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PJ37-W3-ITARO

INTEGRATED TMA, AIRPORT AND RUNWAY OPERATIONS

This Safety Assessment Report is part of project PJ.37-W3-ITARO that has received funding from the SESAR Joint Undertaking under grant agreement No 101017622 under European Union's Horizon 2020 research and innovation programme.



Abstract

The present document constitutes Safety Assessment Report (SAR) Part II of the Demonstration Report (DEMOR), belonging to contractual deliverable D1.5, of the SESAR2020 PJ37-W3-ITARO project. It overviews the results of the various exercises dealing with the Safety aspects of the integrated solutions addressed by solution track PJ.37-W3-01B. This project carries out 'VLD-like' activities that focus on the integration of different SESAR solutions and (pre-) deployment items, already validated to high Technological Readiness Levels (TRLs) individually but being combined and applied for the first time in simulated operational environment. This first-step integration cannot be performed directly in a real-life ATC environment hence requires an integrated Real Time Simulation (RTS) step first, thereby explaining the 'VLD-like' in its naming. As a result, the safety assessment activities have a different character from those usually carried out in VLD exercises. In particular, they do not include the assessment of the Safety Impact of the VLD on current operations, since the exercises take place in a simulation environment only.

The 'VLD-like' activities comprised of 40 exercise runs that took place over a 10-day period which consisted of both Reference and Solution runs, testing with both RECAT-EU and PWS scenarios, in addition to testing Solution runs with and without an emulated TMA data feed. The present document details the safety arguments, activities, and results together with detailed analysis of the safety objectives. Furthermore, two new elements were introduced into the solution track PJ.37-W3-01B therefore, a bespoke safety assessment report has been undertaken and included in the Appendices to ensure there is no safety delta.



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JOINT UNDERTAKING

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1 Executive Summary

This document provides a summary of the ‘VLD-like’ safety assurance activities conducted in accordance with the DEMO Plan Part II Safety Assessment Plan (SAP), including the ‘VLD-like’ safety demonstration with regards to the suitability of the SESAR Solution track PJ.37-W3-01B for deployment by focusing on the safety demonstration objectives and success criterion. It provides detailed examination from a safety perspective of these objectives and includes specific analysis of under separation, TMA catch up and potential wake encounters.

Furthermore, included in the Appendices of this document is a bespoke Safety Assessment Report for two new elements which have been incorporated into the solution track PJ.37-W3-01B.

This presents the assurance that the Safety Requirements for the V1-V3 phases are complete, correct and realistic, thereby providing all material to adequately inform the PJ.37-W3-ITARO project DEMOR.

2 Introduction

2.1 VLD Objectives, Justification and Scope

The main objective for PJ.37-W3-01B is to increase runway efficiency during the initial departure phase of flight whilst enabling a safe and consistent flow of traffic to the TMA controller. The solution ensures a more refined and efficient non-wake Standard Instrument Departure (SID) spacing between departure pairs than current ICAO rules state, whilst increasing consistency in the application of spacing and separations. This is to be achieved by extending the Optimised Separation Delivery (OSD) tool developed in SESAR PJ.02-01-02 [12](AO-0329) in order to support the reduction of departure route spacings to achieve a target distance spacing in the TMA.

The solution also includes an emulated data-feed from the TMA into the extended OSD tool, which will indicate when the departure flow needs to be temporarily reduced in order to avoid putting an excessive traffic demand onto specific TMA sectors.

An overview of the operating method for the PJ.37-W3-01B ITARO departures solution, can be found in PJ.37-W3-ITARO DEMO Plan Part 1 Section 4.3 [9].

The validation simulations aim to demonstrate the ability to manage multiple complex optimised separation and spacing constraints that apply to the runway environment and departure profiles across simulated operational runway conditions. The complexity which exists will be managed through the simulated use of the extended OSD tool on departure and resulting safe runway throughput enhancement. The demonstration will include the use of the following:

- i. Time Based Re-categorisation Europe (RECAT-EU) with extended OSD tool support with and without TMA data feed.
- ii. Time Based Pairwise Separation for Departures (PWS-D) with extended OSD tool support with and without TMA data feed.
- iii. SID spacings with extended OSD tool support, other non-wake separations / spacing without tool support (e.g. speed groups, A340 leader, Minimum Departure Interval (MDI) (support for applying flow restrictions (MDIs) are included in the extended OSD tool 'with TMA data feed' solution)/Average Departure Interval (ADIs) and adjustment to departure flow rate based on an emulated TMA data feed).

