PSR is installed, need to be identified on a case by case basis and where necessary, protected from wind turbine developments. Significant radar upgrades may allow some sensitive areas to support wind turbine developments but the two proposed technologies could not be fully investigated due to commercial sensitivities and unavailability of important field evidence (trial data). Any proposed upgrade should address the impact of wind turbines.

CONTENTS LIST

1. References and Abbreviations

1.1 References

[1] AT04 07 01 Safety Assessment Report Issue 1: The document presenting the methods and results of the safety analysis activities carried out in support of this safety case;

[2A] AT04 13 01 Annex A: Annex A to this report;

[2B] AT04 13 01 Annex B: Annex B to this report;

[3] CAA CAP670 Air Traffic Services Safety Requirements, 12th June 2003;

[4] CAA CAP670: SW01 Air Traffic Services Safety Requirements: Software safety requirements;

[5] CAA CAP760: Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases, 13th January 2006;

[6] CAA Paper 2003/5 On Track – Airspace Infringement Project, 11th July 2003;

[7] CAP 764: Policy and Guidelines on Wind Turbines, First Edition, July 2006.

1.2 Acronyms and Abbreviations

ADT	Advanced Digital Tracker
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATS	Air Traffic Services
ETA	Event Tree Analysis
FFA	Functional Failure Analysis (includes Fault Tree Analysis)
HAZOPS	Hazard and Operability Study (Hazard Identification Methodology)
IMC	Instrument Meteorological Conditions
SAR	Safety Assessment Report: Reference [1]
SME	Subject Matter Expert
SPE3000	SPE3000 Replacement Receiver/Exciter for the Watchman PSR
VMC	Visual Meteorological Conditions

2. Introduction

This document presents the Part 1 Safety Case for the Baseline Watchman PSR as installed at the hypothetical aerodrome RAF Clatter in the presence of wind turbine interference. Because of the lack of supporting evidence (specifically the trials results - see section 4.1.1) it was not possible to produce a full generic safety case.

The Part 1 Safety Case presents the results of a set of safety analyses and defines the *generic* Safety Requirements for operation of a Watchman PSR in the presence of wind turbine interference.

This report does not claim to present an exhaustive list of Safety Requirements because it is highly probable that there will be site specific Safety Requirements for particular Watchman PSR installations.

2.1 Document Structure

2.1.1 Main body – Baseline PSR

The main body of this report presents a part 1 safety case for the Baseline Watchman PSR configured for the hypothetical aerodrome RAF Clatter. The Part 1 presents the results of the safety analysis and includes the definition of generic safety requirements for the Watchman PSR. Additional levels of mitigation thought to have bearing on the safety of the PSR service are presented and an initial case is made for the safety of the Baseline PSR.

2.1.2 Annexes

There are four annexes to this document; annexes A and B present a set of Safety Requirements for each of the two candidate mitigating technologies and annex C presents the outline safety argument for the Baseline Watchman PSR. Annex D presents the revisited event tree diagrams (see section 3.2).

2.2 Relationship with the Safety Assessment Report (SAR)

Readers of this document are advised to reference the Safety Assessment Report SAR [1] if they require a more detailed description of the safety assessment activities and the methods employed by HVR-CSL during this work. Please be aware that the results of the analyses in the SAR are now out of date due to comments received and agreements made among the Safety Sub Group at the review meeting on 2nd March 2007.

2.2.1 Updates of the SAR

Since the last issue of the SAR there have been a number of revisits to the safety assessment activities. It was agreed at the meeting on 5th October 2006 that further updates of the SAR would not be issued but instead the additional work will be described in this Part 1 Safety Case report.

2.3 Brief Description of Proposed Mitigating Technologies

Two candidate technologies have been proposed that claim to mitigate the effects of wind turbine interference on the Watchman PSR. These technologies are:

- Advanced Digital Tracker ADT: Developed by BAE Insyte and designed to be integrated into the current Watchman PSR system;

- SPE3000 Replace Receiver/Exciter: Developed by SELEX SI and designed to replace the signal processing element of the current Watchman PSR system.

3. Background to this Report

3.1 General

This report was originally intended to present a full safety case for a radar service using the Baseline Watchman PSR in the presence of wind turbine interference. It was then intended to compare the safety of the radar service when the baseline Watchman was enhanced with each of two mitigating technological solutions.

The Safety Case was to draw evidence from the safety analysis carried out by HVR-CSL (and presented in the SAR [1]), evidence from the manufacturers of the radar and key evidence from the results of Trial Celtic Storm.

The unavailability of key evidence from Trial Celtic Storm and the sensitivity of commercial evidence meant that a full Safety Case could not be developed. Hence this report is a Part 1 Safety Case as described in section 2.

3.2 Revisiting the Safety Analysis

The analysis activities as presented in the original SAR [1] concluded that the safety of the Watchman PSR in the presence of wind turbines could not be guaranteed. However, the SAR concluded that even where the hazards were not related to wind turbine interference, the Watchman PSR could still be shown to be unsafe. These results lead the Safety Sub Group to question the reliability of the safety analysis. The Watchman PSR has been in service for decades and there are over thirty systems in use on UK soil thus overwhelming field evidence exists to support its safety record. Therefore HVR-CSL concluded that additional levels of mitigation that were not borne out in the original safety analysis (in particular the event trees) must exist.

At the review meeting on 2nd March 2007 it was agreed that additional levels of mitigation were required within the Event Trees and HVR-CSL took an action to revisit the event tree analysis with the military SME. The revised event trees are contained as Annex D to this report.

4. Aim

The purpose of this part 1 safety case is to show *analytically* that the Baseline Watchman PSR is safe in terms of the hazards that are *not* related to wind turbine interference and to identify the baseline level of safety for hazards that *are* related to wind turbine interference. The original supplementary aim of this safety case was to measure the net safety effect of the two candidate technologies that claim to mitigate the effects of wind turbine interference on the PSR service. For reasons outside of the control of HVR and the DTI customer, this has not been possible and instead, this report aims to present a set of safety requirements that must be met by the technologies if they are to *safely mitigate* against the interference from wind turbines.

4.1 Limitations

4.1.1 Trials Results

Trial Celtic Storm was carried out at RAF Clatter and was designed to test the performance of the Watchman PSR in the presence of wind turbine interference. The general aim of the trial was to assess the Baseline PSR, the ADT and the SPE3000 against military 'Fit for Purpose' requirements; the main 'purpose' being the provision of Air Traffic Services (ATS). The development of this safety case was delayed significantly by the non-availability of the trials results, which would have provided valuable independent evidence in support (or otherwise) of the two mitigating technologies. The trials results have now been declared unsuitable for release into the public domain due to the commercial sensitivity of the results and hence key safety evidence is unavailable.

4.1.2 Confidentiality

At the beginning of this work programme, HVR-CSL asked the technology manufacturers to declare the confidentiality of all discussions held in support of the task which they did as the work progressed. The results of the analysis performed by HVR-CSL and the trials results were both declared confidential and therefore HVR-CSL are prevented from presenting a full analysis of each technology to all parties. Instead and as agreed, HVR-CSL have produced a set of safety requirements that each technology must meet and these are contained in separate annexes to this report (as described in section 2.1.2).

5. Safety Argument

The top-level safety argument for this safety case consists of the following claim:

"The safety risk resulting from wind turbine interference to the Radar Service of a Pseudo airfield operation (with mixed civilian and military aircraft) is reduced to acceptable levels and is As Low As Reasonably Practicable (ALARP) through the use of mitigating technologies".

Implicit in this claim is that the use of mitigating technologies does not adversely affect the Radar Service of the pseudo airfield operation at RAF Clatter.

5.1 Outline Safety Argument using GSN

HVR-CSL developed the top-level safety argument into an outline safety argument using Goal Structured Notation (GSN). The GSN diagrams are contained in Annex C to this report.

The GSN diagram shows how HVR-CSL would have attempted to prove that the Watchman PSR system is safe if the supporting evidence had been made available. Colour coding is used to show where the evidence is incomplete and arguments for the safety of the mitigating technologies are included. HVR-CSL hope that the GSN safety argument will be of use in the development of aerodrome specific safety cases where the intent is to introduce such technology to combat the impact of nearby wind turbines.

5.2 Outline Strategy for Arguing the Top-level Goal

In order to satisfy the top-level safety argument the original plan was to develop a generic safety case that demonstrated the safety of the baseline Watchman and then compared this with the safety of the two mitigating technologies. The trial at RAF Clatter was to have provided independent and significant safety evidence for both the Baseline Watchman and each of the two mitigating technologies. For any future safety case based on the analysis in this report, the SME derived values will have to be substantiated with real data and that is why the GSN diagram shows that the goals have not been achieved. This does not imply that the technologies are unsafe, simply that the argument is incomplete.

The safety of the Baseline Watchman is argued using significant field evidence i.e. a safe service record (implied by the experience of several SME and the absence of any incident reports) of multiple systems operating over several decades and through the use of the analytical data contained in the SAR[1] and this report.

6. Safety Analysis

The original risk matrix from the SAR [1] is reproduced below in Table 1 as a reminder of the tolerability of event severities. The quantitative values are per operational hour.

Probability **Severity**	*Extremely Improbable* $<10^{-9}$	*Extremely Remote* 10^{-7} to 10^{-9}	*Remote* 10^{-5} to 10^{-7}	*Reasonably Probable* 10^{-3} to 10^{-5}	*Frequent* 1 to 10^{-3}
Catastrophic	Review	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Hazardous	Review	Review	Unacceptable	Unacceptable	Unacceptable
Major	Acceptable	Review	Review	Review	Review
Minor	Acceptable	Acceptable	Acceptable	Acceptable	Review
Negligible	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Table 1. Risk Matrix as described in the SAR [1]

6.1 Accident Sequences: Event Tree Analysis

HVR-CSL revisited the event tree analysis using the expertise of the original military SME (two current serving ATCO personnel from RAF Waddington and one ex ATCO) in order that the results better reflect the accepted safety record of the Watchman PSR. Section 6.1.2 describes the assumptions made during the event tree analysis.

6.1.1 Event Tree Assumptions: Factors Influencing the Mitigating Events

When revisiting the event trees the SME defined many factors that may have influence on the mitigating events. For example, the extent to which a false plot appearing on the screen would affect the radar service (H9) depends heavily on whether the false plot is in an ‘area of significance’, how long it appears for or the behaviour it exhibits. These factors had always been discussed but it was felt that they ought to be formally described as assumptions in this safety case report. Table 2 shows the assumptions and the events to which they relate. It is recommended that the reader have this table to hand when looking at the event trees in Annex D.

Note: The assumptions contained in table 2 are the combined opinions of several SME with approximately fifty years of ATC experience between them. These assumptions should always be substantiated with real data prior to being used in any future safety case.

No	Assumption	Event Number
AS 1	M38: Operational Hours are assumed as 10 hours per day, 5 days per week, 50 weeks of year: 2500 out of 8760hrs per year = failure rate of 0.296	M38 Inside Operating Hours
AS 2	M6: The option to use procedural control only applies to civil (in terms of mitigation) due to the way they are trained. Military will never follow the success branch as it is not part of their procedures. Majority of SME were military and were unable to comment fully on procedural based services, they were of the opinion that with the increased reliance on radar vectoring and the use of procedural service as a mitigation needs to be reviewed, furthermore, given it is now accepted that termination of a service cannot be seen as a mitigation and that many civil airports provide the LARS service the whole ethos of reliance on procedural techniques is suspect.	M6 Procedures: Switch to Procedural Control
AS 3	M11: SME assumed that there is 40% chance that ALL aircraft can be transferred based on: 50% tracks can be transferred (availability of radar overlap) * 80% availability of accepting airfield	M11 Procedures: Transfer of Control to Alternative Agency
AS 4	M13: The SME assumed that there is a 30% chance our aircraft is flying IMC because: assume a 40% chance bad weather; of that, assume 50% would affect ALL aircraft flight levels and the other 50% would only affect half the aircraft. SME suggested 2 day per week is IMC and of those two days and on one day ALL aircraft (all levels) are affected and on the other approximately 50% of aircraft will be affected (50% of flight levels)	M13 Visual Meteorological Conditions
AS 5	M39: SME prediction of probability that aircraft will be flying on quadrantals is 95%. Vast majority of traffic under 10,000ft (LARS Limit) would be flying on quadrantals or the ATCO will put them on a quadrantal. Generally would only consider the success branch in IMC conditions therefore microlights, gliders etc. would not be a factor. The remaining 5% could be manoeuvring aircraft (climbing, turning, following other ATCO instructions etc.)	M39 Aircraft Flying Quadrantal Procedures or having been stopped at a safe level by ATCO
AS 6	An assumption was made by SME that the additional mitigations from the external operational environment as shown in Sub Event Tree H13 could be applicable to all of the fault trees.	All Trees
AS 7	Use of STCA: Not all terminal airfields are fitted	M60

No	Assumption	Event Number
	with the technology, particularly military airfields. However the assumption was made that it could provide mitigation in some cases.	
AS 8	SME have assumed a 1 in 100 chance that based on the 'big sky' theory there is a conflicting aircraft that is on course for a collision. Current technology is making 'the Big Sky smaller' i.e. aircraft at exactly the same height and lateral position so this needs further thought.	M25 See AS 11
AS 9	SME have assumed a 1 in 100 chance that aircraft is in conflict with the ground. The provision of the radar service precludes operators descending an aircraft below the predefined safety altitude. New wind turbines may affect the safety altitude but processes are in place to change these.	M29
AS 10	M27: Pilot may see and avoid, or some aircraft have on-board radars (military) and some are fitted with conflict alerting technology such as TCAS. This safety analysis does not allow for secondary radar and TCAS is dependent on secondary radar technology.	M27
AS 11	If all else fails, there is still a slight chance that the aircraft will avoid an actual collision. This is accepted by the CAA as valid mitigation in the final instance. However, concerns were raised that AS8 and AS11 are essentially the same and hence for all future safety cases the arguments for each, must be carefully assessed to rule out duplication of a single level of mitigation.	
AS 12	H2: SME based his opinion on the Flight Refuelling displays where the map data is stored on each individual display. If there were to be a single database that was distributed to the displays then this should be looked at as a single point of failure. So the event M35 is a valid mitigation where there are additional serviceable consoles and the map data is individually stored at that console but perhaps not if the map database is centralised. If the operator was providing a service using two consoles where one was unserviceable then the 99% chance of another being available Is not valid.	M35 Other Consoles Available
AS 13	It was the SME opinion that at an average military airfield during operational hours, there would be 6 events per year where an aircraft couldn't divert (due to emergency). For each incident there would be a time period (from declaration of emergency to landing) of around 10 minutes so that equates to	M32 Aircraft NOT operating with an emergency

