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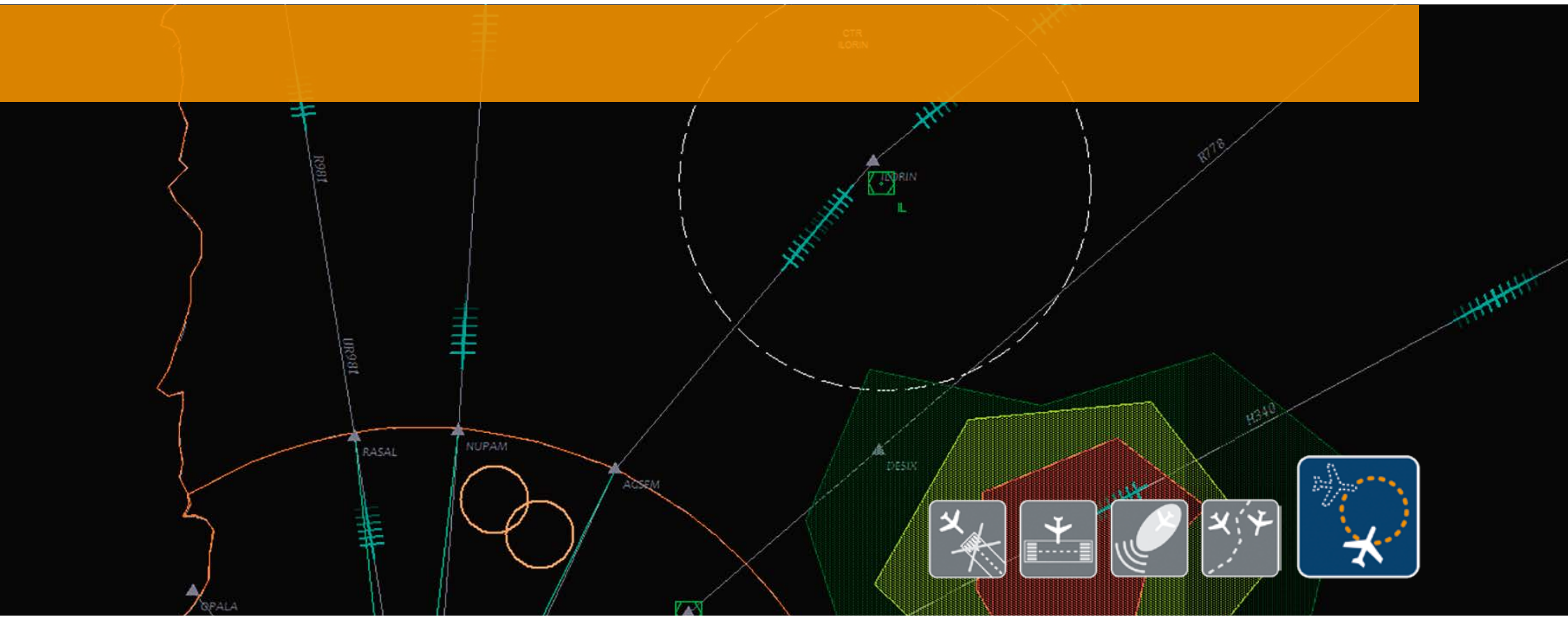
EUROCONTROL

Operational Safety Study: Risk of operation without a transponder or with a dysfunctional one



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The following table identifies all management authorities who have successively approved the present issue of this documents.

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The following table records the complete history of the successive editions of the present document.

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EXECUTIVE SUMMARY

The EUROCONTROL Safety Improvement Sub-Group (SISG), reporting to the EUROCONTROL Safety Team, was tasked to identify the Top 5 ATM Operational Safety Priorities.

SISG performed a review during summer 2012 and involved a series of dedicated workshops with 6 ANSPs, representing a large part of European air traffic.

Comprehensive barrier models - Safety Functions Maps (SAFMAPs) - were developed and populated with representative data from the participating ANSPs. The incident data is for high severity (classified as 'A' and 'B') events, which are on one side thoroughly investigated and on the other side - highly informative because the incident scenarios 'test' the majority of the available safety barriers.

As a result of the SAFMAP analysis the Top 5 priority areas were suggested, agreed by SISG and endorsed by the Safety Team:

- Risk of operation without transponder or with a dysfunctional one
- Landing without ATC clearance
- Detection of occupied runway
- "Blind spot" – inefficient conflict detection with the closest aircraft
- Conflict detection with adjacent sectors

This purpose of this report is twofold:

- To document the operational safety study on one of the Top 5 Network Manager operational safety priorities for 2013 – "Risk of operation without transponder or with a dysfunctional one".
- To serve as a reference for the Network actors in case they undertake operational safety analysis and improvement activities regarding the risk of the operation of an aircraft without a transponder or with a dysfunctional one".

The priorities were reviewed by SISG with SAFMAP analysis of the data for year 2013 and re-confirmed as Top 5 priorities for 2014.

The methodology employed was as follows:

- Generate a set of generic scenarios that could pose a safety risk due to the operation of an aircraft without a functioning transponder or with a dysfunctional one.
- Consider what barriers exist that if implemented and deployed could mitigate the result of an aircraft operating without a transponder or a dysfunctional one causing an operational impact leading to a risk.
- Analysis each generic scenario against the potential barriers to establish which of these barriers could be effective over the whole range of scenarios.
- Review a set of actual events and plausible scenarios to confirm that the barriers suggested by the generic analysis to validate that the same barriers should be the most effective in the live environment.

A series of conclusions are drawn regarding the effectiveness of the identified barriers. Further work will be necessary to validate these conclusions.

CHAPTER 1 - INTRODUCTION

1.1 What is the purpose of this document?

Documenting and communicating

This purpose of this report is twofold:

- To document the operational safety study on one of the Top 5 Network Manager operational safety priorities for 2013 – "Risk of operation without transponder or with a dysfunctional one".
- To serve as a reference for the Network actors in case they undertake operational safety analysis and improvement activities regarding the risk of the operation of an aircraft without a transponder or with a dysfunctional one.

1.2 What are the Network Manager Top 5 ATM Operational Safety Priorities for 2013?

Risk of operation without transponder or with a dysfunctional one	Operations without transponder or with a dysfunctional one constitute a single threat with a potential of "passing" through all the existing safety barriers up to "see and avoid".
Landing without ATC clearance	For various reasons, aircraft sometimes land without ATC clearance resulting in Runway Incursions that are often only resolved by 'providence'.
Detection of occupied runway	Some Runway Incursion incidents could have been prevented if controllers had had better means to detect that the runway was occupied at the time of issuing clearance to the next aircraft to use the runway.
"Blind spot" - inefficient conflict detection with the closest aircraft	Loss of separation "Blind Spot" events are typically characterised by the controller not detecting a conflict with the closest aircraft. They usually occur after a descent clearance and in the context of a rapidly developing situation – often when the conflicting aircraft are 1000ft and 15 nm apart.
Conflict detection with adjacent sectors	Losses of Separation in the En-Route environment sometimes involve "inadequate coordination" of clearance with an adjacent sector. These typically involve either an early (premature) transfer of control to or from the neighbouring sector.

1.3 How did we identify the 'Top 5'?

The Network Manager identifies Network safety issues to enable aviation stakeholders to mitigate existing hazards and anticipate new operational risks

Our ultimate goal is to keep the Network safe and able to increase its capacity and efficiency.

The EUROCONTROL Safety Improvement Sub-Group (SISG), reporting to the EUROCONTROL Safety Team, was tasked to identify the Top 5 ATM Operational Safety Priorities. In 2012, the SISG followed a structured two-step process of operational safety prioritisation. Firstly SISG identified a list of priority areas.

The first step was to define broad priority areas for further prioritisation

The agreed list contains work priority areas addressing operational threats, safety precursors or undesired safety outcomes. The list includes:

- Airspace Infringement
- Runway Incursion
- Loss of Separation
- ATC sector overloads
- Level Bust
- Severe Weather Risk
- Air Ground communications
- Runway Excursion

The list of agreed priority areas contains issues that are too broad to be a part of a focussed work program. There was a need to get more "granularity" and select some of the areas for a detailed review. Based on the availability of reliable safety information, two of the risk areas were selected for detailed review:

- "Runway Incursion" and
- "Loss of Separation En-Route".

The review was performed during summer 2012 and involved a series of dedicated workshops with 6 ANSPs, representing a large part of European air traffic.

The second step was a detailed review with SAFMAPS.

Comprehensive barrier models – Safety Functions Maps (SAFMAPs) - were developed and populated with representative data from the participating ANSPs. The incident data is for high severity (classified as 'A' and 'B') events, which are on one side thoroughly investigated and on the other side – highly informative because the incident scenarios 'test' the majority of the available safety barriers.

As a result of the SAFMAP analysis the Top 5 priority areas were suggested, agreed by SISG and endorsed by the Safety Team:

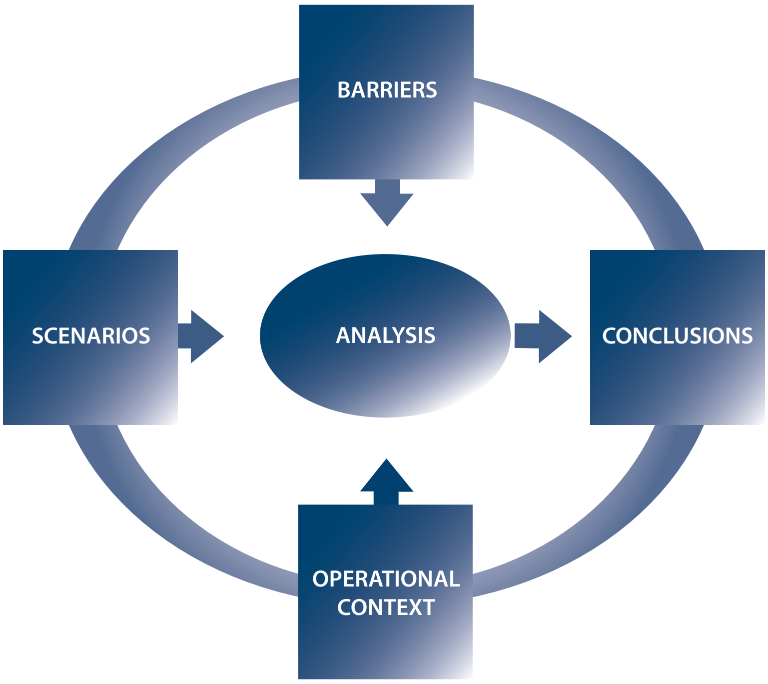
- Risk of operation without transponder or with a dysfunctional one
- Landing without ATC clearance
- Detection of occupied runway
- "Blind spot" – inefficient conflict detection with the closest aircraft
- Conflict detection with adjacent sectors

The priorities were re-confirmed for 2014

The priorities were reviewed by SISG using the same approach of analysing the high severity incident with SAFMAPs. As a result SISG re-confirmed the Top 5 priorities for 2014.