(Note: Bullet items i and ii are used as alternatives of each other during simulations, however bullet item iii is used throughout simulations.)

The 'VLD-like' demonstration objective is to test the solution and the elements listed above in a simulated operational environment so that the performance and interoperability can be validated. Full details of the demonstration activities can be found in the PJ.37-W3-ITARO DEMO Plan, Part 1, Section 5.3 [9]. High-level objectives have been created and can be found in the PJ37-W3-ITARO DEMO Plan, Part 1 Section 5.3.3 [9].

As detailed within the PJ.37-W3-ITARO DEMO Plan Part I Section 5.3 [9], the validation simulations have taken place in the NATS simulation environment at Heathrow Airport with the platform layout being based on the Heathrow Tower Simulation suite. It was setup for two Air Traffic Control Officers (ATCOs), and in addition a TMA controller was present to observe the departure traffic from a TMA perspective.

The safety objective is to demonstrate that the implemented functional System delivers the expected safety performance. Table 1 lists the demonstration safety objectives together with success criteria (criteria Identifier is provided in brackets).

Identifier		Demonstration Objectives	Exercise Demonstration Success criteria
OBJ-01	OBJ-37-W3-003-DEMOP-SAF1-0008	To assess the impact of the ITARO Departures Solution on operational safety in the Tower compared to the Reference Scenario.	There is evidence that the level of safety for the Tower controllers' operations is maintained and not negatively impacted with the ITARO Departures Solution compared to the Reference Scenario (CRT-37-W3-DEMOP-004-SAF-001). There is evidence that the ITARO Departures Solution does not increase the number of minor wake under-separations and decreases the number of large wake under-separations (i.e. those with potential for severe wake encounters and / or loss of separation) compared to the Reference Scenario. (CRT-37-W3-DEMOP-004-SAF-002a). There is evidence that the ITARO Departures Solution does not increase the number of route under spacing events relative to the target distance spacing and compared to the Reference Scenario. (CRT-37-W3-DEMOP-004-SAF-002b)
OBJ-02	OBJ-37-W3-003-DEMOP-SAF1-0009	To assess the impact on safety by the associated procedures	Evidence is gathered regarding the impact on safety and associated procedures that the ITARO Departure Solution has. (CRT-37-W3-DEMOP-004-SAF-003)
OBJ-03	OBJ-37-W3-003-DEMOP-SAF1-0010	Understand the equipment requirements, e.g., corrupt data, hardware failure	Evidence is gathered regarding equipment requirements and the ITARO Departure Solution (CRT-37-W3-DEMOP-004-SAF-004)

Table 1: Safety Demonstration Objectives.

2.2 Justification for PJ.37-W3-01B

The justification for this activity is part of the SESAR Joint Undertaking (SJU) agreement. By conducting PJ.37-W3-01B validation simulations, under controlled conditions, the performance of the solution is tested, and the results and benefits recorded.

The following benefits (KPA's) from a safety perspective are expected:

Runway Capacity: The reduction and refinement of the spacing delivered between departing non wake pairs is facilitated by the extended OSD tool. This has a direct impact on increasing runway throughput and therefore capacity at the airport could increase.

Safety: Efficient and consistent separation delivery to the SID spacing rules facilitated by the extended OSD tool improves conformance to the required separation and spacing minima. This means that the rate of under-spacing delivery should be significantly reduced, which improves safety related to SID separation delivery conformance in both the runway environment and the TMA.