No	Assumption	Event Number
	one hour per year. This equates to 1 in 2500, a failure rate of 1*10^-4	
AS 14	M19 Dense/complex traffic was defined by the SME as where there is sufficient traffic to require increased controller input to maintain safe separation between aircraft. Individual airfields would be required to define what density/complexity of traffic actually means in terms of operations at that airfield. This is a generic safety case and as such the SME declared that on average their definition of dense/complex traffic would occur in 2hrs of each day (10hrs per day hence 20% figure used in event trees)	M19 Low Density/Complexity of Traffic
AS 15	M40 The availability of ILS or PAR has been assumed to be 95% based on SME experience. This is based on an estimated 98% procured availability of the PAR less a small amount for maintenance downtime. Thought needs to be given to the availability of the ILS installation at a particular airfield and the % of aircraft equipped with ILS.	M40 ILS/PAR available at affected aerodrome
AS 16	ATCO would have to not notice the absence of known PE, radar touchdown markers, absence of constant air traffic etc. and there be no warning from engineers. (2am or first aircraft of the day) ATCO could clear a/c for takeoff without noticing failure and then the 5min period of risk is in effect - after 5 min a/c either called someone else, ATCO notices the problem or a safety event will have occurred. SME estimate is 1 in 100 failure rates M26	M26DP ATCO Situational Awareness; Detects the Failure to Display Plots
AS 17	M26 Detection within 3 sweeps is the norm, based on SME experience. The ATCO would only fail to detect in extremely light traffic and even then the SME suggested that it was inconceivable that he would still fail to detect this after a minute (15 radar updates). In light traffic conditions the SME assumed that an additional minute would not add to the risk levels of a radar failure.	M26DP ATCO Situational Awareness; Detects the Failure to Display Plots
AS 18	Severity of the consequences errs on the side of the worst case scenario. It may be prudent to review these severities on a case by case basis to ensure that they are not unduly severe.	All trees
AS 19	M63 on H5: According to SME experience, acceptable performance of the radar is judged to be 90% PD. All radar will drop plots and still be deemed serviceable. When the loss of plot rate	M63 Plot Loss Rate is Acceptable i.e. 2 or less

No	Assumption	Event Number
	rises beyond that that is acceptable it is assumed that ATCO will use the radar to 'clear the skies' then declare it unserviceable.	consecutive sweeps
AS 20	H6: Error could be sufficiently small not to matter or sufficiently large that it would be noticed immediately. If error is in-between these two extremes the assumption is that it would be noticed within 5 minutes - e.g. a/c not lining up to runway. So although the failure branch for M26 could conceivably be followed, the risk is only valid for up to 5minutes. There are many factors affecting detection (M26), these are: density of traffic, adjacent airways, known PEs, TD markers, adjacent airfields, traffic routes, reporting points, Direction Finding (DF).	H6 Corrupted Plot Data: Absolute Corruption
AS 21	H7 only applies to processed radar.	H7 Corrupted Plot Data: Relative Corruption
AS 22	M34: This is impossible to quantify for a generic analysis. The level of clutter within an area of control (due to windfarms/structures) should be calculated on a case-by-case basis. In this case the SME arbitrarily assumed 10% of control area affected.	H8/M34 target within 5miles of area of clutter
AS 23	H8: The failure rate for this hazard has been assumed to be 65% which is equal to a rough estimate of how often there would be sufficient wind to turn the turbines.	H8 Targets Obscured by Clutter
AS 24	H8 This hazard is excess data on screen (perhaps it is windfarm generated clutter or extreme weather) causing loss of track ID Includes: Masking of Some Plots (i.e. where saturation of an area has occurred) or Screen 'too full' is similar to Partial Loss of Plot Data (H5) and Loss of Display(H1). H8 must occur in an area of ATC concern for it to be a hazard.	H8 Targets Obscured by Clutter
AS 25	M24a The definition of this 'Re-route' includes whether aircraft is in middle of the clutter or if need to fly aircraft through the clutter. NB depending on service provided, aircraft do not have to accept re-route (may choose to fly through clutter and accept a reduced ATS)	M24a ATCO Procedures: Re-route aircraft around affected area
AS 26	M24a SME made the following assumptions regarding probability of re-routing aircraft: 80% initial estimate of probability ATCO will re-route the aircraft. 20% chance a/c won't be able to be re-routed. Pilot more willing to accept re-route round	M24a ATCO Procedures: Re-route aircraft around affected area

No	Assumption	Event Number
	thunderstorms than around other clutter (risk to a/c). depending on service provided, aircraft do not have to accept re-route (may choose to fly through clutter and accept a reduced ATS)	
AS 27	In bad weather traffic density may be assumed to be lower: there may be less GA traffic. Alternatively in areas of high clutter caused by windfarms, GA traffic might be denser as they are known (by SME) to occasionally use windfarms as navigation aids.	M13 Visual Meteorological Conditions
AS 28	M34 Targets within 5 miles of clutter: SME estimate that 5 aircraft per hour will be affected for a period of 6mins each. There will be an aircraft in a hazardous situation for 30mins of each hour * 2500hrs = 1250 hrs or 50% of the operational time.	M34 Target within 5 miles of area of clutter
AS 29	M24a: An estimated (by SME) 50% of affected traffic can likely be re-routed.	M24a ATCO Procedures: Re-route aircraft around affected area
AS 30	M4a SME assumed that the ATCO is less likely to manage workload with a large amount of onscreen clutter - so higher failure rate than M4. The ATCO will be re-routing large percentage of aircraft and may be funnelling aircraft through smaller areas of airspace.	M4a ATCO Procedures: Re-route aircraft around affected area
AS31	There are many influencing factors to take into account when making an assumption about the probability and severity of H9 occurring: E.g. How often they split; for how long; diverging tracks; split track behaviour; are they in an area of significance to the safe provision of the radar service etc.	H9 False Targets and Split Plots
AS 32	SME estimated that only 1 in 10 split plots would result in an experienced ATCO instructing the aircraft to carry out unnecessary avoiding action - e.g. where the aircraft is thought to have diverged and so path is "corrected" by the ATCO. So called 'Avoiding action' is a normal part of air traffic control (for the management of separation of air traffic) and is performed very regularly.	M31 No Unnecessary Action Taken by ATCO
AS 33	Where ATCO workload is not managed effectively, the likelihood of mistakes or unnecessary avoiding action increases. There is an estimated 1% chance the ATCO will not manage the workload when False Targets appear. ATCO treat false targets as 'pop-ups' and those are a regular feature of the generic ATC environment.	M4 Procedures: Manage Workload (H9)

No	Assumption	Event Number
AS 34	Failure is of single console losing map display - with adjacent display being available. SME stated that a failure of the map data on all displays deemed so unlikely as to not need mitigation. However care should be taken to explore this hazard further if the map data is held centrally rather than separately on each display as it is assumed to be at RAF Clatter.	H2
AS 35	This situation will only be major (and only where ILS/PAR not available) because the assumption is that controllers can still vector aircraft into a safe zone on approach to the runway (Only minor where ILS/PAR available)	H2 Major Consequence
AS 36	SME estimate that there is a 1% or (1 in 100) chance of not being able to manage: factors are other consoles, supervisors, training & experience etc. Units with only one console must factor this in.... The fictitious RAF Clatter has more than one console.	M4 in H2
AS 37	H4 is only relevant to processed radar only as the assumption is that is will be caused by failure in the processor or in any upgrade technology. The baseline watchman is raw video only.	H4 Screen Freeze
AS 38	M11: The assumption was made by the SME that the ATCO has more scope to transfer the control of ALL aircraft when H5 has occurred than when there has been a total radar failure (H1) so the consequences of H5 are less severe than H1.	M11 when H5 has occurred
AS 39	The SME assumed that Relative Corruption could be spotted by use of the Direction Finder but relative corruption in range could be more difficult to detect.	M26RC in H7
AS 40	The SME estimated that 90% of time ATCO would notice the error. Factors are: density of traffic, adjacent airways, known PEs, TD markers, adjacent airfields, traffic routes, reporting points, Direction Finding (DF) =99% detection.	M26 AC in H6
AS 41	The consequences are dependent upon how large the corruption is; Therefore the consequences here are based on the largest credible corruption (will vary depending on ATCO and workload). Error could be sufficiently small not to matter or sufficiently large that it would be noticed immediately. If error is in-between these two extremes the assumption is that it would be noticed within 5 minutes - e.g. a/c not lining up to	H6

No	Assumption	Event Number
	runway. If the ATCO notices the failure, he will immediately treat the radar as un-serviceable.	

Table 2. Assumptions made during development of the Event Trees

7. Safety Analysis Results

7.1 Military Application

The most prominent accident sequences derived from the event trees for the Military Application are shown below in table 3. The hazards are colour coded according to the calculated risk class and the events in the accident sequences are colour coded to show whether the Success, Failure or Null branch was followed within the event tree.

Branch Key	Risk Class Key
Success Branch - this event contributed to mitigation of the hazard.	Risk Acceptable
Failure Branch - this event failed to contribute to mitigation of the hazard.	Risk Unacceptable
Null Branch - this event had no effect on the hazard.	Risk Acceptable with Review

HAZID & Description	Prominent Accident Sequence (Events)							Severity	Frequency
H1Complete Loss of All Display Consoles	M38	M6	M4	M11	M13	M19	M39	Hazardous	Extremely Remote 2.34E-07
H2 No Map Data Displayed	M35	M4	M11	M32	M13	M19	M40	Major	Extremely Remote 2.35E-09
H3 Undetected Failure of Radar to Display Plots	M26DP	M6	M4	M11	M13	M19	M39	Major	Remote 1.34E-06
H4 Screen Freeze **See 7.2.3**	M26SF	M6	M4	M11	M39	M13	M19	Hazardous	Remote 1.43E-06
H5 Partial loss of Plot Data		M26DP	M63	M11	M13	M19	M39	Minor	Reasonably Probable 6.76E-04
H6 Corrupted Plot Data: Absolute Corruption	M26AC	M6	M4	M11	M13	M19	M39	Major	Remote 2.28E-06
H7 Corrupted Plot Data: Relative Corruption	M26AC	M6	M4	M11	M13	M19	M39	Major	Remote 2.28E-06
H8 Targets Obscured by Clutter		M34	M24a	M4a	M13	M19	M39A	Hazardous	Reasonably Probable 4.88E-03
H9 False Targets and Split Plots				M31	M4	M13	M19	Hazardous	Remote 3.90E-05

Table 3. Event Tree Analysis Results: Prominent Accident Sequences - MILITARY

7.2 Military Hazard Risk Classes

7.2.1 Acceptable Risks

The risk associated with the following hazard has been shown to be Acceptable:

- H5 Partial Loss of Plot Data.

The risk associated with **Hazard H5** is an acceptable risk and has been shown *analytically* to be ALARP however: in light of all the assumptions made regarding the mitigating events, HVR-CSL recommend that this risk is reviewed for any future aerodrome specific safety cases to ensure that it remains ALARP and Acceptable for the military application.

7.2.2 Acceptable with Review

The risks associated with the following hazards have been declared as *Acceptable with Review*; the risk can be tolerated so long as there are processes in place to ensure that the risk is and remains ALARP for all future applications of this analysis:

- H1 Complete Loss of All Display Consoles;
- H2 No Map Data Displayed;
- H3 Undetected Failure of Radar to Display Plots;
- H6 Corrupted Plot Data: Absolute Corruption;
- H7 Corrupted Plot Data: Relative Corruption.

7.2.3 Unacceptable Risks

According to the analysis, the risks associated with the following hazards are Unacceptable:

- H4 Screen Freeze;
- H8 Targets Obscured by Clutter;
- H9 False Targets and Split Plots.

Hazard H4 is not applicable to the baseline Watchman because it is a raw video system and H4 can only occur with processed/ plot extracted radar.

Hazard H8 occurs at a frequency that closely mirrors the probability that there is sufficient wind to operate the turbine. Because of this high occurrence rate, the mitigations in place appear insufficient to counteract the effects of wind turbine interference. However, there are many factors that influence the extent to which the risk is unacceptable. The most important factor is LOCATION of the wind turbines with respect to the service provided and the significant areas relating to phases of flight. In particular the location of turbines with respect to aerodrome approach and departure paths, radar patterns and emergency patterns should be managed with extreme care. Hazard H8 highlights that wind turbines can only be located in areas where they will not have an adverse affect on the provision of a safe radar service.

Hazard H9 also occurs at a frequency that closely mirrors the probability that there is sufficient wind to operate the turbine. Because of this high occurrence rate, the mitigations in place appear insufficient to counteract the effects of wind turbine interference. Again there are many factors that influence the Unacceptability of this hazard and the attention to location of the turbines as described above for H8, are also applicable to H9.

7.3 Civil Application

The Civilian ATCO can make use of the mitigation M6: Switch to Procedural Control. Because of limitations of time and availability of civilian ATCO expertise at this late stage, the extent to which he successfully uses this mitigation has been estimated pessimistically at 95%. The estimate draws on previous estimates given by the Military SME who have been involved in this work. The prominent accident sequences are shown in table 4 with colour coding as in the military application in section 7.1.