CHAPTER 2 - THE GENERIC PROCESS: OVERVIEW

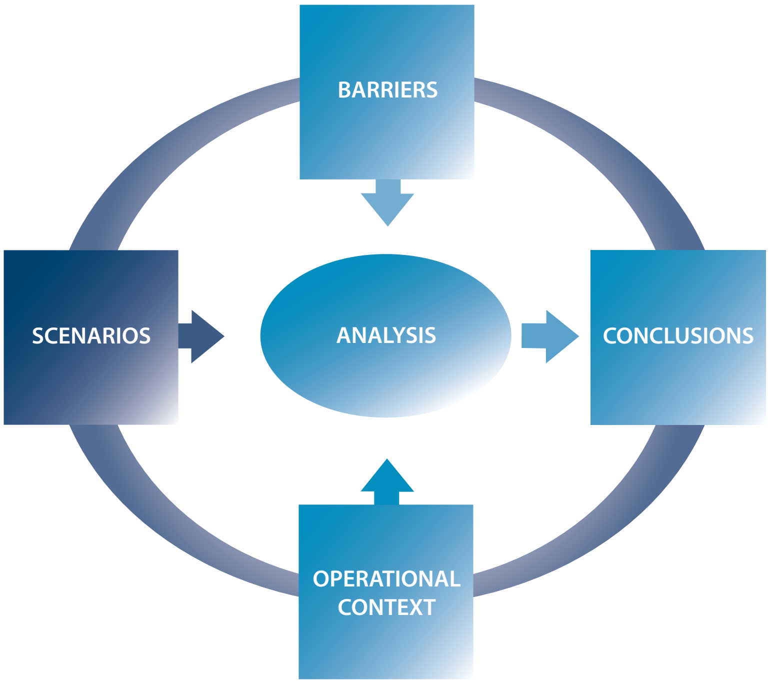
The figure below provides an overview of the generic steps in the Operational Safety Study



This particular "Top 5" study is unique, in that it refers to a series of technical failure modes which lead to an operational event. The generic process is still followed, but the scenarios relate to the specific failure modes of a transponder and the impact on the various operational risk controls (barriers) applicable for an ATS provider.

The barrier analysis then looks at how these risk controls can be repaired, reinforced, or whether new barriers can be identified. An assessment of the effectiveness of these risk controls is carried out and presented in a matrix, with a series of recommendations and conclusions drawn from the results.

CHAPTER 3 - GENERIC SCENARIOS



3.1 How should generic operational scenarios be defined?

Combination of top-down and bottom-up approaches

Generic operational scenarios are used to help reduce the complexity of the subsequent analysis. Scenario definition is by "story telling", specific to help assess the effectiveness of the proposed safety barriers and generic enough to keep their number relatively small. The scenarios draw upon two sources of information:

- A systematic analytical de-construction of each failure mode and its impact on the operational uses of surveillance (transponder-based) information. This is based on all theoretically possible combinations of scenario (1) failure modes, (2) mechanisms (impacts on the barrier model) and (3) outcomes.
- A review of the publicly available information from investigation reports of accidents and serious incidents investigated following the provisions of ICAO Annex 13, and confidentially provided data in respect of less significant incidents.

3.2 Analytical deconstruction of operational scenarios

Scenario Sources

Transponders failure can occur from a number of reasons. These can include incorrect input data, electrical faults, and simple communication problems, such as a bit flip.

The cause of the failure of the transponder is outside of the scope of this report. The report focuses on the different types of failure and ways these can be detected and mitigated against.

Importantly, this study does not aim to repeat the other reports looking at the controller's ability to detect and resolve conflicts operationally (e.g. blind spot). The operational barriers, non-specific to a transponder failure, are dealt with in those studies. It is recommended that integration of the conclusions is carried out in a future step to give a full picture of the interactions at equipment, human and procedural level.

Failure Element

Four potential transponder information failures have been identified. This report will review the failures of:

- Mode A code only (Aircraft Identifier)
- Mode C information only (Altitude data)
- Mode S 24-bit address only
- Total failure (A, C & S)

Note that because the study focuses on transponder generated issues, the loss or corruption of position information derived by the Secondary Surveillance Radar has not yet been considered. Of course, position could be lost as a knock-on effect of the loss of all data, or in some cases, through a dropped track.

Given the information elements above, there are a number of failure types (characteristics) which have been seen. These include:

Failure Type

- Loss
- Intermittent
- Corrupted
- Duplicated

Failure types are only applicable to certain failure elements. For example, it is non-logical to have "duplicated Mode C".

Full definitions of each type are shown below.

Scenario Environment

The scenarios will look at two environments:

- The Terminal Control Area (TMA), and
- En-route.

A number of operational contexts are then applied to understand the effectiveness of various barriers. These are summarised in Section 5.

Possible Failure Modes

This gives a number of possible failure modes, summarised in Table 3 1.

	Type:			
Element:	**Loss**	**Intermittent**	**Corrupt**	**Duplicated**
Mode 3/A code only	A1	A2	A3	A4
Mode C only	C1	C2	C3	
Mode S 24 bit adress only	S1	S2	S3	S4
Total failure	T1	T2		

3.3 Selection of specific failure modes for further analysis

The potential failure modes have been down-selected in this analysis to focus on areas where operational examples exist through incident reports, or where expert judgement assessed them as leading to the greatest risk. These down-selected failure modes were presented to the SISG in 2013, and the initial list was agreed. The failure modes not analysed in this version could be assessed in future iterations.

The specific failure modes addressed are:

- Total loss of transponder (T1)
- Corrupted Mode A (A3)
- Intermittent Mode C (C2)
- Duplicated Mode S (S4)

Definitions for each of the failure modes are as follows:

- Total loss: There is no transponder-based data received at the CWP. For the purposes of this study, it is assumed that the loss is maintained through an entire sector or multiple sectors.
- Corrupted Mode A: Information received at the CWP is incorrect, primarily due to an error input into the transponder, or the processing and transmission of the Mode A code by the transponder. Whilst errors leading to an incorrect Mode A code could occur in the ground ATM system, they are not the focus of this study.
- Intermittent Mode C: Transponder-based altitude information is lost from the CWP for short periods of time, long enough to cause the end effect (risk), for example 1-2 minutes. This is assumed to be due to transponder-based errors or detection failures, rather than ground system processing failures.
- Duplicated Mode S 24-bit address: Two aircraft are operating with the same aircraft ID, specifically the same Mode S 24-bit address. The aircraft would usually need to be proximate for this to have a significant safety impact e.g. within the same sector or adjoining sectors – although it is recognised that the resulting potentially unexpected trajectory may cause confusion even where aircraft are not proximate.

These failure modes are then used to derive the scenarios below.

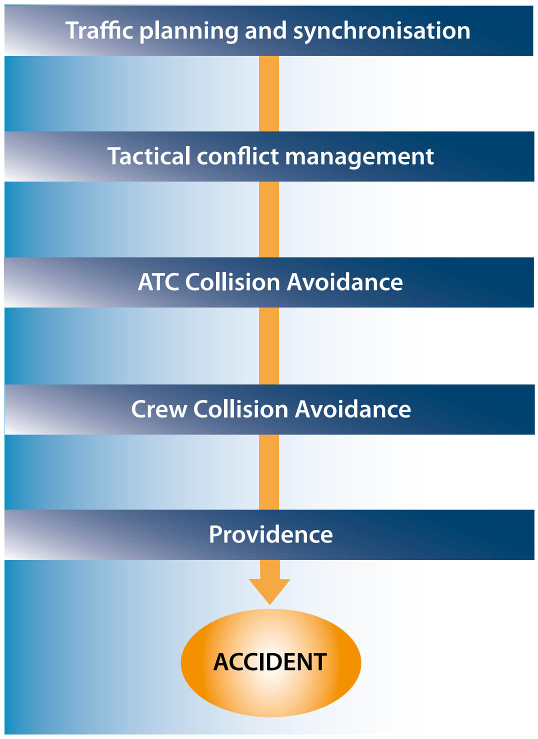
***Note:** whilst earlier versions of this study differentiated controller detection within the scenarios, it was felt that this was better examined within the barriers (and effectiveness) themselves. Therefore, all scenarios are now independent of controller detection.*

3.4 Assessing the effect using a generic barrier model

In order to assess the effect of the specific failures modes outlined above, a generic barrier model has been used. This model outlines the operational risk controls which exist in Air Traffic Services provision, and is based on that used for the SAFMAP developments. Seven high level barriers are identified, within which several detailed tools or techniques may exist.

Since this is an operational safety study, and transponder failure is a technical issue, all the barriers examined below tend to be recovery-based rather than preventative i.e. they mitigate the consequence of the failure, rather than stopping the failure occurring in the first place. For preventative barriers for transponder failures or dysfunction, appropriate design, maintenance and interoperability are required.

Firstly, provided below is a graphical representation of the Barrier Model, followed by a table explaining each element in more detail.



Design and strategic planning	The scope of this barrier has been widened from purely operational airspace design, and now includes other design aspects (such as the system), since many barriers are only effective if designed and calibrated appropriately. Design and planning does not directly use any input from transponders. Nevertheless, the ability of the ANSP to design and plan to cope with potential failures is considered, since the barrier is important in preventing eventual operational risk impacts. This may include controller training for unusual circumstances and emergencies, with practice in synthetic environments (e.g. simulators) to remain current for events that rarely occur in the live environment. Also included in this element is the design of technical systems and procedures; this may include standardisation efforts for airborne or ground tools.
Demand and capacity balancing	Demand and capacity balancing, including multi-sector planning, is based upon schedules and flight plan data as opposed to track data. Therefore, the impact of an incorrectly operating transponder on flow control and sector loading is classified as negligible. Again, the effectiveness of DCB barriers may assist in mitigating the consequences of the transponder failure or dysfunction.

Traffic planning and synchronisation

Traffic planning and synchronising uses transponder-based information to update predictive tools and form tracks, so would be negatively impacted by a transponder that is not operating correctly. However, as traffic planning and synchronisation is a prediction tool, an error at this stage is unlikely to lead directly to a loss of separation. Nevertheless, it may impact trusted predictive tools such as MTCD and AMAN, causing knock-on consequences. It may also impact the planning controller's task of detecting future conflicts using planned trajectories, leading to incorrect or no action taken to resolve the potential conflict at an early (strategic) stage. The traffic planning and synchronisation barriers will have a role in mitigating the consequences of a transponder failure, particularly due to the use of (static or dynamic) flight plan data.

New technological developments (making more use of predicted trajectories) are likely to increase the criticality of this barrier in the overall system.

Tactical conflict management

Tactical conflict management is the first phase of this barrier model where executive controllers are using, and basing decisions on, transponder data in real time for separation assurance (conflict management). This may be done in addition to deconfliction by flight strips, with incorrect transponder data leading to confusion and inappropriate instructions. Transponder functionality may impact the ability of controller tools to warn the controller regarding the conflict. At this phase any inaccuracies or loss in the transponder data could lead directly to a loss of separation, since the controller's ability to detect and resolve the conflict may be degraded. Since the tactical conflict management barriers will in some form use transponder-based data, the effectiveness of these barriers in mitigating the consequences of a transponder failure may not be great.

ATC collision avoidance

ATC collision avoidance refers to the ground-based (executive controller and tools) techniques to ensure imminent potential collisions are avoided. It may include alerts from safety nets such as Short Term Conflict Alert, and the executive controller's treatment of the alert. It also includes situations where no alert exists, but the controller still provides urgent instructions (e.g. turn left, climb, descend) to avoid a collision. Any inaccuracies or problems with transponder data at this phase could have serious consequences on the effectiveness of the barriers. The ability of the barriers to mitigate any consequences of a transponder failure would be minimal.

Crew collision avoidance

Crew collision avoidance includes manual and tool-based support. Collision Avoidance Systems[1] are the prime barrier at this stage. It is a safety net, requiring immediate action by the flight crew in response to a Resolution Advisory to avoid a potential collision, such that a minimum of 500ft separation is assured if the guidance is followed.

If the transponder data is lost or dysfunctional, this will have an immediate impact upon e.g. ACAS, which utilises this data in various forms to form the Traffic Advisories and Resolution Advisories. This could especially be the case for corrupt data, since ACAS actions are prioritised over ATC, so incorrect advisories are particularly concerning. If the transponder data is lost, Collision Avoidance Systems (CAS) will not function. Likewise, if the data emanating from a threat aircraft is intermittent or corrupt, there is the possibility that the CAS will filter out the threat aircraft and no advisory will be made.

The pilot may still be able to resort to "see-and-avoid" (i.e. out the window situational awareness).