Predictability: The extended OSD tool, by facilitating delivery to the optimised departure SID spacing minima, will help to maintain runway throughput and reduce delays in peak periods. The reduction in flight duration due to reduced aircraft spacing on departure will improve the predictability of flights. Due to a reduction in holding time on the ground, the taxi-out time will reduce, therefore reducing the variability in departure times. The consistency of spacing delivery into the TMA should also be improved due to the aircraft being delivered to a target distance spacing with tool support thus reducing tactical conflicts and potential minimum radar separation infringements.

Punctuality: By increasing predictability and helping to maintain runway throughput, the extended OSD tool will increase punctuality. This benefit will be seen for airlines and their customers, but additionally should reduce workload for both ATCOs and ground handlers.

Fuel Efficiency: Through reducing delay and disruption there is a positive impact on fuel efficiency and the associated emissions impact on the environment.

Human Performance: The extended OSD support tool helps to manage the complexity of employing the efficient non-wake SID spacing minima. By facilitating efficient and consistent delivery to the SID spacing minima it helps to mitigate the associated impact on ATC workload and Situational Awareness (SA).

2.3 Scope of the VLD Safety Assessment

The scope of the 'VLD-like' safety assessment is to demonstrate the suitability of the integrated solution for the deployment. Since the 'VLD-like' Safety Assessment is not performed in an operational environment, safety is not compromised during the 'VLD-like' Safety Assessment, therefore the safety impact on current operations is not within scope. The scope of the Safety Assessment covers the safety assurance evidence output from the validation simulations, the recording of the safety findings from the 'VLD-like' activities and only addresses the safety issues related to the *integration* of the solution.

The exercise safety objectives can be found in PJ37-W3-01B DEMOP Part 1, Section 5.3.3 [1] and the analysis method to assess the objectives included in Section 5.3.8.

NB. Due to the inclusion of two new elements into the Solution (the SID/ Route countdown timer and the TMA data feed), a bespoke safety assessment has been undertaken and completed and included in this document. (Appendix C to Appendix N inclusive). This is to fully assess these 2 elements and ensure no safety delta exists.

3 VLD Safety Argument and Assurance Activities

The relevant initial aviation Hazards were discussed and identified at a Scoping and Change Workshop with Solution members present. From this workshop the relevant AIMs were determined (See Appendix F), and the SACs (See Appendix C.7) subsequently derived. The safety impact of the change introduced in this solution is limited to the take-off phase, the initial departure path and SID. The relevant pre-existing hazards, together with the corresponding ATM-related accident types and AIMs are presented in Table 2.

Pre-existing hazards (Hp)	ATM-related accident type & AIM model
Hp#D1 Adverse Wake Encounter on Initial Common Departure Path	Wake Turbulence-induced Accident (WTA) on initial common Departure Path – associated AIM model
Hp#D2 Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict – Initial Common departure Path	Mid-Air Collision (MAC) on the initial Common Departure path – associated AIM model
Hp#D3 Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict in the TMA	Mid-Air Collision (MAC) in the TMA – associated AIM model

Table 2: Pre-existing hazards relevant to PJ.37-W3-01B.

Although the solution track PJ.37-W3-01B is a ‘VLD-like’ demonstration, there are two new elements which have been added to this solution, which include:

- A data-feed from the TMA into the extended OSD tool, which will indicate when the departure flow needs to be temporarily reduced in order to avoid putting an excessive traffic demand onto specific TMA sectors.
- A countdown timer for SID / route spacing which will allow a more consistent and accurate delivery of aircraft into the TMA.

In order to ensure there is no safety delta between the solution, and to highlight any safety requirements of the two new elements described above, a bespoke safety assessment has been undertaken and is detailed from Appendix C to Appendix N.

To aid the successful completion of the PJ.37-W3-01B DEMO Report Part II (this document) and to allow reader understanding and continuity, the remaining content of this document (up to and including Appendix B) will include the two new elements as listed above as part of the solution to be deployed.

Note the data-feed from the TMA during this ‘VLD-like’ demonstration and referred to in this document was an emulation of TMA data.