HAZID & Description	Prominent Accident Sequence (Events)							Severity	Frequency
H1Complete Loss of All Display Consoles	M38	M6	M4	M11	M13	M19	M39	Hazardous	Extremely Remote 1.76E-08
H2 No Map Data Displayed	M35	M4	M11	M32	M13	M19	M40	Major	Extremely Remote 2.35E-09
H3 Undetected Failure of Radar to Display Plots	M26DP	M6	M4	M11	M13	M19	M39	Major	Remote 1.34E-06
H4 Screen Freeze	M26SF	M6	M4	M11	M39	M13	M19	Hazardous	Remote 7.13E-08
H5 Partial loss of Plot Data		M26DP	M63	M11	M13	M19	M39	Minor	Reasonably Probable 6.76E-04
H6 Corrupted Plot Data: Absolute Corruption	M26AC	M6	M4	M11	M13	M19	M39	Major	Remote 2.28E-06
H7 Corrupted Plot Data: Relative Corruption	M26AC	M6	M4	M11	M13	M19	M39	Major	Remote 2.28E-06
H8 Targets Obscured by Clutter		M34	M24a	M4a	M13	M19	M39A	Hazardous	Reasonably Probable 4.88E-03
H9 False Targets and Split Plots				M31	M4	M13	M19	Hazardous	Remote 3.90E-05

Table 4. Event Tree Analysis Results: Prominent Accident Sequences - CIVIL

7.4 Civilian Hazard Risk Classes

7.4.1 Acceptable Risks

The risk associated with the following hazard has been shown to be Acceptable:

- H5 Partial Loss of Plot Data.

The risk associated with **Hazard H5** is an acceptable risk and has been shown *analytically* to be ALARP however: in light of all the assumptions made regarding the mitigating events, HVR-CSL recommend that this risk is reviewed for any future aerodrome specific safety cases to ensure that it remains ALARP and Acceptable for the civil application.

7.4.2 Acceptable with Review

The risks associated with the following hazards have been declared as *Acceptable with Review*; the risk can be tolerated so long as there are processes in place to ensure that the risk is and remains ALARP for all future applications of this analysis:

- H1 Complete Loss of All Display Consoles;
- H2 No Map Data Displayed;
- H3 Undetected Failure of Radar to Display Plots;
- H4 Screen Freeze;
- H6 Corrupted Plot Data: Absolute Corruption;
- H7 Corrupted Plot Data: Relative Corruption.

Hazard H4 is Acceptable with Review for the civil application whereas it was Unacceptable for the military application. The reason is that there is an additional level of mitigation available to the civilian ATCO which is not available to the military ATCO: M6 Switch to Procedural Control. H4 is not applicable to the baseline Watchman as configured for Trial Celtic Storm because it is raw video radar. The civilian radar service is more likely to be provided using a plot extracted/ processed video radar configuration and therefore Hazard H4 should be considered as part of an aerodrome specific safety case.

7.4.3 Unacceptable Risks

Hazard H8 occurs at a frequency that closely mirrors the probability that there is sufficient wind to operate the turbine and hence the mitigations in place appear insufficient to counteract the effects. The management of location of windfarms is of equal importance to the civil aerodromes as to the military and hence the considerations as described for Hazard H8 in section 7.2.3 for the military application apply here.

Hazard H9 also occurs at a frequency that closely mirrors the probability that there is sufficient wind to operate the turbine. Because of this high occurrence rate, the mitigations in place appear insufficient to counteract the effects of wind turbine interference. Again there are many factors that influence the Unacceptability of this hazard and the attention to location of the turbines as described for H8, are also applicable to H9.

7.5 Relationship of Hazards to Windfarm Interference

Table 5 shows the hazards that are related to (in part caused by) the presence of wind turbine interference for the Baseline PSR (raw video only system) and for the two mitigating technologies (both processed/plot extracted video systems).

Hazard		**Baseline PSR**	**Mitigating Technologies**
H5	Partial Loss of Plot Data	✓	✓
H7	Corrupted Plot Data: Relative Corruption		✓
H8	Targets Obscured by Clutter	✓	✓
H9	False Targets and Split Plots	✓	✓
H10	Track Seduction	Hazard not applicable to Baseline	✓
H12	Delayed Display of Targets	Hazard not applicable to Baseline	✓ See Safety Requirements in Annexes

Table 5. Hazards Related to Wind Turbine Interference

8. Other Mitigations for Unacceptable Risks

In the event tree analysis there is a sub-event tree labelled H13 that explores other mitigations that may exist in the operational environment to prevent an actual accident (for example mid-air collision, collision with terrain, significant separation event).

These additional mitigations take the form of the following events:

- M25 No Conflicting Aircraft Nearby;
- M20 No Conflicting Terrain Nearby;
- M60 Short Term Conflict Alert (STCA) Resolves - where available;
- M27 Pilot Assisted Intervention;
- M61 Providence: Aircraft Still Avoids Collision.

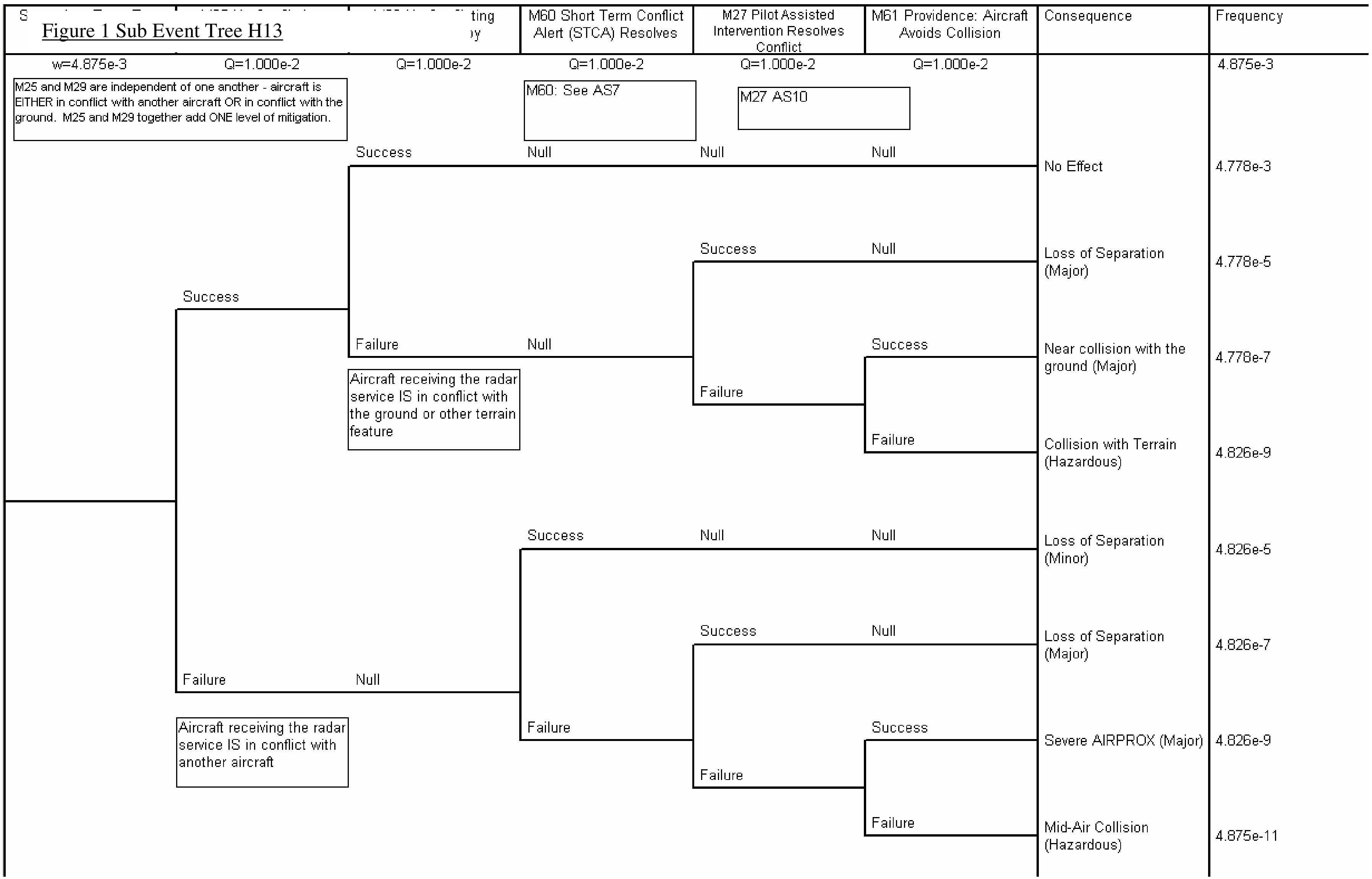
The likelihood of a conflicting aircraft or conflicting terrain feature provides one additional level of mitigation as does the likelihood of pilot intervention. The Short Term Conflict Alert (STCA) system can be considered as a valid mitigation against aircraft collision where it is available. Pilot assisted intervention includes the concept of 'see and avoid' and the availability of any on-board cooperative conflict advisory systems such as TCAS. TCAS is used as a last resort safety net to avoid a mid-air collision and not every aircraft will be equipped and therefore has not been considered as a valid mitigation on its own. In CAP760, Appendix D, Section 3 the example Event Tree presents the idea of providence using the event 'The aircraft collide'. Therefore, HVR-CSL propose that providence be considered a valid mitigation in the prevention of air traffic accidents.

8.1 Sub-Event Tree H13

Sub-event Tree H13 is shown in Figure 1.

There are many difficulties in assigning quantitative values to the events within H13. HVR-CSL investigated several possible sources of information including recent CAA UK Airprox Board data published at http://www.caa.co.uk/default.aspx?categoryid=423 with a view to deriving some sensible estimates. HVR finally elected to use conservative estimates based on the SME opinion and the concept of each mitigating event contributing up to one order of magnitude to the accident frequency.

Figure 1 Sub Event Tree H13



8.2 Applying the Additional Mitigation to the Unacceptable Risks

The events in Sub-Event Tree H13 were appended to each of the worst case consequences of the *Unacceptable* risks in order that a final figure for the likelihood of an actual accident is calculated. In each case the most prominent accident for each of the *Unacceptable* hazards was a Severe Separation Safety Event (classified as Major). The results for each of the *Unacceptable* risks are shown below in table 6 with new risk classes.

Hazard	Accident	Severity	Frequency	New Risk Class
H4 Military	Severe Separation Safety Event	Major	Extremely Remote 1.39e-8	Acceptable with Review
H8 Military	Severe Separation Safety Event	Major	Remote 4.77e-5	Acceptable with Review
H9 Military	Severe Separation Safety Event	Major	Extremely Remote 3.82e-9	Acceptable with Review
H8 Civil	Severe Separation Safety Event	Major	Remote 4.83e-5	Acceptable with Review
H9 Civil	Severe Separation Safety Event	Major	Extremely Remote 3.82e-9	Acceptable with Review

Table 6. New risk classes for the Unacceptable risks based on additional mitigation in the operational environment

8.2.1 Unacceptable risks now Acceptable with Review

The hazards with *Unacceptable* risks as defined in section 7 have now been classified as *Acceptable with Review*. The risk can be tolerated if there are processes in place to ensure that the risk is and remains ALARP for all future applications of this analysis.

9. Safety Requirements Determination

9.1 Safety Requirements

Table 7 defines a list of Safety Requirements for the provision of a safe Air Traffic Service in the presence of wind turbine interference, for the Baseline Watchman PSR. Some of the requirements are based around the events contained within the event trees; these are marked accordingly with the event identification number for traceability.

SR Id.	Safety Requirement	Source
SR1	Following radar failure, the civilian ATCO must continue to provide a safe service through the use of procedural control of all aircraft currently receiving a radar service.	Event M6
SR2	Procedures shall be in place to manage the workload of civilian ATCO such that the probability of them failing to perform their job effectively is <1%	Event M4
SR3	Following radar failure the military ATCO shall achieve transfer of **all** aircraft receiving a radar service to adjacent in 40% of cases.	Event M11
SR4	Alternative display consoles shall be provided to mitigate against screen/console failure	Event M35
SR5	**Recommendation only:** Traffic shall not be flown over areas of wind turbine interference in Instrument Meteorological Conditions	Event M13 and see Section 9 for further description
SR6	Location of wind turbines needs careful management and should seek to avoid areas of significance to safe ATC. These areas include approach/ departure phases, other radar patterns, major flight lanes and other areas of concentrated traffic. This is to enable suitable separation between aircraft and on-screen clutter.	H8 and H9 analysis results section 7
SR7	**Recommendation only:** Safety Case to be developed on a case by case basis for all current and proposed wind turbine developments sited within 'line of sight' of PSR to ensure that SR6 is met.	H8 and H9 analysis results section 7
SR8	Mitigation against the effects of wind turbine interference for the Baseline Watchman PSR may be required but is heavily dependent on wind farm parameters (size, location, number of turbines, line of sight of radar etc.).	

SR9	**Recommendation only:** Airspace Safeguarding methods to be investigated, particularly for Military Aerodromes where airspace significance is less well defined.	
SR10	Severity of the consequences errs on the side of the worst case scenario. It may be prudent to review these severities on a case by case basis to ensure that they are not unduly severe.	

Table 7. Safety Requirements for the provision of a safe ATS in the presence of wind turbine interference

9.2 Deriving the Safety Requirements for the Mitigating Technologies

The safety requirements in table 7 above are also applicable to each of the mitigating technologies; Annexes A and B define the specific requirements for each.

In order to define quantitative requirements for the ADT and SPE3000, HVR-CSL reverse engineered the event trees to calculate the tolerable frequency of each of the hazards. These frequency values translate into the quantitative safety requirements as defined in Annexes A and B. See Annexes A and B for more details.

10. Application of this Safety Case to Airfield Operations in the UK

10.1 Overview

During the safety analysis activities, the Subject Matter Experts (SME) considered different types of airspace and different phases of flight in assessing the severity of the hazard effects. The aim of these considerations was to identify whether the location of wind turbines relative to the airspace operations, had any bearing on the outcomes of the hazards. The phases of flight considered during the analysis were:

- Standard Instrument Departures (SID);
- Low Level Departures;
- Radar Pattern (Approach);
- Short Pattern Circuits;
- Radar Actual/Practise Forced Landing;
- Joining the Visual Circuit;
- Surveillance Radar Approach (SRA);
- Transit En-route;
- Emergencies.