Providence

Providence refers to the non-designed factors which prevent a collision (i.e. it "just happened" that the aircraft were not in the same place at exactly the same time).

3.5 Scenario derivation

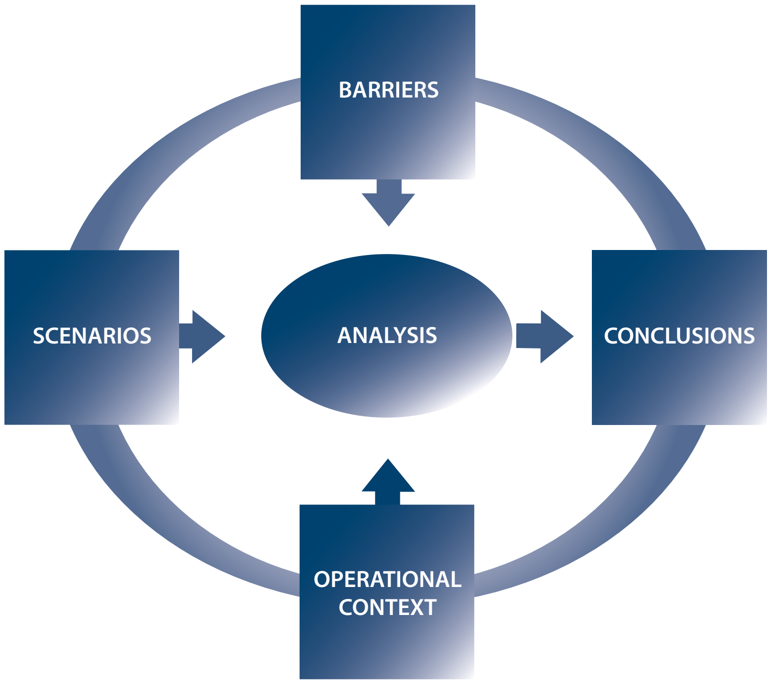
The Scenario derivation section for each failure mode provides an assessment of how each failure mode would affect existing barriers. It provides an explanation of how the barrier is reduced or nullified. It then uses this information to derive scenarios (short generic descriptions of chains of events) based on each failure mode.

In most cases, the severity of the potential scenarios is aligned to their position in the barrier model: on their own, traffic planning failures will generally lead to minor losses of separation, due to the presence of other barriers. If some of the later barriers fail, major losses of separation or potential collisions may result – the scenario is then characterised operationally as an inability to provide collision avoidance.

[1] Collision Avoidance Systems include TCAS I, ACAS II and other systems used by e.g. General Aviation.

CHAPTER 4 - SPECIFIC METHODOLOGY ASPECTS

The figure below provides an overview of the generic steps in the Operational Safety Study



4.1 Assessing the barriers impacted

Barriers

The barriers included in this risk analysis have been identified as possible ways that the consequences arising from various failure types of the transponder could be mitigated. This includes mitigations on first contact, such as validation of Mode A and Mode C information. As noted above, the prevention of transponder failure or dysfunction is outside the scope of this operational safety study, since it looks at detailed technical equipment issues.

The inclusion of the barriers does not imply that they are relevant to all situations and neither does it imply that their adoption by aircraft operators or ANSPs as a group would necessarily be appropriate.

The barriers are arranged by failure mode to show the causal links, then summarised at the end of the section. The providence and end result in the barrier model are not shown, as they are not relevant.

Repairable barriers

The concept of repairable barriers is introduced below. This is where the failure mode of a transponder has reduced the effectiveness of a barrier in the system, but that certain actions may be able to "repair" the effectiveness of this barrier. *For example, re-programming the Medium Term Conflict Detection function such that if Mode C information is lost, it does not assume the aircraft is at all heights and subsequently provide nuisance alerts*.

4.2 Operational context

Operational context

In many cases across Europe, the operational context for a busy sector is similar. This study assumes that the level of traffic and complexity of sector does not act as a differentiator for the effectiveness of the barriers identified. Likewise, the weather conditions may impact the ability to see-and-avoid, but only in terms of the general effectiveness of that barrier.

The following contextual elements may act as a variable on the effectiveness of the mitigating barriers identified above.

- Type of sector: Approach sectors may make more use of surveillance information, whilst en-route sectors may rely more on flight plan data to de-conflict aircraft.
- Availability of Primary Surveillance Radar: PSR may not be available in all sectors, particularly in en-route operations.

In general, controlled airspace is assumed for this study. Nevertheless, the proximity of uncontrolled airspace and potential impact from non-transponding aircraft may change the effectiveness of certain barriers.

4.3 Methodology for barrier effectiveness

Assessing barrier effectiveness

The effectiveness of each of the identified barriers is assessed for each scenario. Where the effectiveness is dependent on operational context, this is noted. If the barrier is not applicable for the scenario (e.g. it is only specific to a unique failure mode), the box is left blank (white).

Green denotes a high barrier effectiveness (i.e. prevents the loss of separation almost every time).

Yellow denotes a dependent barrier effectiveness (i.e. only effective some of the time).

Red denotes a low barrier effectiveness (i.e. not effective for a particular scenario).

White denotes a non-applicable barrier (i.e. cannot judge effectiveness, as it is in no way relevant for the failure mode).

CHAPTER 5 - FAILURE MODE T1: TOTAL LOSS

5.1 Scenario derivation (failure mode T1: total loss of transponder)

This set of scenarios assumes a total loss of the transponder, with no information regarding Mode A, C or S data reaching the controller or ground tools. This includes underlying technical failures within the avionics, the transponder being inadvertently switched off, or the transponder failing to deliver a reply (for whatever reason). Deliberate switching off of the transponder is considered to be out of scope, as it does not involve safety failure but is an illegal act.

Barrier Model	Barriers Affected	Possible scenarios
Design and strategic planning	None	None
Demand and capacity balancing	None	None
Traffic planning and synchronisation	**Controller tools** - A complete loss of track would severely impact controller tools. This would affect tools such as MTCD and AMAN, particularly where the tools require the updating of flight plan based information with track information. The main impact is that the information in the tools is out-of-date and less reliable. In some high complexity environments, the tools may be unusable. The risk may be that an inappropriate plan is generated, leading to higher workload during the execution phase, and potential loss of separation as a result. **ATCO** - Loss of the surveillance track at the CWP level can cause loss of real time situational awareness of the planning controller. This results in a reliance on flight plan data and voice reporting to build a situation picture.	**T1-S1** - Loss of separation due loss of all track information on one aircraft causing inappropriate planning.
Tactical conflict management	**Controller tools** - tools that rely on secondary surveillance information would not operate; for example, all conformance/adherence monitoring tools (to the flight plan data), covering route and height. **ATCO** - The ability of the ATCO to provide tactical clearances and instructions would be severely impacted by the loss of real-time transponder-based surveillance information at the CWP, including the track, altitude and identity. This will usually lead to significant additional workload, since one aircraft will be controlled procedurally. The detectability of the aircraft may also be compromised, particularly if sector handover procedures are not effective.	**T1-S2** - Loss of separation due loss of all track information on one aircraft impacting tactical control.
ATC collision avoidance	**Ground-based safety nets** - The safety nets would not operate without real-time track information derived from the transponder. No alerts would be issued. **ATCO** - The ability of the ATCO to provide instructions for collision avoidance would be compromised by the loss of track and label surveillance data. The barrier would be almost ineffective using the CWP. Some effectiveness remains from voice reporting and procedural clearances (e.g. stop descent, climb not above…)	**T1-S2** - Loss of separation due loss of all track information on one aircraft impacting tactical control.
Crew collision avoidance	**Airborne tools** - ACAS and other CAS would not operate. No RA (or TA) would be given if the transponder was not operational on the aircraft involved.	
Providence	n/a	

5.2 List of resultant scenarios (failure mode T1)

	ID	Scenario description
Scenarios arising from transponder failure or dysfunction (XX-YY denotes failure mode and scenario ID)	T1-S1	Loss of separation due loss of all track information on one aircraft causing inappropriate planning
	T1-S2	Loss of separation due loss of all track information on one aircraft impacting tactical control

Following further analysis of the operational events, it is recommended that these scenarios are re-visited to understand the ones highlighting the greatest risk to operations.

5.3 Barriers to mitigate total loss (failure mode T1)

Barrier Model	Repairable barriers	Existing or new barriers
Design and strategic planning	**MB04: Application of transponder validation procedures on first contact** - On first radar contact with an aircraft, the ATCO should validate the transponder function, including e.g. operation, Mode A code and Mode C operation. This could include on start-up or departure. The thoroughness of completion of this procedure could be improved for certain sectors or environments.	**MB01: Airspace design gives positive separation** - This includes the systematic separation of aircraft using de-conflicted RNAV/RNP based routes. Free-route airspace may reduce the effectiveness of this barrier. **MB02: Procedure design for transponder malfunction** - Procedures can be defined and implemented for transponder loss. If primary radar is available, flight plan correlation should be maintained. If not (e.g. in the subsequent sector), procedures may vary, and may include military escort or in extremis refusing the aircraft entry or returning the aircraft to an airfield. Procedures may also include assistance of the supervisor or planner. The aircraft should also be cleared out of RVSM airspace. **MB03: Appropriate ATC system design and calibration** - In the case of total loss of a transponder, design and calibration of an effective tool for alerting ATCOs in the event of: a dropped track (across one or more sectors); or a non-correlated track (i.e. without flight plan data); or a track without secondary surveillance information (i.e. primary only, but still correlated).
Demand and capacity balancing	None	**MB08: Sector capacity planning** - Ensuring that the number of aircraft the controller can handle if a track is lost is appropriate i.e. ensuring that sector capacity limits are appropriate by "sensitivity analysis" of track drop scenarios.
Traffic planning and synchronisation	**MB09: More effective flight plan data** - This is the improvement of controller prediction tools to give more accurate performance when using only flight plan data (even if designed for "dynamic" updates using track data), for example when manually updated by the ATCO. The ATCO also requires clear procedures and training for manually inputting and updating flight plan data for the most effective use during a loss of track scenario. This also reflects the general mitigation of appropriate use of flight plan data in the event of a loss of track for both ATCO tools and the controller.	**MB10: Use of voice reporting** - Use of voice reporting is particularly relevant as a barrier during sector handover, when defined procedures may be followed. If silent handover is used, this barrier may not be applicable. If the ATCO has detected the track drop/loss, it may also be used within a sector for improved situational awareness.

Tactical conflict management	**MB12: Regular scanning by ATCO** - The controller should maintain an effective regular scan (e.g. to be able to detect non-alerted dropped tracks), rather than solely rely on "first contact" procedures. This also applies to detection of incorrect aircraft being given a clearance (due invalid correlation). There is some debate as to the effectiveness of this barrier, since in en-route controlled airspace, strip management is traditionally the primary means of deconfliction. **MB13: Use of primary radar data** If available, this can be used to maintain a correlated track to support tactical conflict management in the event of a loss of secondary surveillance information. Note that this may be assisted by cooperation with the military, allowing the sharing of primary radar data. **MB15: Crew detection of transponder failure** Existing alerts are incorporated on most commercial aircraft, but may not be immediately noticeable in flight (e.g. Embraer Legacy-B737 accident in Brazil). Fail-safe indications of transponder failures or malfunctions, if detected, should be given to the flight crew.	**MB14: Alert for change in track status** - Any change of track status should be alerted to the controller. This includes the loss of transponder information (i.e. primary only, or flight plan track), or the total loss of a track. Alerting improves the detectability. This is also applicable for multiple sectors, i.e. also alerting the next sector the aircraft is due to enter, and may be used at the planning stage. **MB10: Use of voice reporting** remains important to resolve conflicts and separate traffic, as long as the ATCO is aware of the two aircraft.
ATC collision avoidance	None	**MB16: Collision avoidance via procedural control** - Use of altitude information acquired through voice reporting to achieve vertical separation.
Crew collision avoidance	None	**MB19: See and avoid practiced by aircraft** - This could include the executive controller actively encouraging the aircraft to see-and-avoid through informing them of the track loss situation (if detected) and notifying them of proximate aircraft's approximate or last known position. The effectiveness of see-and-avoid for Commercial Air Transport is not thought to be high, particularly where there is no indication of the other aircraft through other means (e.g. via TCAS display or through party-line situational awareness).