The initial safety assurance strategy encompasses the following activities,

- Initial workshop with Solution Members to review requirements and determine their applicability/satisfaction in/for the simulation activities.
- Subsequent workshop to identify, in more detail, the simulation objectives/high-level requirements from a safety point of view.
- Provide the necessary safety assurance to initiate the simulation activity.
- Prepare and produce safety observation questionnaires to support the simulation activities.
- Provide a safety briefing to the simulation participants and solution members.
- Support the validation simulation activities.
- Conduct Safety workshops post-validation simulation activities to assess and analyse any safety issues, derive mitigations.
- Produce a PJ.37-W3-ITARO DEMO Report Part II – Safety Assessment Report to document all safety results and evidence.

Table 3 shows the safety assurance strategies used to provide the evidence per safety demonstration objective.

ID	Demonstration Objectives	Exercise	Strategy
OBJ-37-W3-DEMOP-SAF1-0008	To assess the impact of the ITARO Departures Solution on operational safety in the Tower compared to the Reference Scenario.		• Observations during the validation simulations to identify safety issues. • Safety questionnaires for ATCOs to complete at the end of the day asking for their opinions on operational safety • Post validation simulation workshop to discuss feedback & recommendations. • Collect and analyse data from the validation simulations relating to achieved separations standards. (Wake / Under separations). • An internal analytical study on catch-up in the TMA. • End of day validation simulation discussions with ATCOs to identify safety issues.

ID	Demonstration Objectives	Exercise	Strategy
OBJ-37-W3-DEMOP-SAF1-0009	To assess the impact on safety by the associated procedures		- Safety questionnaires for ATCOs to complete at the end of the day asking for their opinions and any relevant impact on procedures. - Post validation simulation workshop to discuss feedback & recommendations. - End of day discussion with ATCOs post exercise to identify safety issues.
OBJ-37-W3-DEMOP-SAF1-0010	Understand the equipment requirements, e.g. corrupt data, hardware failure		- Safety questionnaires for ATCOs to complete at the end of the day asking for their opinions on failures & corrupt data. - End of day discussion with ATCOs post exercise to identify safety issues. - Post validation simulation workshop to discuss feedback & recommendations.

Table 3: Safety Assurance Activities to be conducted to provide the necessary evidence per Safety Demonstration Objective.

Following the validation simulation and subsequent discussions, analysis of the completed controller questionnaires was undertaken which highlighted possible safety issues/hazards. These issues were fully discussed in the post validation simulation workshop with ATCOs and if relevant, suitable mitigations or recommendations were suggested. The salient points and proposed recommendations are detailed in Appendix A.

ID	Safety issue	Description	Link with SO
SI-01	Separations Standards	The ATCOs noted that the tool on occasions appeared to give a spacing which appeared on the screen very close to the minimum separation required especially those which were departing on same-SID routes.	OBJ-37-W3-DEMOP-SAF1-0008
SI-02	Increase in tactical conflicts / MRS	ATCOs commented that the expected increase in departure rate due to the tool delivering a reduced spacing between aircraft compared to what is delivered in	OBJ-37-W3-DEMOP-SAF1-0008, OBJ-37-W3-DEMOP-SAF1-0009



	infringements in TMA	today's operation could cause an increase in tactical conflicts and/or MRS infringements in the TMA	
SI -03	Overload of traffic in TMA	ATCOs commented that the expected increase in departure rate due to the tool delivering a reduced spacing between aircraft compared to what is delivered in today's operation could cause PJ37-W3-01B DEMO Report Part III an overload to the ATCOs in the TMA	OBJ-37-W3-DEMOP-SAF1-0009
SI -04	Reversion / de-skilling following tool failure	Once ATCOs become reliant on the tool providing the correct separations (wake and SID) the need to calculate these manually may not be required. If the tool, failed, ATCOs would need to revert quickly and seamlessly to undertaking manual calculations to provide accurate separations. If this skill is not practiced regularly and fully understood by all ATCOs aircraft could depart with the incorrect separation thus causing a safety event.	OBJ-37-W3-DEMOP-SAF1-0008, OBJ-37-W3-DEMOP-SAF1-0009, OBJ-37-W3-DEMOP-SAF1-0010
SI-05	Corrupt but believable data /information	There is a potential that the tool could give the ATCO corrupt but believable data / information. This could be a false indication to the ATCO that an aircraft could depart safely when in fact the data is incorrect, and this could lead to separation standards being eroded. This error may only be noticeable after a short period of time has elapsed and a number of aircraft have departed and transferred to the TMA controller without the correct separations being achieved.	OBJ-37-W3-DEMOP-SAF1-0009, OBJ-37-W3-DEMOP-SAF1-0010