10.2 Hazard Application to Phases of Flight

Of the wind turbine related hazards, the SME identified hazard H5: Partial loss of Plot Data as being the most significant hazard when considering the most critical areas of the PSR Service. H5 is closely followed by hazards H8: Targets Obscured by Clutter and H9 False Targets and Split Plots. The effects of these three hazards and the severity of the subsequent consequences will be closely related to the phase of flight in which the hazard occurs.

Based on their extensive experience, the SME estimated a notional probability of 1 in 20 occurrences of H5 could be in an 'area of significance'. An increase in this probability (regardless of the cause) might seriously affect the safety of the PSR service.

10.3 Wind Turbine Hazards and Airspace Infringements

During the safety analysis activities, one of the most serious aviation hazards identified was the infringement of Controlled Airspace (CAS), where an aircraft enters CAS without ATCO permission. Most commonly, infringements occur due to a general aviation aircraft accidentally entering the CAS. The CAA commissioned a study on infringements by General Aviation (GA) aircraft which is detailed in [6].

The wind turbine related hazards (e.g. H8 targets obscured by clutter) could seriously affect ATCO ability to detect airspace infringements.

10.4 Airspace Safeguarding

Wind farm developers are required to notify the CAA of proposals for wind farms via the CAA Notification System. CAP 764 states that developers should advise airports with radar of all proposals within 30km of the affected airport. Civil airports are responsible for their own safeguarding activities however; the implementation of safeguarding procedures and the processing of wind development proposals by airports is inconsistent. Government targets for the employment of wind energy as part of a wider policy on environmental issues induces a pressure upon all stakeholders to work constructively towards the delivery of the targets.

The MoD considers all applications for wind developments based on theoretical line of sight criteria and areas of operational significance around the aerodrome are less well defined.

10.5 Transit Aircraft

Many of the civil and military radar units located at airports provide an ATS to transit aircraft. The routes of these aircraft are random and hence may transit over areas occupied by wind turbines. A formally defined service is the Lower Airspace Radar Service (LARS), which selected civil/military airports throughout the country provide and the SME expressed concerns that the proliferation of wind development may have a serious impact on the provision of LARS.

Safeguarding methods are generally aerodrome specific and do not easily account for the hazards relating to transiting aircraft and the LARS due to the random nature of the traffic patterns.

11. Conclusions and Recommendations

11.1 Safety Analysis Conclusions

Through the analysis in sections 7 and 8, the Baseline Watchman PSR has been demonstrated as broadly safe for provision of a radar service in the presence of wind turbine interference. However there are no mitigations within the system itself to counteract the effects of this interference and the risks that are associated with the wind farm related hazards (primarily H8 and H9) rely heavily on factors within the external operational environment to provide mitigation. In order to apply this analysis to any aerodrome specific safety cases the operational environment of the aerodrome MUST be analysed to ensure that similar external mitigating factors exist.

The quantitative values used throughout this safety case are based upon assumptions made by SME with a collective fifty years of ATC experience between them and on estimated failure rates provided by the radar manufacturer. Various external factors meant that HVR-CSL were not furnished with the empirical data that they had hoped for; the value of this report is as a robust generic safety argument on which to base a safety case for the provision of Air Traffic Services in areas affected by wind turbine interference. If the results of Trial Celtic Storm were made available in the future it may be possible to make a better quantitative argument for the safety of the affected radar service. For an aerodrome specific safety case all of the SME assumptions should be substantiated with real data provided by the subject ATS providers.

11.2 Technology versus Procedural Mitigation

The decision on whether to provide technological mitigation against wind turbine interference should remain an aerodrome-specific concern. In the long term a technological solution across the fleet of Watchman radars would be an effective type of mitigation given the government targets for wind energy. A number of other areas that could provide mitigation were discussed during this analysis but ultimately the ability to distinguish real targets from 'false' targets generated by the turbines is desired. The other areas discussed were:

- additional ATCO procedures/policies specifically aimed at wind turbine interference e.g. identifying maximum tolerable clutter, use of secondary radar only (SSR) to maintain identity of aircraft through small areas of airspace affected by turbine interference (note that permanent use of SSR is not approved in the UK) [7];

- airspace safeguarding for those airports not officially safeguarded (i.e. those that are not military aerodromes of strategic importance or airports of importance to the UK national air transport system);

- airspace re-design e.g. no fly areas around existing wind farms, particularly when flying IMC;

- Safeguarding of flight paths, reporting points and other areas of concentrated traffic.

11.3 Wind Turbine Location Considerations

The overarching recommendation is that wind turbines are not erected in areas that will adversely affect the safe provision of Air Traffic Services unless acceptable mitigation can be assured.

HVR-CSL recommend that airport operators consider safeguarding techniques when considering proposed wind turbine development plans. Although outside the remit of this safety study, HVR-CSL noted (during conversations with airport authorities and wind farm developers at the trials open day) that discussions between the two parties may be better facilitated if the latter have an appreciation of the reasons behind airspace safeguarding. HVR-CSL suggest a short training course or convention for the dissemination of information to wind farm developers by an independent party.

In summary the areas significant to safe operations at a particular aerodrome need to be determined on a case by case basis and where necessary, protected from wind turbine developments.

11.3.1 Concept Implementation

A full Safety Case is required for the implementation of either of the two mitigating technologies into the current Watchman PSR system. The restrictions regarding the commercially sensitive nature of data pertaining to each technology and the unavailability of the trials results (no independent verification of the proposed solutions) have prevented HVR-CSL from developing the generic Safety Cases for each.

Instead, HVR-CSL derived a set of provisional quantitative requirements that the technologies should meet in order to satisfy the accident frequency tolerability of each hazard. These requirements are **provisional and subject to substantiation of the event tree assumptions**. The responsibility of proving that the solutions meet these requirements must lie with the respective manufacturer. The provisional requirements for the ADT and SPE3000 are contained in Annexes A and B respectively.

11.3.2 Concept Transitioning into Service

It is a requirement that a Safety Case be developed on a case by case basis for all current and proposed wind turbine developments sited within 'line of sight' of any installation of the Watchman PSR. The responsibility for assuring the continued provision of a safe ATS lies with the service provider and in order for civilian airports to retain CAA Approval for the provision of the service, they must be able assess the impact of a proposed development on all

Communications Navigation and Surveillance (CNS) systems [7]. For military airports, the MOD are a self regulating body however their safety requirements are regarded as the same as those of the CAA where the contingencies of the Service allow.

Annex A - Advanced Digital Tracker (ADT)

Annex A to this report is supplied as a separate document to minimise the risk of distribution of commercially sensitive information; Annex A carries the Commercial in Confidence classification and so is supplied as a separate document. Reference: [2A].

Annex B - SPE3000 Replacement Signal Processor

Annex B to this report is supplied as a separate document to minimise the risk of distribution of commercially sensitive information; Annex B carries the Commercial in Confidence classification and so is supplied as a separate document. Reference: [2B].

Annex C Safety Argument (Goal Structured Notation)

Annex C contains the outline safety argument diagram that uses Goal Structured Notation (GSN) to represent and expand the Safety Argument as described in Section 6.

Two additional Safety Arguments were developed for each of the two candidate mitigating technologies (Goal 6 and Goal 7) but are not shown in this annex. Goal 6 represents a model safety argument for the ADT and is shown in Annex A. Goal 7 represents a model safety argument for the SPE3000 and is shown in Annex B.