5.4 Matrix of scenarios and barrier effectiveness (failure mode T1)

- Green denotes a high barrier effectiveness (i.e. prevents the loss of separation almost every time).
- Yellow denotes a dependent barrier effectiveness (i.e. only effective some of the time).
- Red denotes a low barrier effectiveness (i.e. not effective for a particular scenario).
- White denotes a non-applicable barrier (i.e. cannot judge effectiveness, as it is in no way relevant for the failure mode).

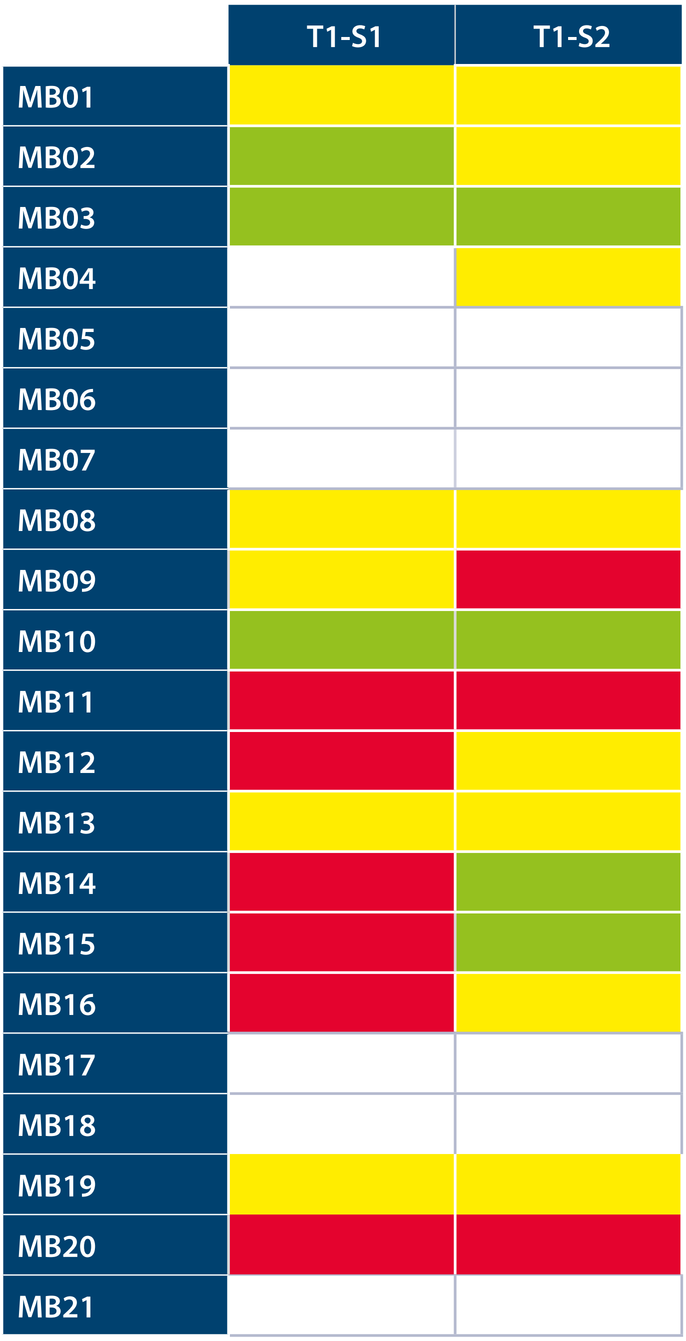
OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB01: Airspace design gives positive separation	**MB02:** Procedure design for transponder malfunction	**MB03:** Appropriate ATC system design and calibration	**MB04:** Application of transponder validation procedures on first contact	**MB05:** Weighted use of all aircraft ID sources in ATC system
T1-S1 - Loss of separation due loss of all track information on one aircraft causing inappropriate planning	Assuming design is utilised (e.g. not free-route)		Aids ATCO detection	n/a	n/a
T1-S2 - Loss of separation due loss of all track information on one aircraft impacting tactical control	Assuming design is utilised (e.g. not free-route)	If transponder failure detected by ATCO	Aids ATCO detection	If transponder failure is pre-flight or at first contact	n/a

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB06: Anomaly reporting and effective response	**MB07:** Maintenance procedures for transponder	**MB08:** Sector capacity planning	**MB09:** More effective flight plan data	**MB10:** Use of voice reporting
T1-S1 - Loss of separation due loss of all track information on one aircraft causing inappropriate planning	n/a	n/a	Mitigates loss of separation due workload	More effective trajectory prediction tools	Improves detectability
T1-S2 - Loss of separation due loss of all track information on one aircraft impacting tactical control	n/a	n/a	Mitigates loss of separation due workload	Unlikely to be effective tactically	Improves detectability

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB11: Sector-sector coordination	**MB12:** Regular scanning by ATCO	**MB13:** Use of primary radar data	**MB14:** Alert for change in track status	**MB15:** Crew detection of transponder failure
T1-S1 - Loss of separation due loss of all track information on one aircraft causing inappropriate planning	No impact	No impact	Effective when primary present	No impact	No impact on planning
T1-S2 - Loss of separation due loss of all track information on one aircraft impacting tactical control	No impact	Improves detection possibility	Effective when primary present	Earlier awareness of dropped track, aiding detection and response	Possible earlier detection than by ATCO

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS					
	MB16: Collision avoidance via procedural control	**MB17:** Controller advisory to other aircraft	**MB18:** Recalibration of ground-based safety nets	**MB19:** See-and-avoid practiced by aircraft	**MB20:** Collision avoidance system	**MB21:** Improvement of collision avoidance system behaviours
T1-S1 - Loss of separation due loss of all track information on one aircraft causing inappropriate planning	No impact on planning	n/a	n/a	Limited effectiveness for CAT	If loss due to transponder failure, CAS do not operate	n/a
T1-S2 - Loss of separation due loss of all track information on one aircraft impacting tactical control	If detected by ATCO	n/a	n/a	Limited effectiveness for CAT	If loss due to transponder failure, CAS do not operate	n/a

5.5 Summary of mitigating barriers (failure mode T1)



CHAPTER 6 - FAILURE MODES A, S & C

6.1 Summary of mitigating barriers (failure mode T1)

6.1.1 Traffic forecast

Failure mode A3 assumes that the Mode A code has been corrupted due to errors in the transponder or data registers. Pilot input of incorrect Mode A is included in another failure mode (not analysed). The Mode A code could be corrupt during the entire duration of the flight (e.g. a software error in the transponder, undetected on first contact) or could become corrupted during flight.

It is important to note that a corrupted Mode A may increase the likelihood of a duplicate Mode A scenario occurring at the same time.

The impact of a corrupt Mode A code will be highly dependent on the ATM system in use. For systems which use "code-callsign correlation", there may be a reliance on the code to ensure correct correlation with the flight plan, thus leading to more serious consequences if the code is corrupt. Other systems use a weighting factor, particularly when the 24-bit aircraft address is present – in these cases, the Mode A code corruption may not have a discernable impact as the system would correlate and track using the 24-bit aircraft address primarily.

Barrier Model	Barriers Affected	Possible scenarios
Design and strategic planning	None	None
Demand and capacity balancing	None	None
Traffic planning and synchronisation	**Controller tools** - corrupt Mode A code may impact controller tools used for planning and synchronisation such as MTCD or AMAN/DMAN. A severe impact is unlikely since the tools primarily use flight plan data, but confusion in the system arising from duplicated Mode A codes may lead to track swaps and generate inaccurate predictions. **ATCO** - Controller confusion could result from non-valid identity being shown (or no identity information, depending on the system), and during a sequencing (synchronisation) task, this could lead to overloading or the ATCO calculating an inappropriate solution.	**A3-S1** - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning. **A3-S2** - Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning. **A3-S3** - Loss of separation due non-valid identity displayed due corrupted Mode A code causing inappropriate planning.
Tactical conflict management	**Controller tools** - Controller tools reliant on effective aircraft identity and flight plan correlation could be impacted by a corrupt Mode A code. This includes tools which check adherence (conformance) with a cleared route. **ATCO** - A corrupt Mode A code could increase a controller's workload, since it may lead to a missing aircraft ID or an incorrect aircraft ID on the CWP. In extremis, this could lead to the incorrect aircraft receiving an instruction or clearance, potentially leading to a loss of separation.	**A3-S4** - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code impacting tactical control. **A3-S5** - Loss of separation due track swap between two aircraft due corrupted Mode A code leading to wrong aircraft receiving instruction. **A3-S6** - Loss of separation due non-valid identity displayed due corrupted Mode A code leading to additional workload.
ATC collision avoidance	**ATCO** - in common with the tactical conflict management barriers, a loss or corruption of aircraft ID may lead to reduced effectiveness of the ATCO providing collision avoidance instructions or clearances. It is not thought that safety nets would be impacted, except in the case where the Mode A code is corrupted to become a code which is excluded by the safety nets (e.g. VFR or military codes).	
Crew collision avoidance	No impact – ACAS and other CAS are not reliant on the Mode A code.	

6.1.2 Scenarios for failure mode C2: Intermittent Mode C

Failure mode C2 assumes that the Mode C signal is intermittent. This factors situations including technical failures within the avionics and radar detection failures. An intermittent mode C could lead to the following problems at the Controllers Working Position, dependent on the exact ATM system processing:

- Complete loss of track (track dropped as system considers it invalid, or when the aircraft is over an aerodrome and the system assumes the track has been terminated as if the aircraft has landed);
- Normal display of track, but with no altitude information in the label;
- Aircraft assumed to be at all heights in the system, creating blocked cylinder of airspace at all flight levels (and thus nuisance alerts).

The table below outlines the barriers impacted by the failure mode C2, and defines potential operational scenarios which may result.

Barrier Model	Barriers Affected	Possible scenarios
Design and strategic planning	None	
Demand and capacity balancing	None	
Traffic planning and synchronisation	**Controller tools** - Tools such as Medium Term Conflict Detection (MTCD) may be affected by an intermittent Mode C failure. Some MTCD designs use a mixture of planned and track data to carry out periodical updates of the planned trajectory – thus altitude data being out of date may have an impact on the accuracy of the conflict detection functions, leading to inappropriate planning and potential extra workload during the execution phase. In limited cases, it has been seen that the MTCD tool assumes the aircraft is at all altitudes if it loses altitude information - this leads to many nuisance alerts.	**C2-S1** - Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload.
Tactical conflict management	**ATCO** - Exact impact is dependent on the local ATM system (see above). If altitude is dropped from the label when intermittent, controller is likely to notice before issuing any instructions or clearances to the aircraft in question. The Mode A would be retained as an identifier, potentially squawking 0000 to indicate transponder malfunction. Having detected the issue, flight progress strips (electronic or paper) or voice reporting of altitude may help the controller to undertake the tactical conflict management task. If the altitude is latent (i.e. shown as out-of-date, e.g. coasted), this may lead to inappropriate instructions or clearances being given. **Primary Radar Track** may be shown on the screen with no SSR track (if the system validates the secondary surveillance based track as invalid due to the intermittent Mode C information); this would alert the controller to a lost track. This is dependent on the system. **Controller tools** - Adherence or conformance monitoring tools may be able to monitor against a) cleared level and b) height of restricted areas, to ensure a flight is proceeding according to clearances and agreed flight plans. These barriers' effective-ness may be impacted by intermittent Mode C.	**C2-S1** - Loss of separation due intermittent Mode C leading to incorrect altitude data **C2-S1** - Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload
ATC collision avoidance	**Ground-based safety nets** using intermittent Mode C will lead to either too many false alerts, or missed alerts. Also, if an alert is generated correctly, and Mode C is lost, the alert may terminate too early, leading to incorrect action on behalf of the controller. **ATCO** - the controller's ability to provide accurate collision avoidance instructions in the vertical dimension would be hindered by intermittent altitude data, particularly if it is shown as incorrect on the CWP.	
Crew collision avoidance	Airborne safety nets – ACAS II will be able to form a TA without Mode C, but not an RA. If the Mode C is intermittent, RAs may end prematurely or be generated with a delay. Other collision avoidance system performance may vary.	