Table 4: Possible Safety Issues highlighted from discussion & questionnaires which were discussed at the workshop

4 VLD Safety Results

4.1 Suitability of the SESAR solution(s) for deployment

The tables below provide an analysis of the validation simulations results per safety objective. For full detailed analysis, justification and further recommendations please see Appendix A.

Identifier	OBJ-37-W3-DEMOP-SAF1-0008	KPA Category	Safety
Title	Safety 0008		
Objective	To assess the impact of the ITARO Departures Solution on operational safety in the Tower compared to the Reference Scenario		
Success Criterion	CRT-37-W3-DEMOP-004-SAF-001	There is evidence that the level of safety for the Tower controllers' operations is maintained and not negatively impacted with the ITARO Departures Solution compared to the Reference Scenario.	
	CRT-37-W3-DEMOP-004-SAF-002a	There is evidence that the ITARO Departures Solution does not increase the number of minor wake under-separations and decreases the number of large wake under-separations (i.e. those with potential for severe wake encounters and / or loss of separation) compared to the Reference Scenario.	
	CRT-37-W3-DEMOP-004-SAF-002b	There is evidence that the ITARO Departures Solution does not increase the number of route under-spacing events relative to the target distance spacing and compared to the Reference Scenario.	


Results

The overall feedback from ATCOs was that safety was not compromised as a result of the concept and discussions with ATCOs revealed they were confident with the output of the tool with regards to wake separations and route spacings. To provide evidence for the success criterion, data created in the validation simulations was collated and specific analysis was undertaken for wake-separations, route under-separations, route under-spacings and potential catch-ups in the TMA. This has provided evidence to support the success criterion; however, the analysis did highlight a number of issues and areas where improvements could be incorporated to progress the concept for future iterations. The following summarises the issues and recommendations:

OK

Safety Issue	Recommendation
To ensure Reduced Separation is recorded correctly and accurately.	REC-37-W3-SAF-R1.1: During future testing of this solution in future projects, more robust procedures should be created to ensure all forms of Reduced Separation that ATCOs apply are recorded accurately and correctly in the simulation environment.
To ensure accuracy amongst all SID profile combinations.	REC-37-W3-SAF-R1.2: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.
Effects of simulated weather conditions on the algorithm	REC-37-W3-SAF-R1.3: Further investigation should be undertaken regarding the MET conditions used in simulations and its interaction with the algorithm in order to refine the calculation of the route time spacing required.
To ensure realistic departure speed profiles are inputted in the simulation environment.	REC-37-W3-SAF-R1.4: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (Note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).
Reduce the probability of under-separations on certain route pairings.	REC-37-W3-SAF-R1.5: Further investigations should be undertaken in future projects to examine the use of 'safety buffers' on certain route pairings.
To understand differing aircraft	REC-37-W3-SAF-R1.6: A larger sample size of differing aircraft types should be