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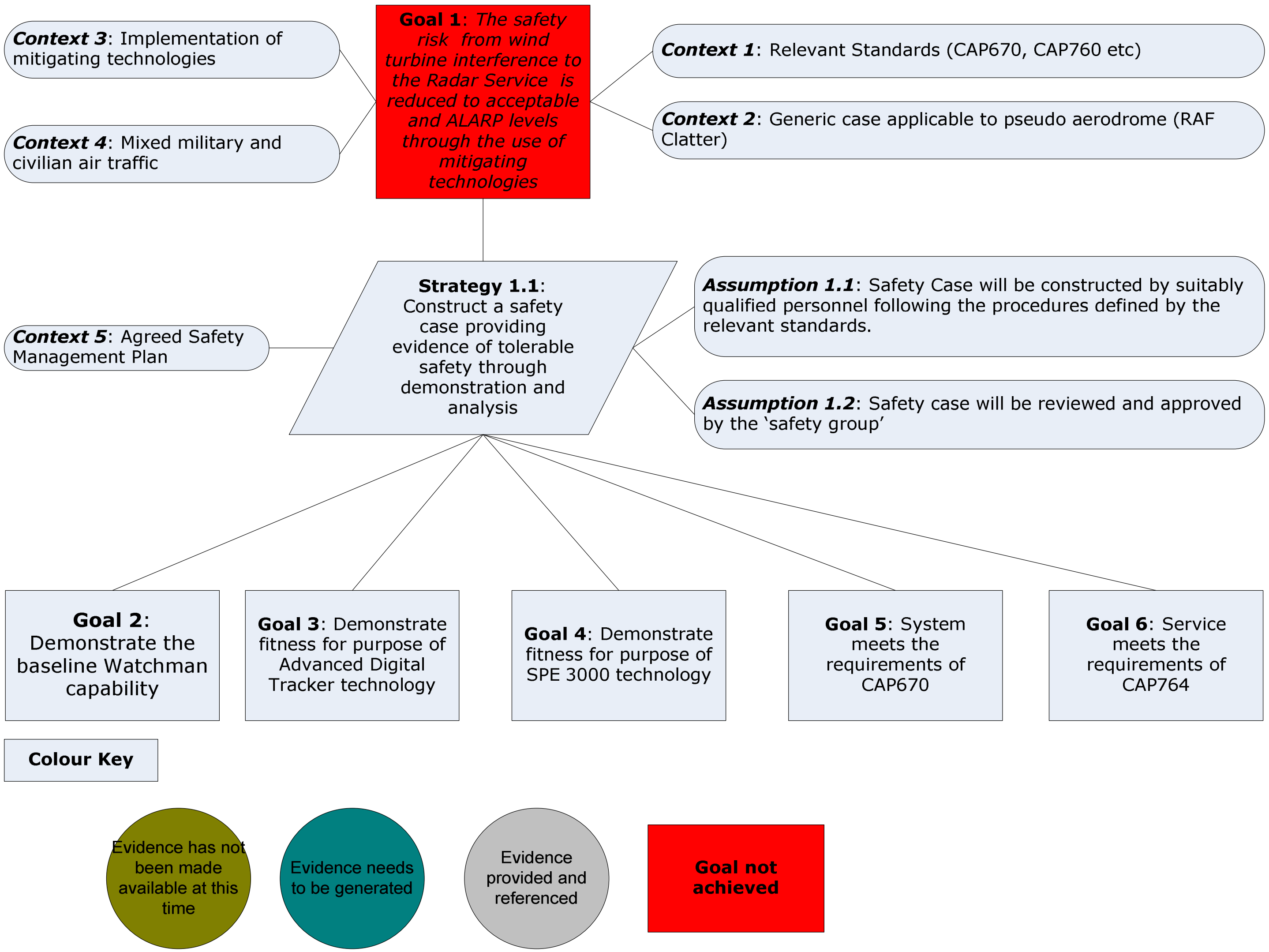
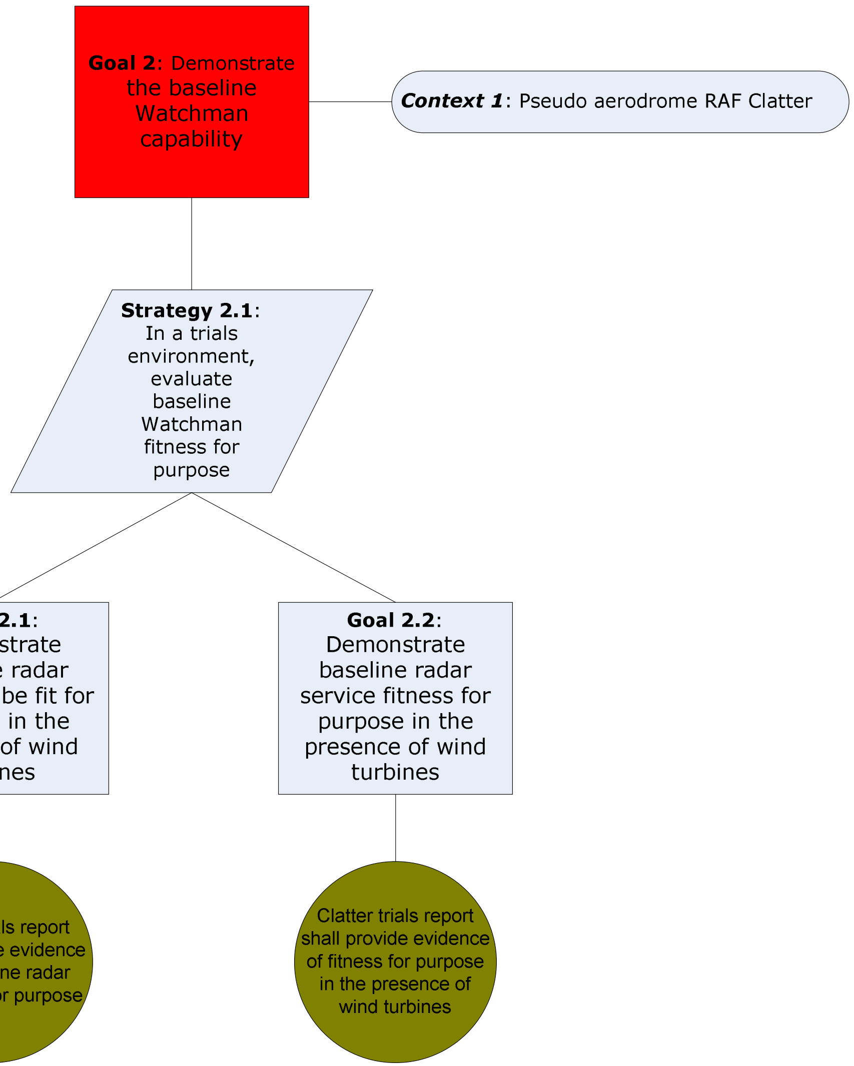
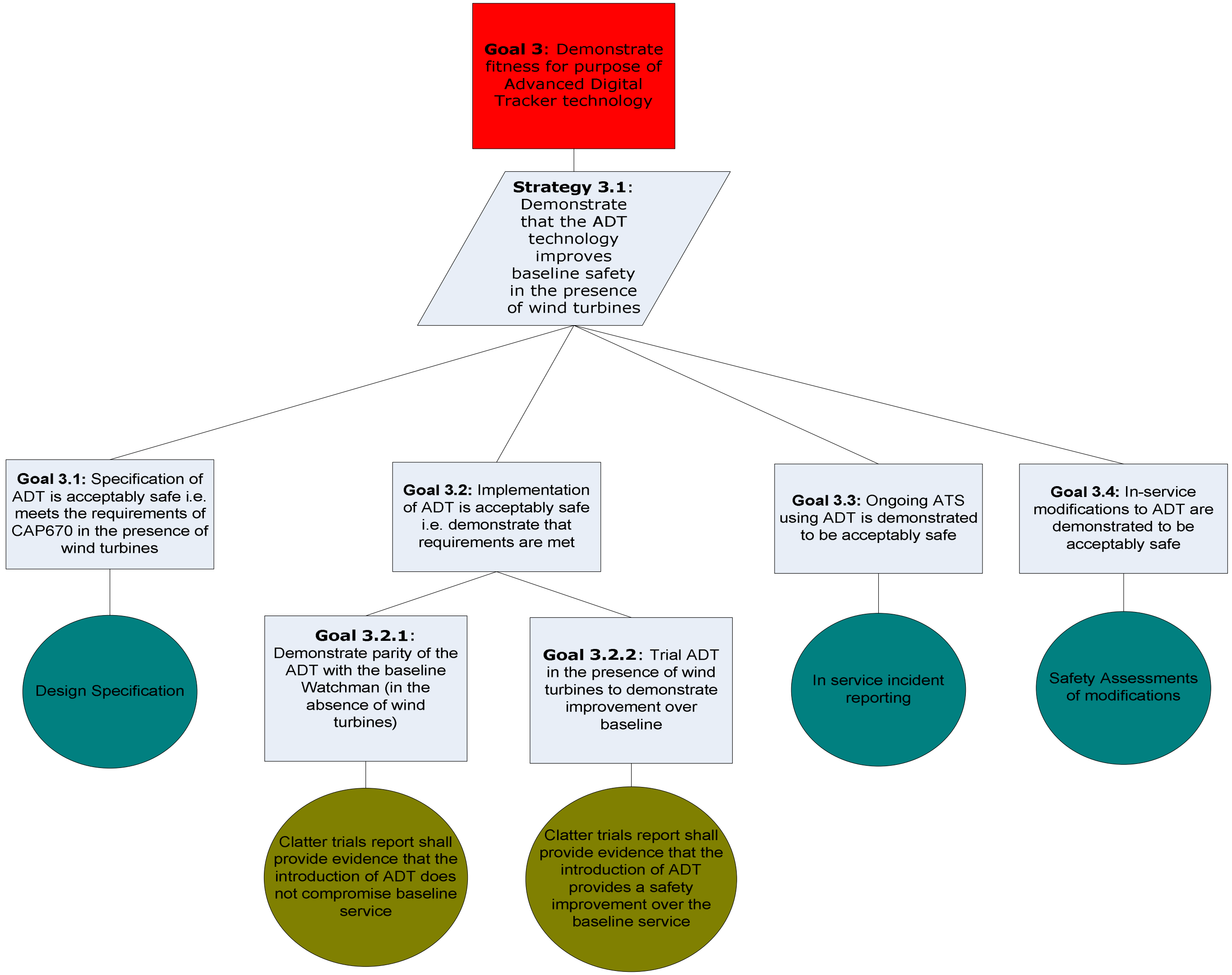
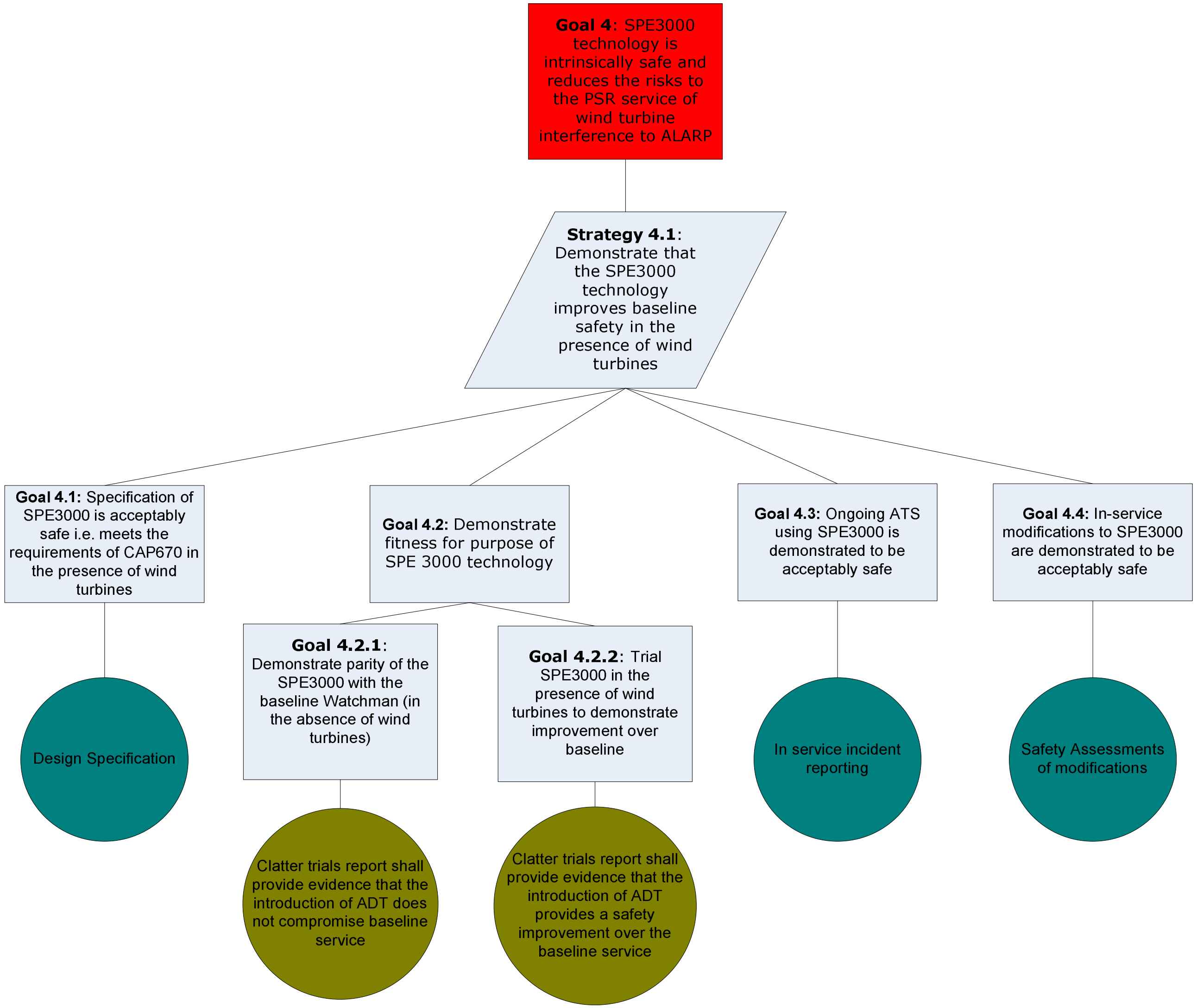
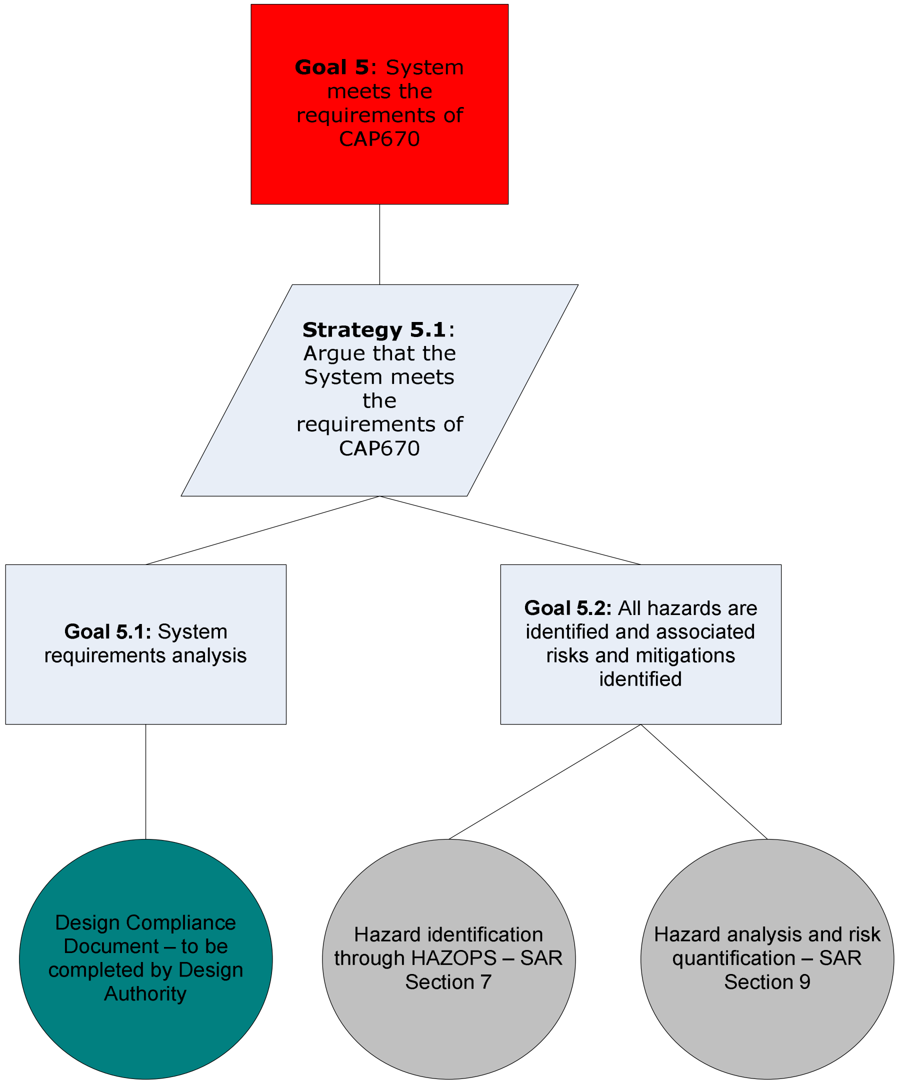


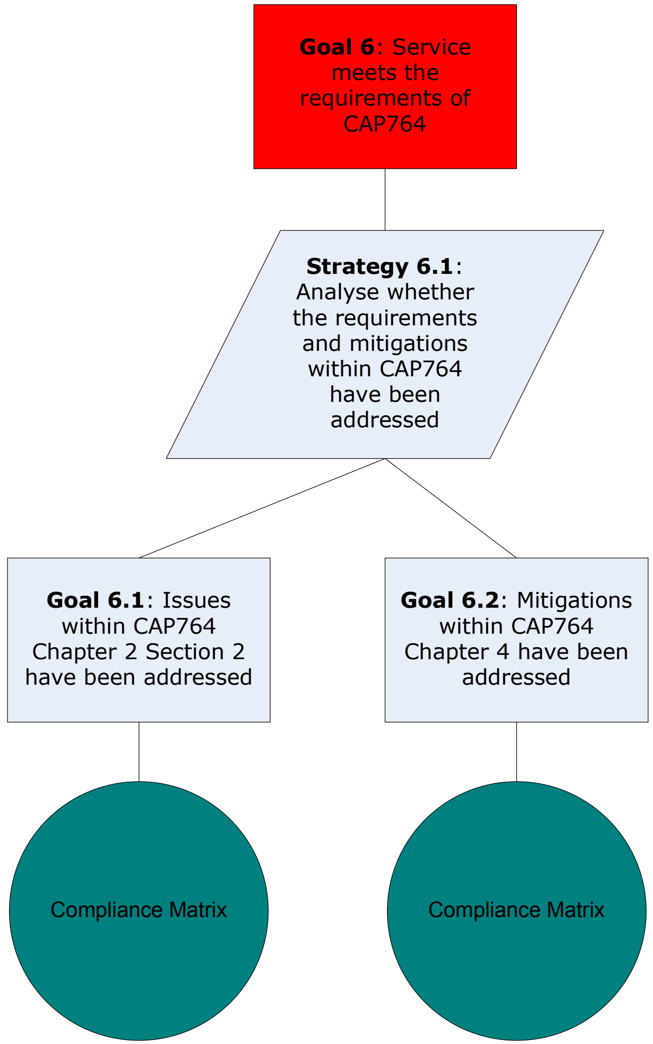
Goal 1: The safety risk from wind turbine interference to the Radar Service is reduced to acceptable and ALARP levels through the use of mitigating technologies
Context 3: Implementation of mitigating technologies
Context 4: Mixed military and civilian air traffic
Context 1: Relevant Standards (CAP670, CAP760 etc)
Context 2: Generic case applicable to pseudo aerodrome (RAF Clatter)
Strategy 1.1: Construct a safety case providing evidence of tolerable safety through demonstration and analysis
Context 5: Agreed Safety Management Plan
Assumption 1.1: Safety Case will be constructed by suitably qualified personnel following the procedures defined by the relevant standards.
Assumption 1.2: Safety case will be reviewed and approved by the 'safety group'
Goal 2: Demonstrate the baseline Watchman capability
Goal 3: Demonstrate fitness for purpose of Advanced Digital Tracker technology
Goal 4: Demonstrate fitness for purpose of SPE 3000 technology
Goal 5: System meets the requirements of CAP670
Goal 6: Service meets the requirements of CAP764
Colour Key
Evidence has not been made available at this time
Evidence needs to be generated
Evidence provided and referenced
Goal not achieved