6.1.3 Scenarios for failure mode S4: Duplicated Mode S 24-bit address

Failure mode S4 assumes that duplicated Mode S 24-bit addresses are sent. Whilst this may seem unlikely, the block allocation of addresses to aircraft within a State means that occasionally this does occur when two of these aircraft are within the same airspace, particularly with newly delivered or registered aircraft. Another cause might be the transfer of a transponder from one aircraft to another, without re-setting addresses (where these are integrated with the transponder box). This also includes technical failures within the avionics.

The impact of the duplicated Mode S 24-bit address would depend on the local ATM system. A track may be dropped (as it assumed to be a "ghost track" even if two valid flight plans exist), never initiated, or swapped. The ATM system may also have validation functions that will alert the controller to the issue, for example noting that the track of one of the aircraft does not conform to the flight plan route, or that no correlation has taken place. If the track is never initiated, for example when entering into coverage of a new system, the track may still appear on the adjacent system's sector.

Barrier Model	Barriers Affected	Possible scenarios
Design and strategic planning	None	
Demand and capacity balancing	None	
Traffic planning and synchronisation	**Controller tools** - If a track is dropped or not initiated, the controller tools could be less effective, having to rely on remaining flight plan data (and/or manual inputs). The correlation of tracks to flight plan data may be impacted. **ATCO** - A duplicated 24-bit address could lead to ATCO's performing inappropriate planning and sequencing tasks, particularly in the case of a swapped track situation. If the information used to plan or sequence is incorrect the solution is likely to be wrong.	**S4-S1** - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning. **S4-S2** - Loss of separation due duplicated Mode S 24-bit address causing detected dropped track, leading to additional workload.
Tactical conflict management	**Controller tools** - Ineffectiveness of existing tools due to either one track being filtered, never initiated, or track swap. This includes non-correlation with flight plan data. This would affect tools such as conformance/adherence monitoring. **ATCO** - All potential outcomes will reduce the effectiveness of the controller's tactical conflict management. The impact of lost tracks may depend on the detectability (system monitoring/validation and alerting), whilst the track swap may lead to incorrect clearances and instructions being given.	**S4-S2** - Loss of separation due duplicated Mode S 24-bit address causing dropped track. **S4-S3** - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction.
ATC collision avoidance	**Safety nets** - Ground-based safety nets will be impacted by a duplicated 24-bit address. A track swap would still allow warnings and alerts to be given, but potentially cause confusion over the correct course of action. A dropped (lost) track at system level (prior to input to the safety net) could render the safety nets ineffective for that aircraft and others in the vicinity. **ATCO** - the controller's ability to provide instructions regarding collision avoidance would be reduced if the track was dropped or swapped. In many cases, the barrier would be rendered ineffective.	**S4-S2** - Loss of separation due duplicated Mode S 24-bit address causing dropped track. **S4-S3** - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction.
Crew collision avoidance	**Airborne tools** - Collision Avoidance Systems, e.g. ACAS, are likely to be compromised where identical 24-bit addresses are present. If another aircraft has the same 24-bit address as ownship, the track will be filtered. Where two other aircraft in the airspace have the same 24-bit address, the aircraft furthest from ownship would be suppressed (i.e. no TAs or RAs).	

6.2 List of resultant scenarios (failure modes A, S and C)

The full list of operational scenarios defined is shown below. In each case, it is recognised that a loss of separation may lead to a more severe outcome (i.e. accident). Nevertheless, for the purposes of this report, identifying the loss of separation is adequate since the resultant barrier effectiveness is still applicable.

In certain circumstances, the dysfunctional transponder could impact the probability of a different end risk; that of Controlled Flight Into Terrain (CFIT). This would occur if the controller gave the wrong aircraft a clearance, taking it below the MSA (Minimum Safe Altitude) and towards terrain. Modern commercial aircraft systems should render the likelihood of this negligible, since all aircraft with Flight Management Systems would contain mitigations in case of vectoring below MSA. As a last resort, the Ground Proximity Warning Systems (airborne) and Minimum Safe Altitude Warning controller safety nets should prevent an accident.

The number and detail of scenarios may seem excessive for this operational safety study. However, as the transponder errors and dysfunctions lead to very specific operational impacts at the CWP level, it was considered useful to highlight the specific "chain of events" as the effective mitigations may differ in each case.

For some scenarios, specific operational events (incidents or occurrence reports) are available to highlight the validity of the scenario. These are described in detail in Appendix A. This is not true for all scenarios – in some cases, expert judgement has been used to derive the feasible scenario.

ID	Scenario description
A3-S1	Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning
A3-S2	Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning
A3-S3	Loss of separation due invalid identity displayed due corrupt Mode A code causing inappropriate planning
A3-S4	Loss of separation due loss of all track information for one aircraft due corrupt Mode A code impacting tactical control
A3-S5	Loss of separation due track swap between two aircraft due corrupt Mode A code leading to wrong aircraft receiving instruction
A3-S6	Loss of separation due invalid identity displayed due corrupt Mode A code leading to additional workload
C2-S1	Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload
C2-S2	Loss of separation due intermittent Mode C leading to incorrect altitude data used
C2-S3	Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload
S4-S1	Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning
S4-S2	Loss of separation due duplicated Mode S 24-bit address causing dropped track
S4-S3	Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction

Following further analysis of the operational events, it is recommended that these scenarios are re-visited to understand the ones highlighting the greatest risk to operations.

6.3 Barriers to mitigate corrupt Mode A code (failure mode A3)

Barrier Model	Repairable barriers	Existing or new barriers
Design and strategic planning	**MB04: Application of transponder validation procedures on first contact** - On first radar contact with an aircraft, the ATCO should validate the transponder function, including e.g. operation, Mode A code and Mode C operation. This could include on start-up or departure. The thoroughness of completion of this procedure could be improved for certain sectors or environments. **MB05: Weighted use of all Aircraft ID sources in ATC system** - Modern ATC systems use a combination of aircraft IDs, primarily Mode A code and Mode S 24-bit address (but also aircraft callsign) to correlate a track. Weightings can be applied per identification element. Implementing this would reduce the likelihood of a corrupt (or duplicated) Mode A code causing a track loss, drop or swap.	**MB01: Airspace design gives positive separation** - This includes the systematic separation of aircraft using de-conflicted RNAV/RNP based routes. Free-route airspace may reduce the effectiveness of this barrier. **MB03: Appropriate ATC system design and calibration** - For a corrupted Mode A code, design and calibration of effective tools for alerting ATCOs in the event of: a dropped track (across one or more sectors); or a non-correlated track (i.e. without flight plan data); or a duplicated (split) track. Further effective alerts for when a Mode A code is detected as being changed or duplicated.
Demand and capacity balancing	None	**MB08: Sector capacity planning** - Ensuring that the number of aircraft the controller can handle if a track is lost is appropriate i.e. ensuring that sector capacity limits are appropriate by "sensitivity analysis" of track drop scenarios.
Traffic planning and synchronisation	None	**MB11: Sector-sector coordination** - The upstream sector may not have duplicated Mode A, and therefore may have correlated tracks, and be able to assist with planning.
Tactical conflict management	**MB12: Regular scanning by ATCO** - The controller should maintain an effective regular scan (e.g. to be able to detect non-alerted dropped tracks), rather than solely rely on "first contact" procedures. This also applies to detection of incorrect aircraft being given a clearance (due invalid correlation). There is some debate as to the effectiveness of this barrier since, in en-route controlled airspace, strip management is traditionally the primary means of deconfliction. **MB13: Use of primary radar data** - If available, this can be used to maintain a correlated track to support tactical conflict management in the event of a loss of secondary surveillance information due corrupt Mode A code. *Note that this may be assisted by cooperation with the military, allowing the sharing of primary radar data.*	**MB14: Alert for change in track status** - Any change of track status should be alerted to the controller. This includes the loss of transponder information (i.e. primary only, or flight plan track), or the total loss of a track. Alerting improves the detectability. This is also applicable for multiple sectors, i.e. also alerting the next sector the aircraft is due to enter.
ATC collision avoidance	None	**MB15: Collision avoidance via procedural control** - Use of altitude information acquired through voice reporting to achieve vertical separation.
Crew collision avoidance	None	**MB18: See and avoid practiced by aircraft** - This could include the executive controller actively encouraging the aircraft to see-and-avoid through informing them of the track loss situation (if detected) and notifying them of proximate aircraft's approximate or last known position. The effectiveness of see-and-avoid for Commercial Air Transport is not thought to be high, particularly where there is no indication of the other aircraft through other means (e.g. via TCAS display or through party-line situational awareness). **MB19: Collision avoidance system** - The airborne Collision Avoidance System (e.g. TCAS) should continue to alert on aircraft with corrupt Mode A codes.

6.4 Barriers to mitigate intermittent Mode C (failure mode C2)

This section presents a number of barriers, ether previously identified barriers that are repairable, or entirely new ones that can be used to mitigate the effect of an aircraft with intermittent Mode C.

Barrier Model	Repairable barriers	Existing/Possible new barriers
Design and strategic planning	**MB04: Application of transponder validation procedures on first contact** - On first radar contact with an aircraft, the ATCO should validate the transponder function, including e.g. operation, Mode A code and Mode C operation. This could include on start-up or departure. The thoroughness of completion of this procedure could be improved for certain sectors or environments. **MB06: Anomaly reporting and effective response** - Ensuring that current procedures on anomaly reporting are effectively followed and actioned.	**MB01: Airspace design gives positive separation** -This includes the systematic separation of aircraft using de-conflicted RNAV/RNP based routes. Free-route airspace may reduce the effectiveness of this barrier. **MB02: Procedure design for transponder malfunction** - Specific procedures should be designed and trained on in the event of intermittent Mode C being detected, for example squawking 0000 for malfunctioning transponder, and the ATCO using cleared flight level inputs to show current level. If Mode C is not available, the aircraft should also be cleared out of RVSM airspace. **MB03: Appropriate ATC system design and calibration** - For intermittent Mode C, this refers to standards, local specification and calibration ensuring the effectiveness of ground-based safety nets (and MTCD) to handle intermittent mode C. The track should not be judged invalid in the event of intermittent Mode C.
Demand and capacity balancing	None	**MB08: Sector capacity planning** - Ensuring that the number of aircraft the controller can handle if a track is lost is appropriate i.e. ensuring that sector capacity limits are appropriate by "sensitivity analysis" of track drop scenarios.
Traffic planning and synchronisation	**MB09: More effective flight plan data** - This includes continued appreciation of the importance of flight plan (strip) based deconfliction, and the use of cleared levels. As the use of trajectory prediction tools becomes more critical, the effectiveness of these tools in case of non-nominal scenarios should be ensured. For example, the MTCD could be recalibrated in case of intermittent Mode C so that tracks that are not shown at every altitude in the case of periodical updates. Instead, the update should potentially rely on the flight plan altitude. Controller updates (via level changes into e.g. electronic flight strips) could also be input.	None
Tactical conflict management	**MB12: Regular scanning by ATCO** - The controller should maintain an effective regular scan (e.g. to be able to detect non-alerted dropped tracks), rather than solely rely on "first contact" procedures. This also applies to detection of incorrect aircraft being given a clearance (due invalid correlation). There is some debate as to the effectiveness of this barrier since, in en-route controlled airspace, strip management is traditionally the primary means of deconfliction. **MB13: Use of primary radar data** - If available, this can be used to maintain a correlated track to support tactical conflict management in the event of a loss of secondary surveillance information. *Note that this may be assisted by cooperation with the military, allowing the sharing of primary radar data*. **MB15: Crew detection of transponder failure** - Existing alerts are incorporated on most commercial aircraft, but may not be immediately noticeable in flight (e.g. Embraer Legacy-B737 accident in Brazil). Fail-safe indications of transponder failures or malfunctions, if detected, should be given to the flight crew.	**MB14: Alert for change in track status** - Any change of track status should be alerted to the controller. This includes the loss of transponder information (i.e. primary only, or flight plan track), or the total loss of a track. Alerting improves the detectability. This is also applicable for multiple sectors, i.e. also alerting the next sector the aircraft is due to enter.