speed data and performance.	utilised in future projects to deduce whether improved departure speed profiles are required and if there are any issues with specific aircraft speed data.
To ensure that the target distance separations used in the extended OSD tool are sufficiently accommodating of all traffic operating in the wider TMA environment.	REC-37-W3-SAF-R1.7: Additional simulations should be undertaken to explore the interactions of Heathrow departures with all traffic movements both through the TMA and into and out of the major airports in the London TMA, with a consideration to include unfavourable wind profiles at all levels.
To understand whether other parameters need to be included in the solution to increase accuracy.	REC-37-W3-SAF-R1.8: Further investigation should be undertaken in future projects to ascertain whether other significant parameters need to be included in the Solution (e.g., Airline, destination, and air pressure.)
To understand what impact the Solution has on traffic above the Controlled Traffic Region.	REC-37-W3-SAF-R1.9: Further investigations should be undertaken in future projects regarding same SID pair departures, catch-ups and potential wake encounters above the Controlled Traffic Region.
To ensure wake separations are clearly displayed to the ATCO	REC-37-W3-SAF-R1.10: The HMI needs to clearly display when there is wake separation.
To understand the impact of the extended OSD tool on catch-ups in the TMA.	REC-37-W3-SAF-R1.11: Further investigations should be undertaken to assess the impact of the extended OSD tool on catch-up occurring in the TMA and if the defined spacing delivery points for the leader and follower aircraft are appropriate on a SID pair basis.
To assess the target distance spacings for SID pair combinations.	REC-37-W3-SAF-R1.12: Further investigations should be undertaken to assess whether the target distance spacings assigned to SID pair combinations are sufficient.
To assess the differences in aircraft performance, particularly the planned distances to be flown and associated differing	REC-37-W3-SAF-R1.13: An investigation into whether a destination reference table should be an input to the extended OSD tool should be carried out.

	Take-Off Weights for different aircraft.	
Reference	Appendix A.1.4 - End of Day Question ‘<i>What the level of impact will the concept have on Operational Safety?</i>’ Out of 14 ATCOs, 7 highlighted ‘same as current operations’, 7 highlighted ‘positive impact’. This provides evidence (although of a subjective nature) to support CRT-37-W3-DEMOP-004-SAF-001. Appendix A.1.1.1 – Analysis of Wake Encounter Risk provides partial evidence to support CRT-37-W3-DEMOP-004-SAF-002a. Appendix A.1.1.2 – Analysis of total number of Wake Under Separations (Solution vs Reference Runs) provides evidence to support CRT-37-W3-DEMOP-004-SAF-002a. Appendix A.1.1.2 – Controller Delivery performance using the Wake Countdown timer provides partial evidence to support CRT-37-W3-DEMOP-004-SAF-002a. Appendix A.1.1.3 - End of Day Question ‘<i>When using their own experience and judgement, what would the probability of a wake separation infringement occurring using this concept in comparison to current operations?</i>’ Out of 15 ATCOs, 6 highlighted ‘same as current operations’, 8 highlighted ‘less likely to occur’. This provides partial evidence (although of a subjective nature) to support CRT-37-W3-DEMOP-004-SAF-002a. Appendix A.1.2.1 – Analysis of Total Number of Route Under-Separations / Under-Spacings (Solution vs. Reference Runs) provides evidence to support CRT-37-W3-DEMOP-004-SAF-002b. Appendix A.1.2.1 - Analysis of Rate of Route Under-Separations / Under-Spacings per 100 000 Departures (Solution vs. Reference Runs) provides evidence to support CRT-37-W3-DEMOP-004-SAF-002b. Appendix A.1.2.1 - Analysis of Under Separations / Under- Spacings per SID Pair (Solution vs Reference Runs) provides partial evidence to support CRT-37-W3-DEMOP-004-SAF-002b. Appendix A.1.2.1 - Analysis of Under Separation / Under- Spacings per MET Condition (Solution vs Reference Runs) provides partial evidence to support CRT-37-W3-DEMOP-004-SAF-002b. Appendix A.1.2.2 - End of Day Question asked when using their own experience and judgement, what would the probability of an under separations (SID/Route) occurring using this concept in comparison to current operations? <i>Out of 15 ATCOs, 10 highlighted ‘same as current operations’, 4 highlighted ‘less likely to occur’ and 1 highlighted ‘more likely to occur’.</i> This provides evidence (although of a subjective nature) to support CRT-37-W3-DEMOP-004-SAF-002b. Appendix A.1.3.2 - Analysis of Extended OSD tool Impact on Departure Catch-Ups in the TMA provides evidence to support CRT-37-W3-DEMOP-004-SAF-002b.	

Table 5: Results for OBJ-37-W3-DEMOP-SAF1-0008.