Goal 2: Demonstrate the baseline Watchman capability
Context 1: Pseudo aerodrome RAF Clatter
Strategy 2.1: In a trials environment, evaluate baseline Watchman fitness for purpose
Goal 2.1: Demonstrate baseline radar service to be fit for purpose in the absence of wind turbines
Goal 2.2: Demonstrate baseline radar service fitness for purpose in the presence of wind turbines
Clatter trials report shall provide evidence that baseline radar service fit for purpose
Clatter trials report shall provide evidence of fitness for purpose in the presence of wind turbines


Goal 3: Demonstrate fitness for purpose of Advanced Digital Tracker technology
Strategy 3.1: Demonstrate that the ADT technology improves baseline safety in the presence of wind turbines
Goal 3.1: Specification of ADT is acceptably safe i.e. meets the requirements of CAP670 in the presence of wind turbines
Goal 3.2: Implementation of ADT is acceptably safe i.e. demonstrate that requirements are met
Goal 3.3: Ongoing ATS using ADT is demonstrated to be acceptably safe
Goal 3.4: In-service modifications to ADT are demonstrated to be acceptably safe
Design Specification
Goal 3.2.1: Demonstrate parity of the ADT with the baseline Watchman (in the absence of wind turbines)
Goal 3.2.2: Trial ADT in the presence of wind turbines to demonstrate improvement over baseline
In service incident reporting
Safety Assessments of modifications
Clatter trials report shall provide evidence that the introduction of ADT does not compromise baseline service
Clatter trials report shall provide evidence that the introduction of ADT provides a safety improvement over the baseline service


Goal 4: SPE3000 technology is intrinsically safe and reduces the risks to the PSR service of wind turbine interference to ALARP
Strategy 4.1: Demonstrate that the SPE3000 technology improves baseline safety in the presence of wind turbines
Goal 4.1: Specification of SPE3000 is acceptably safe i.e. meets the requirements of CAP670 in the presence of wind turbines
Goal 4.2: Demonstrate fitness for purpose of SPE 3000 technology
Goal 4.3: Ongoing ATS using SPE3000 is demonstrated to be acceptably safe
Goal 4.4: In-service modifications to SPE3000 are demonstrated to be acceptably safe
Goal 4.2.1: Demonstrate parity of the SPE3000 with the baseline Watchman (in the absence of wind turbines)
Goal 4.2.2: Trial SPE3000 in the presence of wind turbines to demonstrate improvement over baseline
Design Specification
Clatter trials report shall provide evidence that the introduction of ADT does not compromise baseline service
Clatter trials report shall provide evidence that the introduction of ADT provides a safety improvement over the baseline service
In service incident reporting
Safety Assessments of modifications


Goal 5: System meets the requirements of CAP670
Strategy 5.1: Argue that the System meets the requirements of CAP670
Goal 5.1: System requirements analysis
Goal 5.2: All hazards are identified and associated risks and mitigations identified
Design Compliance Document – to be completed by Design Authority
Hazard identification through HAZOPS – SAR Section 7
Hazard analysis and risk quantification – SAR Section 9


Goal 6: Service meets the requirements of CAP764
Strategy 6.1: Analyse whether the requirements and mitigations within CAP764 have been addressed
Goal 6.1: Issues within CAP764 Chapter 2 Section 2 have been addressed
Goal 6.2: Mitigations within CAP764 Chapter 4 have been addressed
Compliance Matrix
Compliance Matrix

Annex D Event Tree Analysis

Note on the Quantitative Values in the Event Trees

The reader should be aware that the quantitative values contained in the event trees in this annex may not reflect the values in the tables in the main report. This is because the event trees were used dynamically and certain values were changed for different hazards to reflect the changing probabilities relating to the sequence of events. For example event M60: Switch to Procedural Control is only relevant for the civil application and hence when the event trees were analysed for the military application the failure rate for this event was changed to 100%. Similarly the probability of a success in event M4: Manage Workload depended on the events that preceded it.

The event tree diagrams begin on the next page.

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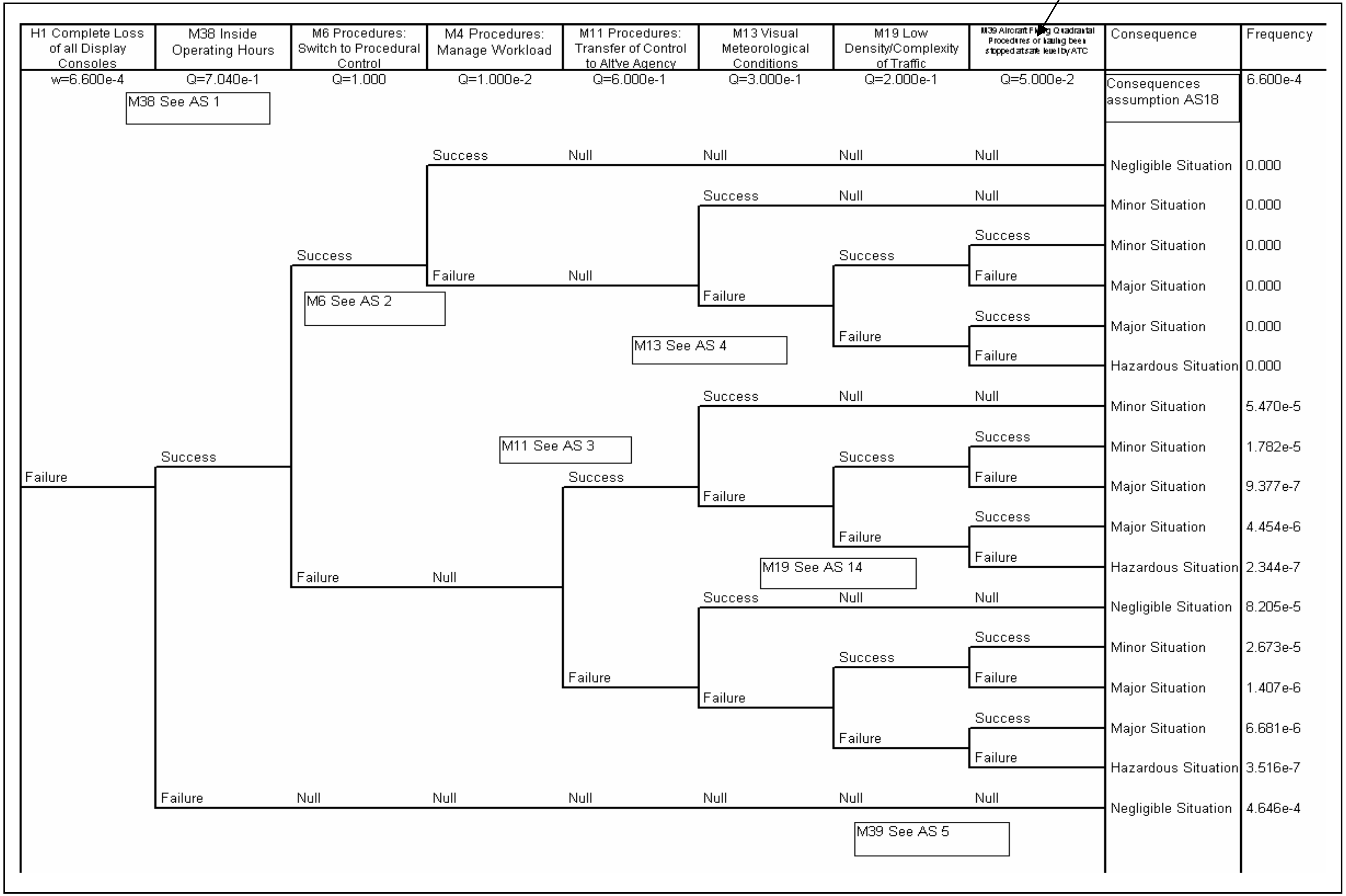
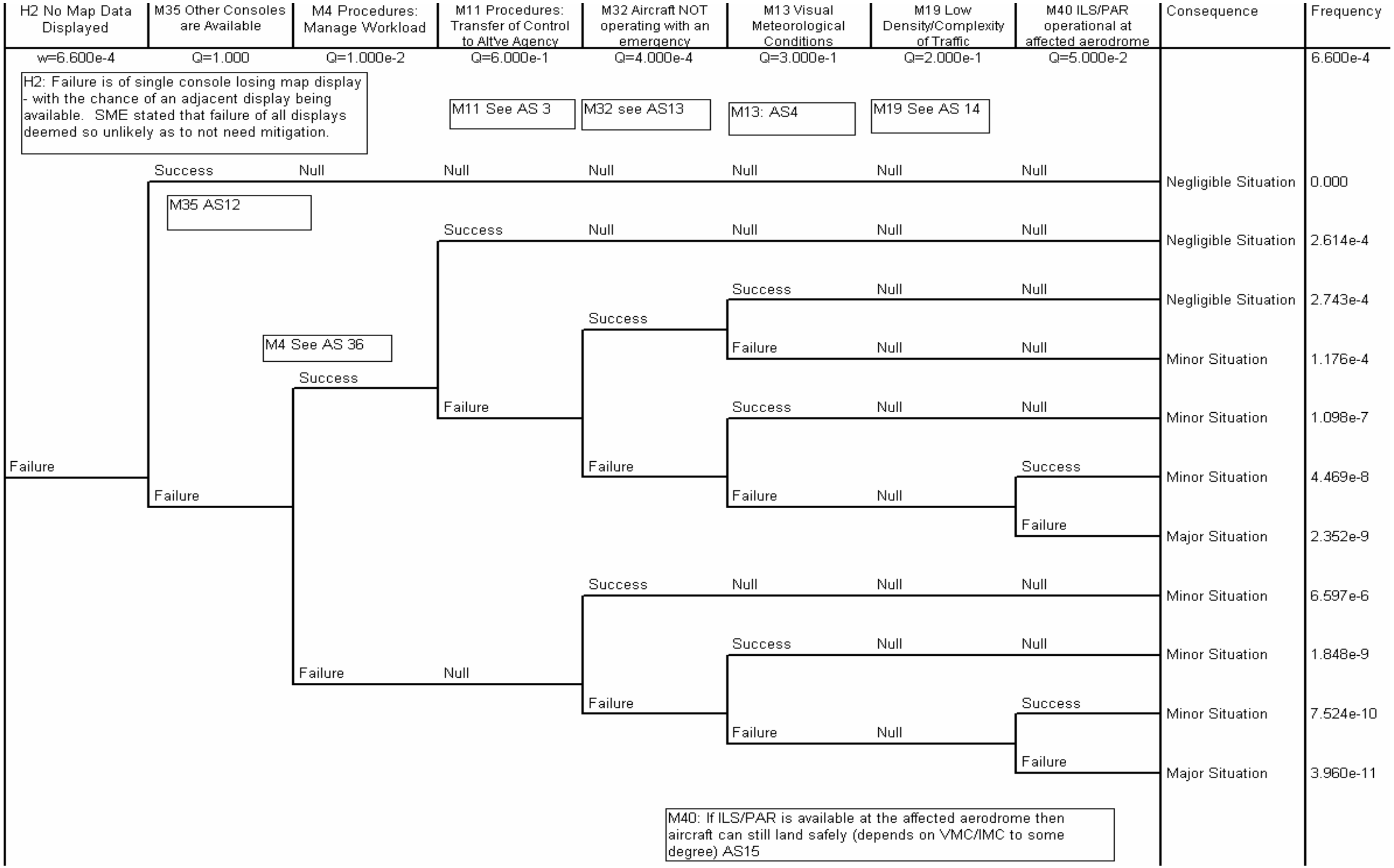
M39 Aircraft are flying Quadrantal procedures




H2 No Map Data Displayed
M35 Other Consoles are Available
M4 Procedures: Manage Workload
M11 Procedures: Transfer of Control to Alt've Agency
M32 Aircraft NOT operating with an emergency
M13 Visual Meteorological Conditions
M19 Low Density/Complexity of Traffic
M40 ILS/PAR operational at affected aerodrome
Consequence
Frequency
w=6.600e-4
Q=1.000
Q=1.000e-2
Q=6.000e-1
Q=4.000e-4
Q=3.000e-1
Q=2.000e-1
Q=5.000e-2
6.600e-4
H2: Failure is of single console losing map display - with the chance of an adjacent display being available. SME stated that failure of all displays deemed so unlikely as to not need mitigation.
M11 See AS 3
M32 see AS13
M13: AS4
M19 See AS 14
M35 AS12
M4 See AS 36
M40: If ILS/PAR is available at the affected aerodrome then aircraft can still land safely (depends on VMC/IMC to some degree) AS15
Success
Null
Failure
Negligible Situation
Minor Situation
Major Situation
0.000
2.614e-4
2.743e-4
1.176e-4
1.098e-7
4.469e-8
2.352e-9
6.597e-6
1.848e-9
7.524e-10
3.960e-11