ATC collision avoidance	**MB18: Recalibration of ground-based safety nets** - There are two options where the safety net assumes the aircraft is at all altitudes where Mode C is lost. Some may prefer to limit the number of nuisance alerts by inhibiting the functionality when an aircraft is not reporting Mode C, whilst others would prefer not to inhibit, and thus to deal with nuisance alerts given the potential benefit from reception of the valid alert.	**MB16: Collision avoidance via procedural control** - Use of altitude information acquired through voice reporting to achieve vertical separation. **MB17: Controller advisory to other aircraft** - If detected, the ATCO could provide an advisory to all other aircraft on frequency of the non-operational Mode C aircraft, so that they understand that TCAS RAs will not be initiated.
Crew collision avoidance	None	**MB19: See and avoid practiced by aircraft** - This could include the executive controller actively encouraging the aircraft to see-and-avoid through informing them of the track loss situation (if detected) and notifying them of proximate aircraft's approximate or last known position. The effectiveness of see-and-avoid for Commercial Air Transport is not thought to be high, particularly where there is no indication of the other aircraft through other means (e.g. via TCAS display or through party-line situational awareness). **MB20: Collision avoidance system** - The airborne Collision Avoidance System (e.g. TCAS) will provide Traffic Advisories only on aircraft not sending Mode C reports. The flight crew's awareness will be improved with solely TAs, but they must be aware of the lost Mode C information to react on the TA appropriately (without waiting for an RA).

6.5 Barriers to mitigate duplicated Mode S 24-bit address (failure mode S4)

This section presents a number of barriers, ether previously identified barriers that are repairable, or entirely new ones that can be used to mitigate the effect of an aircraft with intermittent Mode C.

Barrier Model	Repairable barriers	Existing/Possible new barriers
Design and strategic planning	**MB05: Weighted use of all Aircraft ID sources in ATC system** - Modern ATC systems use a combination of aircraft IDs, primarily Mode A code and Mode S 24-bit address (but also aircraft callsign) to correlate a track. Weightings can be applied per identification element. Implementing this would reduce the likelihood of a duplicated Mode S 24-bit address causing an undetected track drop or split. **MB06: Anomaly reporting and effective response** - Ensuring that current procedures on anomaly reporting are effectively followed and actioned.	**MB03: Appropriate ATC system design and calibration** - In the case of duplicated Mode S 24-bit address, this includes effective standards, specifications and calibration for STCA to handle duplicated addresses without loss of function. It also includes the effective alerting of dropped tracks (e.g. due to duplication), and alerting if the aircraft is not conforming to its flight plan route (e.g. if correlated with an incorrect track). **MB07: Maintenance procedures for transponder** - Appropriate oversight of maintenance (particularly for leased aircraft between States). Swapping transponders between aircraft should include specific quality checks on 24-bit address.
Demand and capacity balancing	None	**MB08: Sector capacity planning** - Ensuring that the number of aircraft the controller can handle if a track is lost is appropriate i.e. ensuring that sector capacity limits are appropriate by "sensitivity analysis" of track drop scenarios.

Traffic planning and synchronisation	None	**MB10: Use of voice reporting** - Use of voice reporting is particularly relevant as a barrier during sector handover, when defined procedures may be followed. If silent handover is used, this barrier may not be applicable. If the ATCO has detected the track drop/loss, it may also be used within a sector for improved situational awareness. **MB11: Sector-sector coordination** - The upstream sector may not see duplicated Mode S 24-bit addresses, and therefore may have correctly correlated tracks, and may be able to assist with planning.
Tactical conflict management	**MB12: Regular scanning by ATCO** - The controller should maintain an effective regular scan (e.g. to be able to detect non-alerted dropped tracks), rather than solely rely on "first contact" procedures. This also applies to detection of incorrect aircraft being given a clearance (due invalid correlation). There is some debate as to the effectiveness of this barrier since, in en-route controlled airspace, strip management is traditionally the primary means of deconfliction.	**MB14: Alert for change in track status** - Any change of track status should be alerted to the controller. This includes the loss of transponder information (i.e. primary only, or flight plan track), or the total loss of a track. Alerting improves the detectability. This is also applicable for multiple sectors, i.e. also alerting the next sector the aircraft is due to enter.
ATC collision avoidance	None	**MB16: Collision avoidance via procedural control** - Use of altitude information acquired through voice reporting to achieve vertical separation, if track swap or drop detected by ATCO.
Crew collision avoidance	**MB21: Improvement of collision avoidance system behaviours** - Two situations are defined: Conflict between ownship and another aircraft with duplicated Mode S address – ACAS currently ignores any duplicated Mode S. All other aircraft (with non-duplicated Mode S) are alerted upon as normal. A workaround for this is not available but could be investigated. Conflict between ownship, and two or more other aircraft with duplicated Mode S addresses – Another issue is that, if ACAS sees two or more surveillance tracks with the same Mode S 24-bit address, only the track closest in range shall be retained. This may mean that a potential RA is suppressed against the furthest aircraft with the same Mode S 24-bit address.	**MB19: See and avoid practiced by aircraft** - This could include the executive controller actively encouraging the aircraft to see-and-avoid through informing them of the track loss situation (if detected) and notifying them of proximate aircraft's approximate or last known position. The effectiveness of see-and-avoid for Commercial Air Transport is not thought to be high, particularly where there is no indication of the other aircraft through other means (e.g. via TCAS display or through party-line situational awareness).

6.6 Matrix of scenarios and barrier effectiveness (failure modes A, S and C)

- Green denotes a high barrier effectiveness (i.e. prevents the loss of separation almost every time).
- Yellow denotes a dependent barrier effectiveness (i.e. only effective some of the time).
- Red denotes a low barrier effectiveness (i.e. not effective for a particular scenario).
- White denotes a non-applicable barrier (i.e. cannot judge effectiveness, as it is in no way relevant for the failure mode).

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB01: Airspace design gives positive separation	**MB02:** Procedure design for transponder malfunction	**MB03:** Appropriate ATC system design and calibration	**MB04:** Application of transponder validation procedures on first contact	**MB05:** Weighted use of all aircraft ID sources in ATC system
A3-S1 - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning	Assuming design is utilised (e.g. not free-route)		Aids ATCO detection	If transponder failure is pre-flight or at first contact	Avoids issues due to code-callsign correlation
A3-S2 - Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning	Wrong a/c may be cleared - not always effective	n/a	Aids ATCO detection through alert	Aids ATCO detection in some cases	May mitigate likelihood of track swap
A3-S3 - Loss of separation due invalid identity displayed due corrupt Mode A code causing inappropriate planning	Wrong a/c may be cleared - not always effective	n/a	Not effective if invalid identity displayed	Aids ATCO detection in some cases	Can prevent invalid identity
A3-S4 - Loss of separation due loss of all track information for one aircraft due corrupt Mode A code impacting tactical control	Assuming design is utilised (e.g. not free-route)	If detected by ATCO	Aids ATCO detection through alert	Aids ATCO detection in some cases	Can prevent track drop (by establishing valid identity)
A3-S5 - Loss of separation due track swap between two aircraft due corrupt Mode A code leading to wrong aircraft receiving instruction	Wrong a/c may be cleared - not always effective	n/a	Aids ATCO detection	Aids ATCO detection in some cases	May mitigate likelihood of track swap
A3-S6 - Loss of separation due invalid identity displayed due corrupt Mode A code leading to additional workload	Wrong a/c may be cleared - not always effective	n/a	Not effective if invalid identity displayed	Aids ATCO detection in some cases	Can prevent invalid identity
C2-S1 - Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload		If detected by ATCO	Effective design and reversion to flight plan data		n/a
C2-S2 - Loss of separation due intermittent Mode C leading to incorrect altitude data used	Dependent on geometry and airspace	If detected by ATCO			n/a
C2-S3 - Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload	Dependent on geometry and airspace	If detected by ATCO		Increases effectiveness of detection	n/a
S4-S1 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning	Wrong a/c may be cleared - not always effective	n/a	May alert if a/c does not conform to flight plan	Aids ATCO detection	Dependent on weighting (assuming 24-bit takes priority)
S4-S2 - Loss of separation due duplicated Mode S 24-bit address causing dropped track	Assuming design is utilised (e.g. not free-route), and dependent on geometry of airspace	If detected by ATCO	Alerts dropped track if detected	Aids ATCO detection	Dependent on weighting (assuming 24-bit takes priority)
S4-S3 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction	Wrong a/c given instruction	n/a	May alert if a/c does not conform to flight plan	Aids ATCO detection	Dependent on weighting (assuming 24-bit takes priority)

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB06: Anomaly reporting and effective response	**MB07:** Maintenance procedures for transponder	**MB08:** Appropriate ATC system design and calibration	**MB09:** More effective flight plan data	**MB10:** Use of voice reporting
A3-S1 - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning	n/a	n/a	Mitigates loss of separation due workload	More effective use of flight plan based planning	Improves detectability
A3-S2 - Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning	n/a	n/a	Mitigates loss of separation due workload	No impact	Improves detectability
A3-S3 - Loss of separation due invalid identity displayed due corrupt Mode A code causing inappropriate planning	n/a	n/a	Mitigates loss of separation due workload	Possible improved detection of invalid identity	Improves detectability
A3-S4 - Loss of separation due loss of all track information for one aircraft due corrupt Mode A code impacting tactical control	n/a	n/a	If detected, can mitigate workload impacts	No impact for planning tools	Improves detectability
A3-S5 - Loss of separation due track swap between two aircraft due corrupt Mode A code leading to wrong aircraft receiving instruction	n/a	n/a	May assist detecting wrong instruction (ATCO not too busy)	No impact	Improves detectability
A3-S6 - Loss of separation due invalid identity displayed due corrupt Mode A code leading to additional workload	n/a	n/a	May assist detecting wrong instruction (ATCO not too busy)	No impact	Improves detectability
C2-S1 - Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload	If on-going	n/a	Mitigates loss of separation due workload	Effective updates in tool reduce workload	No impact
C2-S2 - Loss of separation due intermittent Mode C leading to incorrect altitude data used	If on-going	n/a	No impact	May assist detection	Potential updates on altimeter readings if detected
C2-S3 - Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload	If on-going	n/a	Mitigates loss of separation due workload	Could override Mode C information using cleared flight levels	No impact
S4-S1 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning	If on-going	Preventative, but also on-going Preventative, but also on-going	Mitigates loss of separation due workload	No impact	Improves detectability
S4-S2 - Loss of separation due duplicated Mode S 24-bit address causing dropped track	If on-going	Preventative, but also on-going Preventative, but also on-going	Mitigates loss of separation due workload (if detected)	No impact	Improves detectability
S4-S3 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction	If on-going	Preventative, but also on-going Preventative, but also on-going	May assist detecting wrong instruction (ATCO not too busy)	No impact	Improves detectability