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Identifier	OBJ-37-W3-DEMOP-SAF1-0009	KPA Category	Safety
Title	Safety 0009		
Objective	To assess the impact on safety by the associated procedures		
Success Criterion	CRT-37-W3-DEMOP-004-SAF-003	Evidence is gathered regarding the impact on safety and associated procedures that the ITARO Departure Solution has.	




Results

Overall, once the ATCOs became familiar with the extended OSD tool during the validation simulations, there was little impact on safety and associated procedures. After collating information from the questionnaires and discussing the pertinent points in the workshop, the main issues which were raised surround the placement and design of the countdown timers, MDI and TMA data information (HMI design) and the potential failure of the tool and the subsequent procedures associated with these issues. The following summarises the issues and recommendations:

OK

Safety Issue	Recommendation
Timer display.	REC-37-W3-SAF-R2.1:- A toggle switch should be provided to enable ATCO personalisation of the timer. (see also REQ-37-W3-HP-6)
Placement of wake and SID countdown timer.	REC-37-W3-SAF-R2.2: A HMI workshop should be held to discuss suitable placement of the extended OSD tool output. (See also REQ-37-W3-HP-7)
Placement of MDI and TMA data feed information.	REC-37-W3-SAF-R2.3: A HMI workshop should be held to discuss the suitable placement of the MDI and TMA data feed information.
Ability for ATCO to undertake other safety critical tasks.	REC-37-W3-SAF-R2.4: During the next wave of this solution, more scenarios and tasks that ATCOs experience daily should be incorporated into the simulated exercises.
Procedures when extended OSD tool fails.	REC-37-W3-SAF-R2.5: A simple to follow separations matrix and immediate action procedures should be produced to enable safe operations to continue.
Procedures to deal with skill fade.	REC-37-W3-SAF-R2.6: HF, Safety and ATCOs should fully investigate the required procedures, tasks and possible ATCO training requirements in the event of tool failure.
Future deployment and effect on current procedures.	REC-37-W3-SAF-R2.7: All ATC procedures which will be affected by the deployment of the tool should be highlighted early in future projects to assess for any major safety issues.
Refresher training to enable ATCOs to manually calculate separations if extended OSD tool fails.	REC-37-W3-SAF-R2.8: Further investigations are required to fully understand the content and duration and frequency of training required for ATCOs to sufficiently maintain currency and skills

		to manually apply accurate and efficient separations.	
Reference	Appendix A.2.1 - End of Day Question <i>'Are there any circumstances that you think using this concept will have a SAFETY impact on associated procedures and or other tasks that are performed by you?'</i> ATCO 6 – 'As long as the timer HMI is good then no' ATCO 10 – 'not if it works correctly' ATCO 17 – 'Potentially if an ATCO becomes over reliant on timer and it fails, your workload could increase significantly to compensate and calculate separations' ATCO18 – 'Need to ensure all separations wake/route/MDI can be understood by the ATCO' End of Day Question – <i>'Are there any scenarios you can envisage where the failure of the tool could have a SAFETY impact?'</i> ATCO 12 – 'If the ATCO could not revert to manual application successfully due skill fade etc' ATCO 11 – 'Feel you could become reliant on the tool and if failed, increase in mental workload would be significant during high traffic volumes and MDIs'.		

Table 6: Results for OBJ-37-W3-DEMOP-SAF1-0009.


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Identifier	OBJ-37-W3-DEMOP-SAF1-0010	KPA Category	Safety
Title	Safety 0010		
Objective	Understand the equipment requirements, e.g. corrupt data, hardware failure		
Success Criterion	CRT-37-W3-DEMOP-004-SAF-004	Evidence is gathered regarding equipment requirements and the ITARO Departure Solution	