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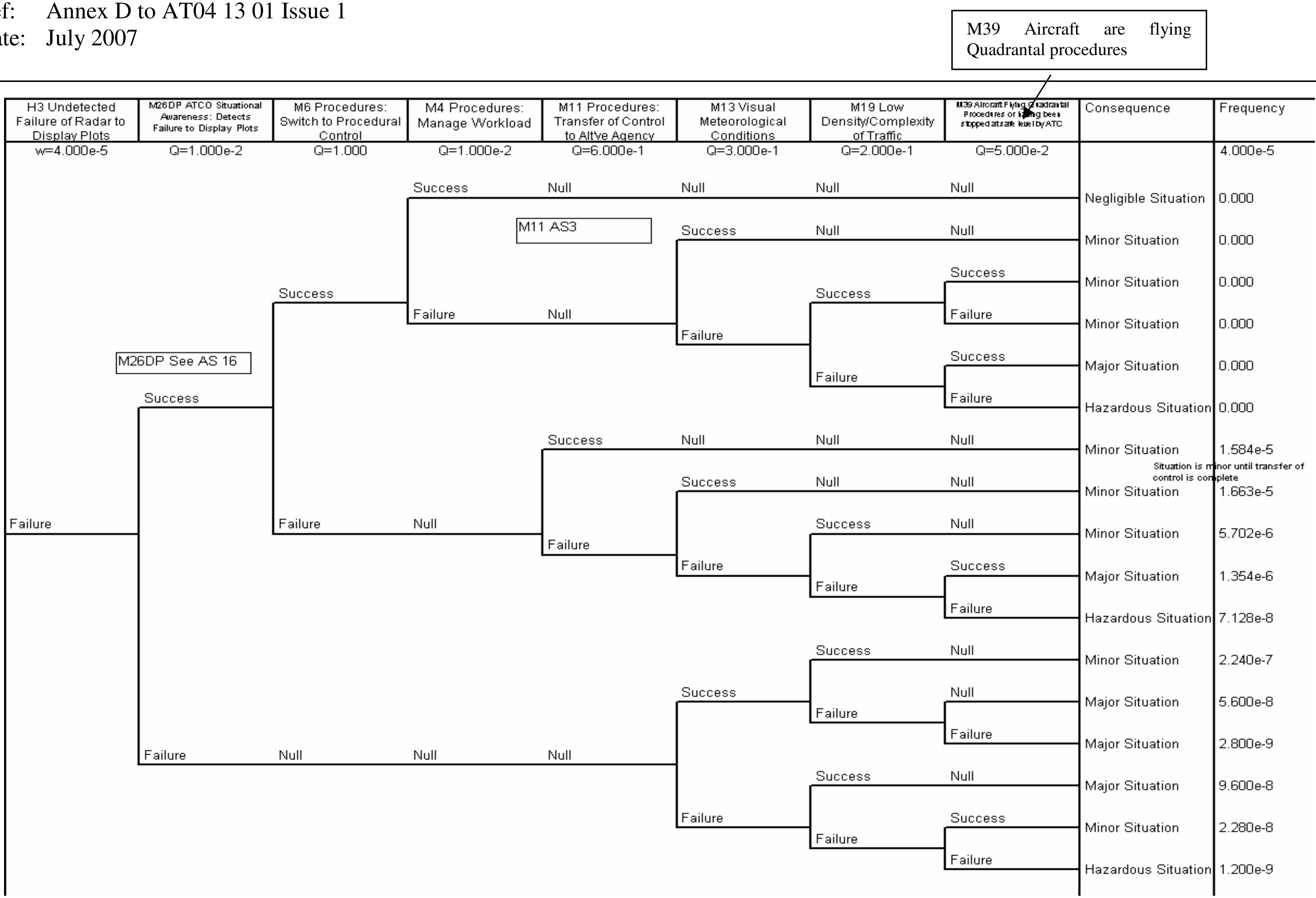

Ref: Annex D to AT04 13 01 Issue 1
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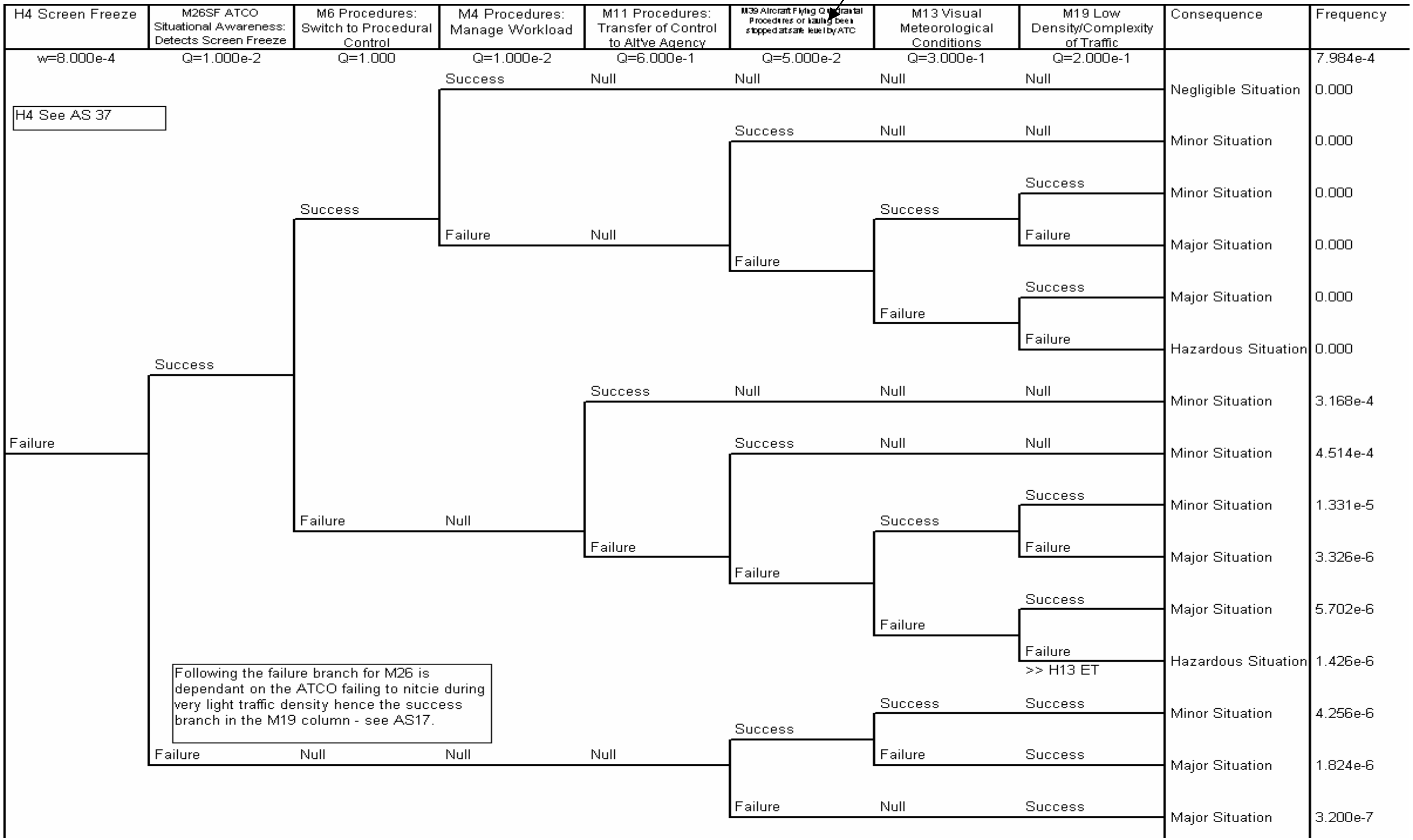
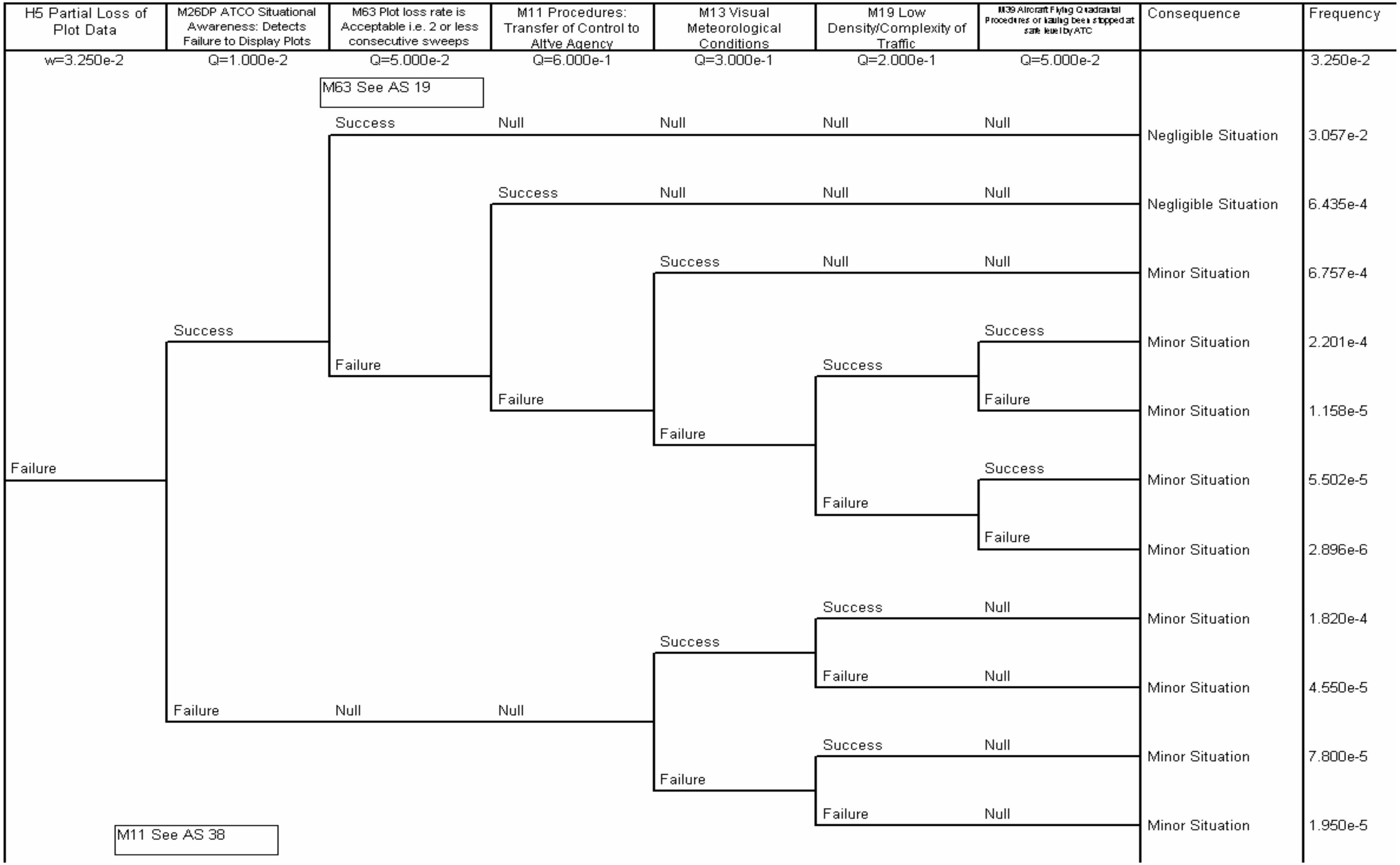
M39 Aircraft are flying Quadrantal procedures



Ref: Annex D to AT04 13 01 Issue 1
Date: July 2007



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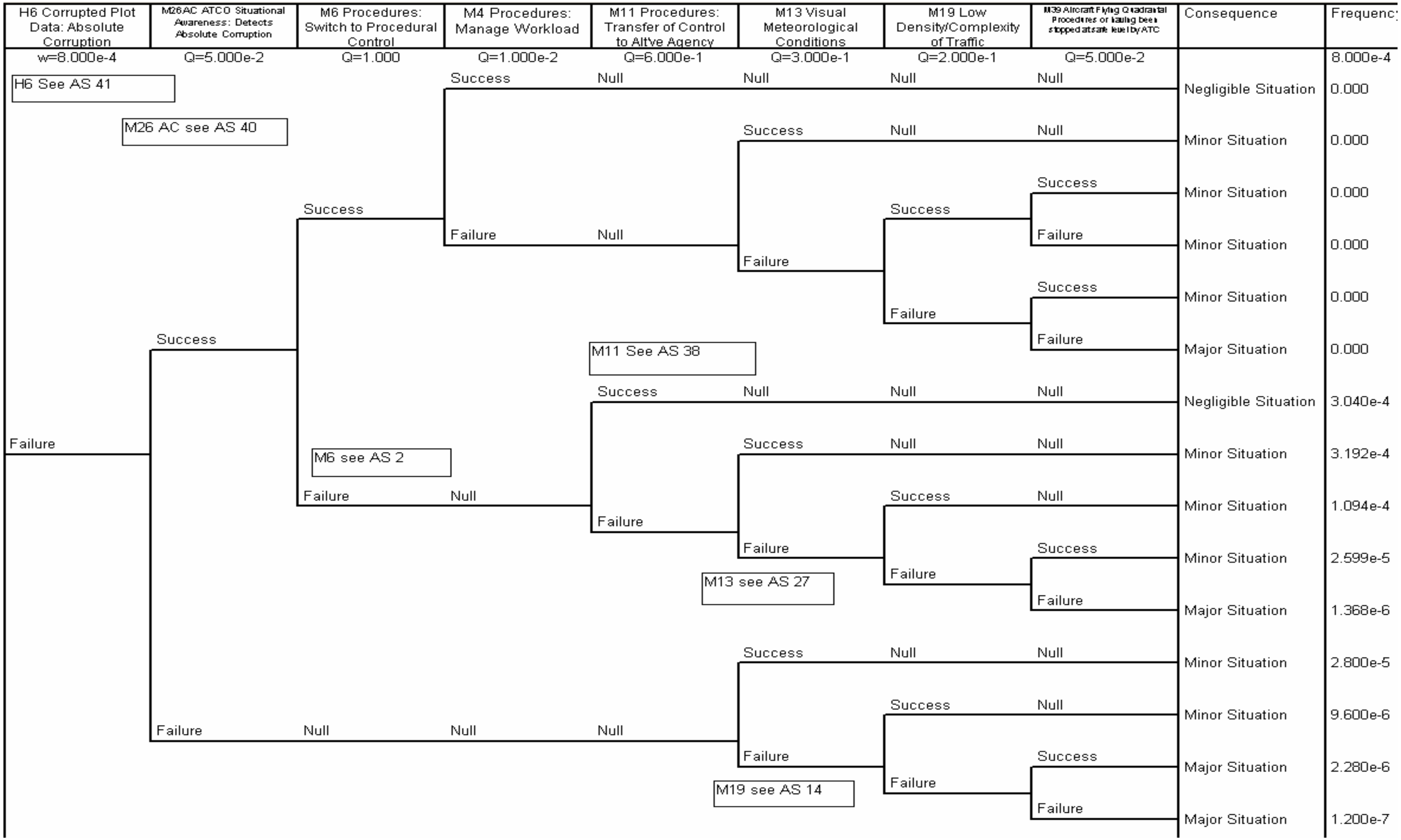