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS				
	MB11: Sector-sector coordination	**MB12:** Regular scanning by ATCO	**MB13:** Use of primary radar data	**MB14:** Alert for change in track status	**MB15:** Crew detection of transponder failure
A3-S1 - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning	Improved situational awareness from adjacent sector	No impact	Effective when primary present	Earlier awareness of dropped track	n/a
A3-S2 - Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning	Improved detection of swap from adjacent sector	No impact	Not likely to be effective in mitigating track swap	Dependent on timing of track swap	n/a
A3-S3 - Loss of separation due invalid identity displayed due corrupt Mode A code causing inappropriate planning	Improved situational awareness from adjacent sector	No impact	Effective when primary present	Dependent on timing of change in Mode A code	n/a
A3-S4 - Loss of separation due loss of all track information for one aircraft due corrupt Mode A code impacting tactical control	Improved detection and situational awareness from adjacent sector	Limited effectiveness	If primary radar present	Earlier awareness of dropped track (detection)	n/a
A3-S5 - Loss of separation due track swap between two aircraft due corrupt Mode A code leading to wrong aircraft receiving instruction	Improved detection of swap from adjacent sector	Limited effectiveness	Not likely to be effective in mitigating track swap	Dependent on timing of track swap	n/a
A3-S6 - Loss of separation due invalid identity displayed due corrupt Mode A code leading to additional workload	Improved situational awareness from adjacent sector	Limited effectiveness	Effective when primary present	Dependent on timing of change in Mode A code	n/a
C2-S1 - Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload	No impact	No impact	No impact	No impact	If detected in time by flight crew
C2-S2 - Loss of separation due intermittent Mode C leading to incorrect altitude data used	No impact	Limited effectiveness	No impact	No impact	If detected in time by flight crew
C2-S3 - Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload	No impact	Limited effectiveness	No impact	No impact	If detected in time by flight crew
S4-S1 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning	Improved detection of swap from adjacent sector	Limited effectiveness	Not likely to be effective in mitigating track swap	Dependent on timing of track swap	n/a
S4-S2 - Loss of separation due duplicated Mode S 24-bit address causing dropped track	Improved situational awareness from adjacent sector	Limited effectiveness in detecting failure	Effective when primary present	Earlier awareness of dropped track	n/a
S4-S3 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction	Improved detection of swap from adjacent sector	Limited effectiveness	Not likely to be effective in mitigating track swapt	Dependent on timing of track swap	n/a

OPERATIONAL SCENARIOS:	MITIGATION BARRIERS					
	MB16: Anomaly reporting and effective response	**MB17:** Maintenance procedures for transponder	**MB18:** Appropriate ATC system design and calibration	**MB19:** More effective flight plan data	**MB20:** Use of voice reporting	**MB21:** Improvement of collision avoidance system behaviours
A3-S1 - Loss of separation due loss of all track information on one aircraft due corrupted Mode A code causing inappropriate planning	No impact on planning	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
A3-S2 - Loss of separation due track swap between two aircraft due corrupted Mode A code causing inappropriate planning	No impact on planning	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
A3-S3 - Loss of separation due invalid identity displayed due corrupt Mode A code causing inappropriate planning	No impact on planning	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
A3-S4 - Loss of separation due loss of all track information for one aircraft due corrupt Mode A code impacting tactical control	If detected by ATCO	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
A3-S5 - Loss of separation due track swap between two aircraft due corrupt Mode A code leading to wrong aircraft receiving instruction	Dependent on ATCO detection of incorrect instruction	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
A3-S6 - Loss of separation due invalid identity displayed due corrupt Mode A code leading to additional workload	Dependent on ATCO detection of incorrect instruction	n/a	n/a	Limited effectiveness for CAT	CAS do not use Mode A code – still effective	n/a
C2-S1 - Loss of separation due intermittent Mode C causing incorrect planned trajectory leading to additional workload	No impact on planning		Increased effectiveness in dealing with intermittent Mode C	Limited effectiveness for CAT	No Resolution Advisories on a/c not sending Mode C – Traffic Advisories give some awareness	n/a
C2-S2 - Loss of separation due intermittent Mode C leading to incorrect altitude data used			No impact	Limited effectiveness for CAT	No Resolution Advisories on a/c not sending Mode C – Traffic Advisories give some awareness	n/a
C2-S3 - Loss of separation due intermittent Mode C causing nuisance or false alerts leading to additional workload			Reduction in nuisance / false alerts	Limited effectiveness for CAT	No Resolution Advisories on a/c not sending Mode C – Traffic Advisories give some awareness	n/a
S4-S1 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, causing inappropriate planning	No impact on planning	n/a	n/a	Limited effectiveness for CAT	Reduction in capability due filtering of duplicated 24-bit address track	Mitigates issue of duplicated 24-bit address tracks
S4-S2 - Loss of separation due duplicated Mode S 24-bit address causing dropped track	Effective if detected by ATCO	n/a	n/a	Limited effectiveness for CAT	Reduction in capability due filtering of duplicated 24-bit address track	Mitigates issue of duplicated 24-bit address tracks
S4-S3 - Loss of separation due duplicated Mode S 24-bit address causing swapped tracks, leading to wrong aircraft being given instruction	Dependent on ATCO detection of incorrect instruction	n/a	n/a	Limited effectiveness for CAT	Reduction in capability due filtering of duplicated 24-bit address track	Mitigates issue of duplicated 24-bit address tracks

6.7 Summary of mitigating barriers (failure modes A, S and C)

	A3-S1	A3-S2	A3-S3	A3-S4	A3-S5	A3-S6	C2-S1	C2-S2	C2-S3	S4-S1	S4-S2	S4-S3
MB01	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Red
MB02	Green			Yellow			Yellow	Yellow	Yellow		Yellow	
MB03	Green	Green	Red	Green	Green	Red	Green	Red	Green	Yellow	Yellow	Yellow
MB04	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Yellow	Green	Yellow	Yellow
MB05	Green	Yellow	Green	Green	Yellow	Green				Yellow	Yellow	Yellow
MB06							Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
MB07										Green	Green	Green
MB08	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow
MB09	Yellow	Red	Yellow	Red	Red	Red	Green	Yellow	Green	Red	Red	Red
MB10	Green	Green	Green	Green	Green	Green	Red	Yellow	Red	Green	Yellow	Yellow
MB11	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Red	Red	Red	Yellow	Yellow	Yellow
MB12	Red	Red	Red	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow
MB13	Yellow	Red	Yellow	Yellow	Red	Yellow	Red	Red	Red	Red	Yellow	Red
MB14	Green	Yellow	Yellow	Green	Yellow	Yellow	Red	Red	Red	Yellow	Green	Yellow
MB15							Yellow	Yellow	Yellow			
MB16	Red	Red	Red	Yellow	Yellow	Yellow	Red	Green	Green	Red	Yellow	Yellow
MB17							Green	Green	Green			
MB18							Yellow	Red	Yellow			
MB19	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
MB20	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
MB21										Green	Green	Green

CHAPTER 7 - CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study has looked at the impact of transponder failure or dysfunction on the operation of ATC. It looks primarily at the boundary between technical inputs and operational impact. Pre-operational preventative barriers are considered to be out of scope, since they refer to transponder design and functionality. However, operational responses to transponder failures (e.g. anomaly reporting, and on-going maintenance) are included as they help mitigate future occurrences.
The scenarios were developed to help assess the combinations of mitigations and their effectiveness for specific operational chains of events. In all cases, a loss of separation was assumed as the end effect, without judging the severity of this effect. It is noted that other risks may exist from a surveillance data chain failure, in particular undetected corruption. It is possible that the controller could clear the aircraft into terrain (e.g. by issues an inappropriate "direct to" clearance) or into weather, causing CFIT or a loss of control in flight. However, this was considered unlikely, since the flight crew would have to ignore their on-board systems and situational awareness.

The scenarios were split into two main sections: the total loss of a transponder, and the dysfunction of an element of the transponder (namely Mode A, Mode C, and 24-bit Mode S address).

The mitigating barriers (MBs) arising from the study were taken from a combination of operational event analysis (through incident/occurrence reports and investigations) and expert judgement.

The barriers which remained (partially) effective in the most scenarios were:

- **MB01:** Airspace design gives positive separation.
- **MB10:** Use of voice reporting.
- **MB19:** See-and-avoid practiced by aircraft.

This is unsurprising, since all the barriers above are independent of the surveillance data chain, and therefore remain somewhat effective in spite of transponder failure or dysfunction. However, it is recognised that MB19 (see and avoid) is only slightly effective for Commercial Air Transport; in recent studies (e.g. UK Airprox Board), it has been shown to assist in uncontrolled airspace, but has not prevented recent mid-air collisions in controlled airspace – for example Embraer Legacy – B737 in Brazil.

Strategic deconfliction of the airspace (MB01) remains one of the most powerful barriers, since if routes never cross, a loss of surveillance should not lead to any increased risk. However, this must be considered in the light of a pressure to allow aircraft to fly point-to-point at optimum climb and descent profiles, giving increased flexibility and efficiency, but also increasing ATC system complexity. This trend may mean that strategic deconfliction of the airspace remains a dream in practical application, even with true 3D or 4D trajectory management.

Therefore, recognition of the importance of these barriers alongside the traditional surveillance-based safety nets is encouraged, particularly where the safety nets are impacted by the failure of the transponder.

In particular, the evolution of voice reporting, either on first contact or as a procedural back-up, should be understood. For example, the use of silent handover procedures may impact the effectiveness of sector handover procedures at mitigating transponder failure or dysfunction.

Flight crew detection of transponder failure or malfunction (Mode C) through an automated flight deck annunciation also appears to give an effective means of detecting and reacting to the failure. The design of this annunciation has been an issue in the past; it must be immediately detectable by the pilots as a critical function of the aircraft. Recent designs and modifications are taking this into account.

The barriers which remain most effective for the scenarios associated with total loss of the transponder were:

- **MB03:** Appropriate ATC system design and calibration – an effective tool for alerting ATCOs in the event of: a dropped track (across one or more sectors); or a non-correlated track (i.e. without flight plan data); or a track without secondary surveillance information (i.e. primary only, but still correlated)
- **MB10:** Use of voice reporting.

The barriers which remain most effective for the scenarios associated with corrupted Mode A were:

- **MB05:** Weighted use of all Aircraft ID sources in ATC system.
- **MB10:** Use of voice reporting.
- **MB20:** Collision avoidance system.

The barriers which remain most effective for the scenarios associated with intermittent Mode C were:

- **MB04:** Application of transponder validation procedures on first contact.
- **MB09:** More effective flight plan data – Particularly, the MTCD could be recalibrated in case of intermittent Mode C so that tracks that are not shown at every altitude in the case of periodical updates. Instead, the update should potentially rely on the flight plan altitude.
- **MB17:** Controller advisory to other aircraft.

The barriers which remain most effective for the scenarios associated with duplicated Mode S 24-bit address were:

- **MB07:** Maintenance procedures for transponder.
- **MB10:** Use of voice reporting.
- **MB21:** Improvement of collision avoidance system behaviours.

For many other barriers, the interesting aspect is how specific they are to each failure mode. For example MB07: Maintenance procedures for transponder and MB21: Improvements of Collision Avoidance System behaviours are only applicable to the duplicated 24-bit address failures. This suggests that a detailed analysis of the failure modes and operational impacts may be necessary to ascertain the true effectiveness of the barriers included in the surveillance data chain. This is consistent with the European legislation requiring a safety assessment on the end-to-end surveillance data chain.