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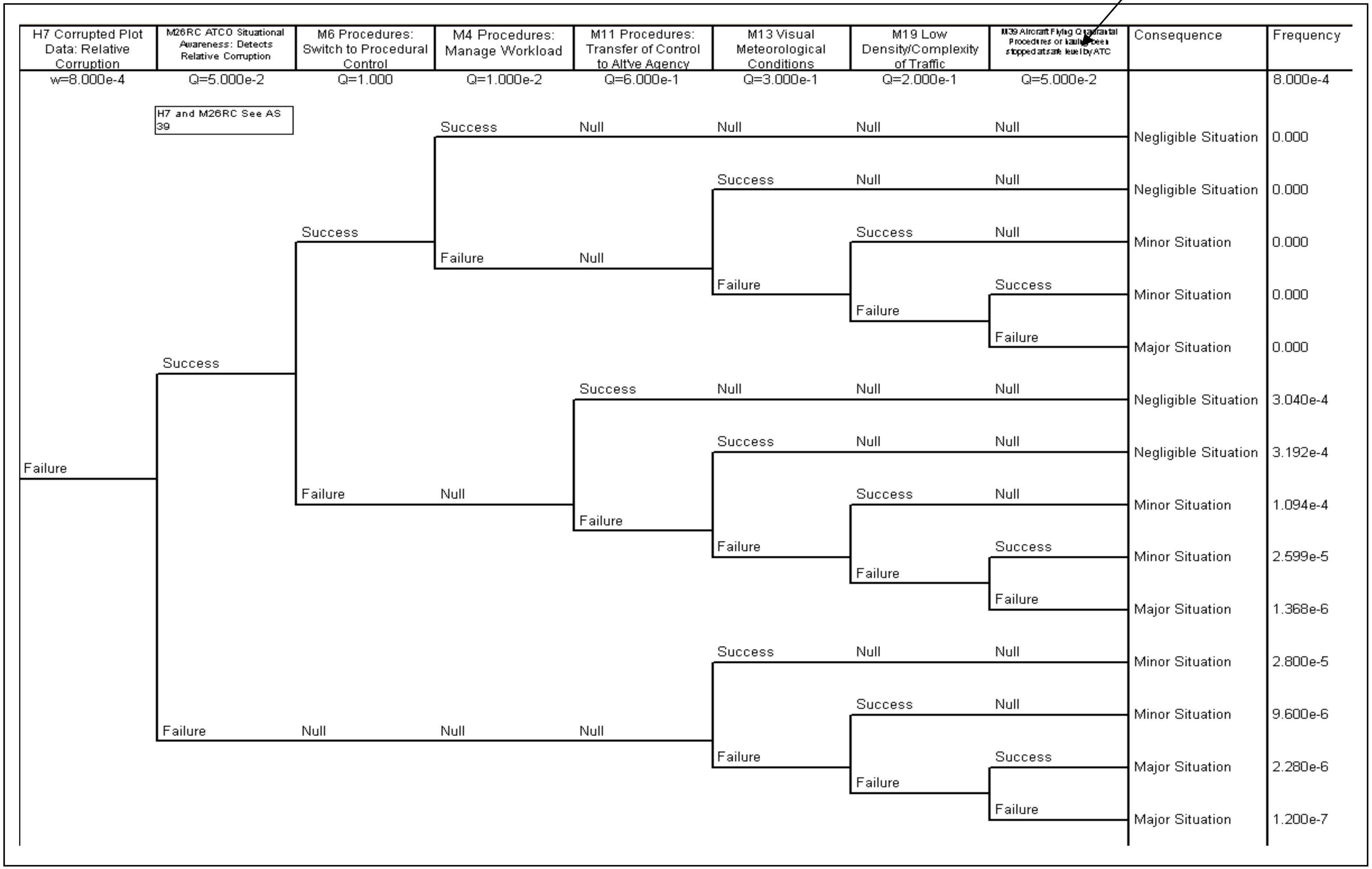
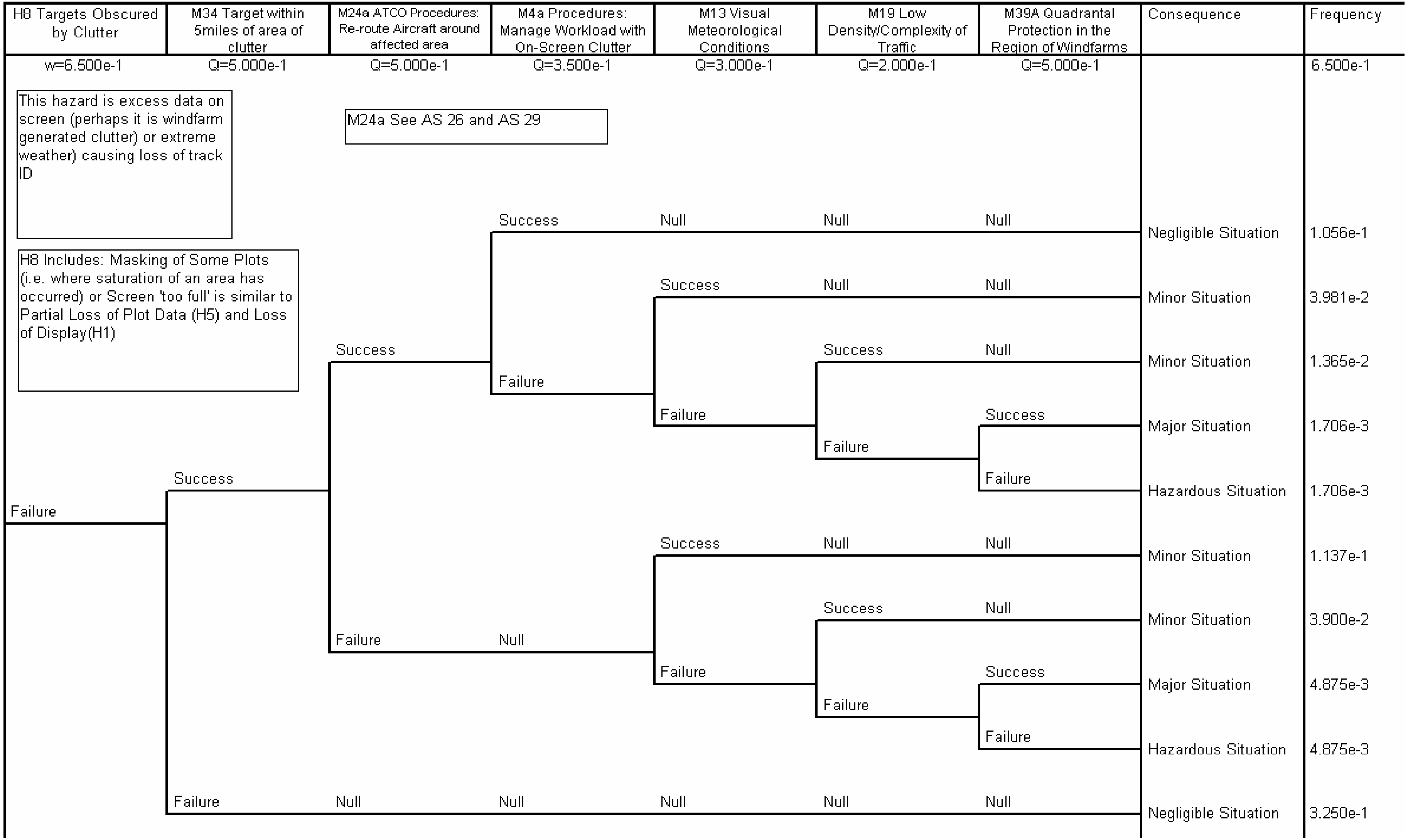
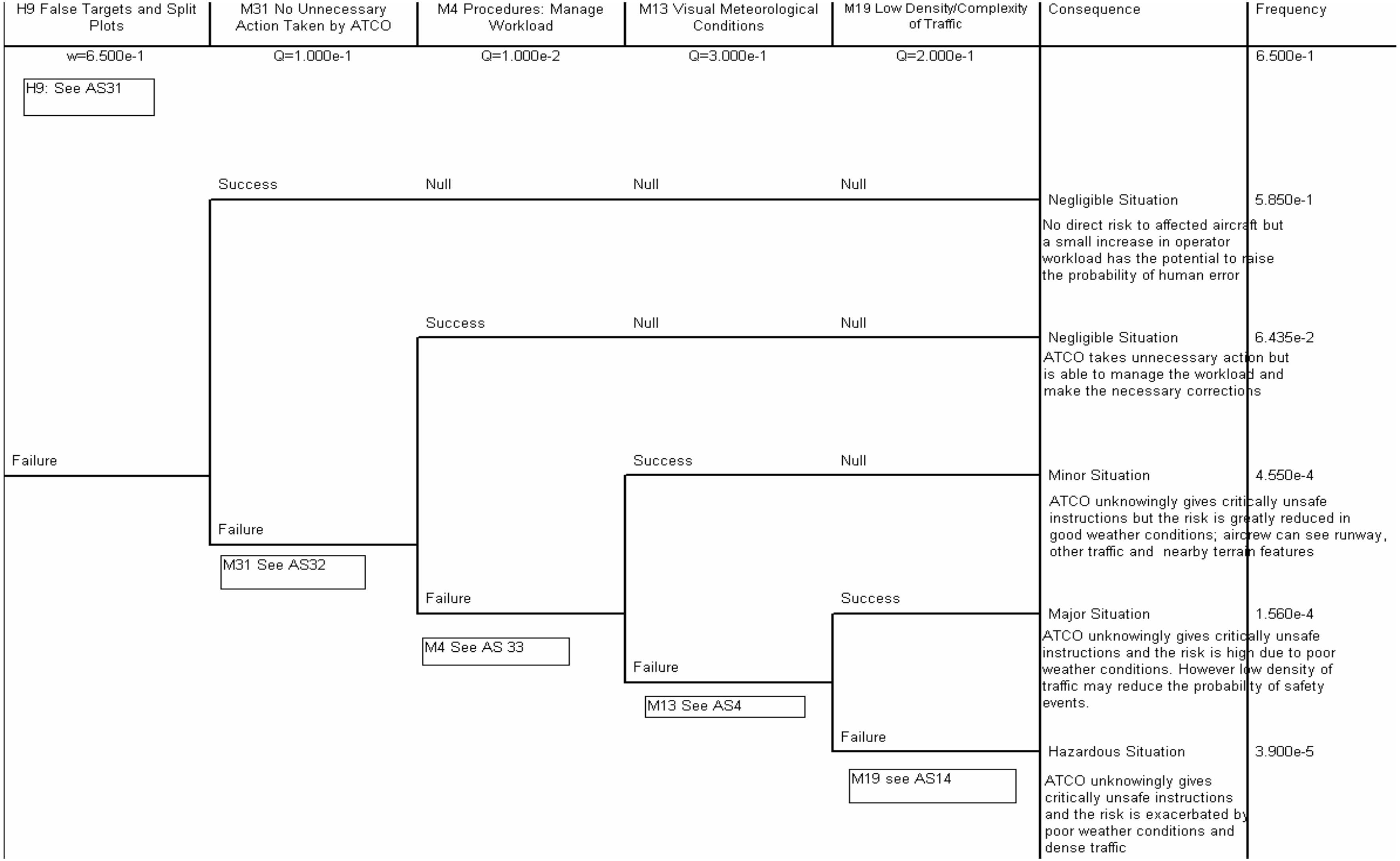
M39 Aircraft flying Quadrantal Procedures




H8 Targets Obscured by Clutter
M34 Target within 5miles of area of clutter
M24a ATCO Procedures: Re-route Aircraft around affected area
M4a Procedures: Manage Workload with On-Screen Clutter
M13 Visual Meteorological Conditions
M19 Low Density/Complexity of Traffic
M39A Quadrantal Protection in the Region of Windfarms
Consequence
Frequency
w=6.500e-1
Q=5.000e-1
Q=5.000e-1
Q=3.500e-1
Q=3.000e-1
Q=2.000e-1
Q=5.000e-1
6.500e-1
This hazard is excess data on screen (perhaps it is windfarm generated clutter) or extreme weather) causing loss of track ID
M24a See AS 26 and AS 29
H8 Includes: Masking of Some Plots (i.e. where saturation of an area has occurred) or Screen 'too full' is similar to Partial Loss of Plot Data (H5) and Loss of Display(H1)
Success
Failure
Null
Negligible Situation
1.056e-1
Minor Situation
3.981e-2
Minor Situation
1.365e-2
Major Situation
1.706e-3
Hazardous Situation
1.706e-3
Minor Situation
1.137e-1
Minor Situation
3.900e-2
Major Situation
4.875e-3
Hazardous Situation
4.875e-3
Negligible Situation
3.250e-1


H9 False Targets and Split Plots
M31 No Unnecessary Action Taken by ATCO
M4 Procedures: Manage Workload
M13 Visual Meteorological Conditions
M19 Low Density/Complexity of Traffic
Consequence
Frequency
w=6.500e-1
Q=1.000e-1
Q=1.000e-2
Q=3.000e-1
Q=2.000e-1
6.500e-1
H9: See AS31
Success
Null
Null
Null
Negligible Situation
5.850e-1
No direct risk to affected aircraft but a small increase in operator workload has the potential to raise the probability of human error
Success
Null
Null
Negligible Situation
6.435e-2
ATCO takes unnecessary action but is able to manage the workload and make the necessary corrections
Failure
Success
Null
Minor Situation
4.550e-4
ATCO unknowingly gives critically unsafe instructions but the risk is greatly reduced in good weather conditions; aircrew can see runway, other traffic and nearby terrain features
Failure
M31 See AS32
Failure
Success
Major Situation
1.560e-4
ATCO unknowingly gives critically unsafe instructions and the risk is high due to poor weather conditions. However low density of traffic may reduce the probability of safety events.
M4 See AS 33
Failure
M13 See AS4
Failure
Hazardous Situation
3.900e-5
M19 see AS14
ATCO unknowingly gives critically unsafe instructions and the risk is exacerbated by poor weather conditions and dense traffic

End of Report