Also, for total loss of transponder, the adequacy of existing barriers must be examined. Historically, an effective barrier has been the presence of primary surveillance radar. This now must be questioned, with many primary radars being taken out of service in the en-route environment. It is noted in the barrier description that an improvement in effectiveness could be sought through appropriate sharing of data with the military – i.e. increased cooperation.

Of more interest for ANSPs may be the operational elements which can mitigate technical failures. Many of these are contained in the planning and tactical barriers MB09-MB17. Some re-arrangement of the information is necessary to identify clear recommendations.

The study shows that there is no "silver bullet" to mitigate all transponder failures or dysfunctions. Rather, a robust strategy must be put in place, taking account of all aspects of the ATC system (airborne and ground), with multiple mitigations identified to give a reasonable likelihood of detecting and reacting to the failure in sufficient time.

APPENDIX A - EXAMPLES OF INDUCED RISK FROM TRANSPONDER FAILURES

Introduction

This section provides specific examples of incidents of transponder failure or dysfunction, leading to a loss of effectiveness of one or more barriers. The examples below have been provided by a number of sources at varying levels of detail. As much detail as possible has been provided, but care has been taken to keep the examples anonymous where appropriate. If a report has been published into an incident, and is available publically, the source is attributed below.

Example A

(source: NTSB investigation report)

This example provides an overview of an incident above Atlanta (USA); a full NTSB investigation into the incident is available. This provides evidence of the severity of incidents that can occur due to a total loss of transponder.

A Delta Airlines Boeing 757-200, registration N693DL was taking off from Atlanta to New York. It departed runway 27R on an RNAV departure route. It was instructed to take switch from Tower to Departure frequency. The crew acknowledged, with a correct read back, but did not change the frequency. After approximately 8 minutes the crew reported again, on hearing this Tower instructed the flight to switch immediately to Departure. Communication was established with departure at this time. The aircraft was already at 10,000ft and 20NM east of Atlanta. After establishing contact with departures the transponder was turned on within 6 seconds.

During this time while not on radar display the Delta flight was involved in three losses of horizontal separation with other aircraft. There is no vertical information as the only track available is from the primary track. The minimum separation distances with other aircraft were 1.44NM, 0.81NM and 2.36NM.

The NTSB released its final report on 8th of August 2012. It stated:

"The air traffic controllers' failure to adhere to required radar identification procedures, which resulted in loss of separation between the departing Boeing 757 and three other airplanes. Contributing to the incident was the pilots' inadequate preflight checks, which resulted in the airplane departing with an inoperative transponder."

Example B

(source: ANSP confidential occurrence report)

An organisation has provided several examples of incidents where problems occurred due to a Mode A/C transponder replying to a Mode S interrogation.

In each case different military aircraft, equipped with only a Mode A/C transponder, were replying more than once to a Mode S all-call. The aircraft was replying more than once to interrogations from a Mode S radar station resulting in several ghost tracks being plotted on the controllers display. In some instances this could be up to 6 ghost tracks.

Some analysis of the events was conducted and it concluded that the root cause of the incidents was a transponder malfunction. The transponder was interpreting the Mode S interrogation as a Mode A signal.

Example C

(source: ANSP confidential occurrence report)

An organisation has provided a number of short summaries of occurrences. These were gathered by ATCOs submitting them to an internal reporting system. The examples provided have been tabulated below.

In all cases, it appears that the transponder malfunction was detected by the ATCO.

Transponder failure type	Event	Action taken by the ATCO
Total loss	The aircraft transponder was lost during flight. The aircraft returned to the departure airport as it was not cleared to enter the neighbouring FIR.	Aircraft not cleared to proceed by ATCO in adjacent FIR, forcing aircraft to return to the departure airport.
Total loss (recycled transponder)	An aircraft was en-route at FL380. 1 minute before entering a sector, radar identification was lost The radar contact was re-established 3 minutes and 16 seconds later.	The ATCO detected the loss, and instructed the pilot to change the transponder set (to back-up).
Total loss (recycled transponder)	An aircraft was en-route at FL 370. The radar contact was lost within the sector and was not established again while the aircraft was within this sector.	The ATCO communicated with the adjacent sector, and notified them that the radar identity had been lost. The aircraft was accepted into the adjacent FIR.
Intermittent total loss (recycled transponder)	An aircraft was en-route at F 360. Radar contact was not established following radio communication. Radar contact was established subsequently, after 1 minute 53 seconds. After a further 36 seconds radar contact was lost, and not re-established within the sector.	ATCOs in adjacent FIRs communicated regarding the problem, at the time it was assumed that the fault was within the transponder. The aircraft was accepted into the adjacent FIR.
Total loss (recycled transponder)	An aircraft was en-route at FL 310. The radar contact was lost within the sector and was not established again while the aircraft was within this sector.	The ATCO communicated with the adjacent sector, and notified them that the radar identity had been lost. The aircraft was accepted into the adjacent FIR.
Corruption of mode A	An aircraft was en-route. The wrong squawk code was appearing on the ATCOs display. This happened on two occasions, for 28 seconds and subsequently for 56 seconds.	The ATCO instructed the pilot to change the transponder setting.
Intermittent total loss (recycled transponder)	An aircraft was on route and climbing from FL360 to FL380. Radar contact was established when the aircraft entered the sector. After 1 minute and three seconds radar contact was lost. It was re-established after 46 seconds, lost again for 56 seconds. 3 minutes 44 seconds after this the radar contact was again lost, but was not re-established within the sector.	ATCO asked for a transponder check and notified the adjacent FIR of the problem. They coordinated with the adjacent FIR and the aircraft was accepted into it.
Corruption of mode C	An aircraft was en-route at FL140. However was displaying the wrong altitude on the controllers display.	The ATCO asked for the transponder to change setting. They notified the adjacent FIR of the problem. Following coordination, the aircraft was accepted into the adjacent FIR.

Example D

(source: ANSP confidential occurrence report and subsequent presentations to SISG)

A European ANSP reported an aircraft as having suffered a failure of the Mode S transponder. It had been positively identified on first contact with the sector, but was not transferred via R/T to the subsequent sector. The transponder failed a few minutes before the sector boundary. In the next sector, solely a primary return was visible to the controllers. Some initial confusion was reported due to the previous presence of "ghost" returns in the area of airspace through which the aircraft with the failed transponder was flying. It was therefore unclear to the controllers whether they were looking at a reflection.

The controllers tried to raise the aircraft on R/T, including via the emergency channel. Eventually the aircraft reported on frequency, and the transponder was switched to the back-up by the flight crew (including squawk "ident" to verify operation).

Example E

(source: ANSP confidential occurrence report)

Two aircraft flying in the airspace of a European ANSP were found to have duplicated Mode S 24-bit addresses. The issue was noticed as one of the aircraft was filtered out by the ATC system, on the basis of anti-reflection.
It was noted at the time that two different ATC systems were tracking the two aircraft with the same 24-bit address. On one system, the anti-reflection algorithms led to a filtering of the track. On the other system, both aircraft were seen at all times.

Example F

(source: ANSP confidential occurrence report)

A controller in a European ANSP filed an occurrence report noting the presence of two flights with the same Mode S 24-bit address in the airspace at the same time. The flight plan was coupled to the wrong flight (i.e. swapped). This was detected, and no loss of separation resulted.

Example G

(public newspaper sites: Reuters, Times of India)

Several instances were reported publically of transponders failing. These incidents have not been followed up directly with the ANSPs involved. The transponders suffered an unexpected total failure during flight in the following reported cases:

- An Air India Boeing 787-8, registration VT-ANE performing flight AI-116 from London Heathrow, EN (UK) to Delhi (India), was enroute at FL370 about 30nm west of Berlin (Germany) when the main transponder and all other transponders failed, the aircraft became completely invisible to secondary (ATC) radar. The aircraft was able to eventually return to London, where it landed safely just before the night curfew at Heathrow.
- The same aircraft, roughly five weeks later, suffered another total loss of transponder functionality when flying from Delhi to Frankfurt, whilst overhead Afghanistan. It was quickly detected, and the aircraft was turned back to Delhi, where it landed safely.
  Note in each instance that the transponder failure appears to have been detected rapidly. Full details should be gathered on these incidents to understand the effectiveness of each barrier – i.e. was a track change alerting tool functioning, or was the detection purely on the basis of the controller's visual scan?

APPENDIX B - SUMMARY OF MITIGATING BARRIERS

Barriers mitigating the effects of transponder failure modes

MB01	Airspace design gives positive separation
MB02	Procedure design for transponder malfunction
MB03	Appropriate ATC system design and calibration
MB04	Application of transponder validation procedures on first contact
MB05	Weighted use of all aircraft ID sources in ATC system
MB06	Anomaly reporting and effective response
MB07	Maintenance procedures for transponder
MB08	Sector capacity planning
MB09	More effective flight plan data
MB10	Use of voice reporting
MB11	Sector-sector coordination
MB12	Regular scanning by ATCO
MB13	Use of primary radar data
MB14	Alert for change in track status
MB15	Crew detection of transponder failure
MB16	Collision avoidance via procedural control
MB17	Controller advisory to other aircraft
MB18	Recalibration of ground-based safety nets
MB19	See and avoid practiced by aircraft
MB20	Collision avoidance system
MB21	Improvement of collision avoidance system behaviours

There are several other detailed operational barriers available in the ATC control room, mainly impacting the detectability of errors on the Controller Working Position. These detailed operational barriers (e.g. proactive colleague, data block clarity) are dealt with in other Top 5 operational studies, for example Blind Spots.

APPENDIX C - GLOSSARY AND ABBREVIATIONS

Glossary

Term	Definition
Approach Path Monitor	Approach Path Monitor (APM) warns the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles during final approach.
Area Proximity Warning	Area Proximity Warning (APW) warns the controller about unauthorised penetration of an airspace volume by generating, in a timely manner, an alert of a potential or actual infringement of the required spacing to that airspace volume.
False Alert	Alert which does not correspond to a situation requiring particular attention or action (e.g. caused by split tracks and radar reflections).
Minimum Safe Altitude Warning	Minimum Safe Altitude Warning (MSAW) warns the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles.
Nuisance Alert	Alert which is correctly generated according to the rule set but is considered operationally inappropriate.
Safety Net	Safety nets help prevent imminent or actual hazardous situations from developing into major incidents or even accidents. A ground-based safety net is functionality within the ATM system that is assigned by the ANSP with the sole purpose of monitoring the environment of operations in order to provide timely alerts of an increased risk to flight safety which may include resolution advice. Ground-based safety nets are an integral part of the ATM system. Using primarily ATS surveillance data, they provide warning times of up to two minutes. Upon receiving an alert, air traffic controllers are expected to immediately assess the situation and take appropriate action. Airborne safety nets provide alerts and resolution advisories directly to the pilots. Warning times are generally shorter, up to 40 seconds. Pilots are expected to immediately take appropriate avoiding action.
Short Term Conflict Alert	Short Term Conflict Alert (STCA) assists the controller in preventing collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima.

Acronyms and Abbreviations

Acronym	Definition
ACAS	Airborne Collision Avoidance System
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
CAS	Collision Avoidance Systems
CAT	Commercial Air Transport
CWP	Controller Working Position
DCB	Demand Capacity Balancing
DMAN	Departure Manager
ICAO	International Civil Aviation Organisation
ID	Identification
MTCD	Medium Term Conflict Detection
PSR	Primary Surveillance Radar
RA	Resolution Advisory (within Collision Avoidance Systems)
RNAV	Area Navigation
RNP	Required Navigation Performance
RVSM	Reduced Vertical Separation Minima
SAFMAP	Safety Functions Maps
SISG	Safety Improvement Sub Group
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
TA	Traffic Advisory (within Collision Avoidance Systems)
TCAS	Traffic Collision Avoidance System
VFR	Visual Flight Rules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