Results	Following ATCOs comments raised in the questionnaires and subsequently discussed in detail in the workshop, the main area of concern was the failure of the extended OSD tool and associated hardware in addition to the delivery of corrupt but believable data to the controller which would be difficult for the ATCO to notice. The conversations allowed a greater understanding of the safety implications of tool failure / corrupt data. The following have been recommended. <table><tr><th>Safety Issue</th><th>Recommendation</th></tr><tr><td>Tool error / failure messages</td><td>REC-37-W3-SAF-R3.1: A visual-only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.</td></tr><tr><td>Interaction between existing ATC equipment (including back-up servers).</td><td>REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.</td></tr><tr><td>Tool Failure – Corrupt but believable data.</td><td>REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects. REC-37-W3-SAF-R3.5: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.</td></tr></table>	Safety Issue	Recommendation	Tool error / failure messages	REC-37-W3-SAF-R3.1: A visual-only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.	Interaction between existing ATC equipment (including back-up servers).	REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.	Tool Failure – Corrupt but believable data.	REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects. REC-37-W3-SAF-R3.5: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.	OK
Safety Issue	Recommendation									
Tool error / failure messages	REC-37-W3-SAF-R3.1: A visual-only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.									
Interaction between existing ATC equipment (including back-up servers).	REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.									
Tool Failure – Corrupt but believable data.	REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects. REC-37-W3-SAF-R3.5: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.									
Reference	Appendix A.3 - End of Day Question ‘Are there any scenarios you can envisage where the failure of the tool could have a SAFETY impact?’ ATCO 1 – ‘Only if the failure was not known about, i.e., issuing corrupt info’.									



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End of Day Questions 15 – ‘Are there any changes or suggestions you would like see to the functions or presentations of the tool that would improve SAFETY?’

ATCO 14 – ‘A clear status of the system’.

Appendix A.3 details how likely a controller would be to identify an error if the indication was early by 10/20/30 seconds.0

Table 7: Results for OBJ-37-W3-DEMOP-SAF1-0010.

4.2 Safety impact of the VLD on current operations

Since the ‘VLD-like’ solution has not been tested in an operational environment, safety has not been compromised during the activities, therefore the safety impact on current operations is not within scope and thus this section is not applicable to this solution.





5 Acronyms and Terminology

Acronym	Definition
AC	Area Control
ADI	Average Departure Interval
AIM	Accident Incident Model
ASM	Assumption
A-SMGCS (62)	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATCOQ	ATCO Question (from fault tree diagram)
ATM	Air Traffic Management
BPK	Brookmans Park (SID profile & Reporting Point)
CPT	Compton DVOR / DME (SID profile & Reporting Point)
CTR	Controlled Traffic Region
DDI	Dynamic Distance Indicator
DEMOP	Demonstration Plan
DEMOR	Demonstration Report
DET	Detling DVOR / DME (SID profile & Reporting Point)
EATMA	European Air Traffic Management Architecture
EFPS	Electronic Flight Progress Strips / System
EHS	Enhanced Mode S Surveillance
ELS	Elementary Mode S Surveillance
Extended OSD	Extended Optimised Separation Delivery tool
FMS	Flight Management System
GAS	GASGU (SID profile)





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GOG	GOGSI (SID profile)
HAZID	Hazard Identification
HF	Human Factors
HMI	Human Machine Interface
HW	Hardware
IFR	Instrument Flight Rules
IM	Impact Modification Factor
KPA	Key Performance Areas
LoS	Loss of Separation
MAC	Mid-Air Collision
MATS	Manual of Air Traffic Services
MAX	MAXIT (SID profile)
MET	Meteorological Data
MDI	Minimum Departure Interval
MID	Midhurst DVOR / DME (SID profile & Reporting Point)
MOD	MODMI (SID profile)
MTFoO	Maximum Tolerable Frequency of Occurrence
MTOW	Maximum Take Off Weight
MRS	Minimum Radar Separation
NM	Nautical Mile
OOD	Out of Date
OSD	Optimised Separation Delivery Tool
PILOTQ	Pilot Question (from fault tree diagram)
PWS-D	Time Based Pairwise Separation for Departures
RECAT-EU	Re-Categorisation (Wake Scheme) Europe
RS	Reduced Separation





RSVA	Reduced Separation in the Vicinity of the Aerodrome
RTS	Real Time Simulation
RWY	Runway
SAC	Safety Criteria
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
S-PWS	Static Pairwise Wake Separation
SQEP	Suitably Qualified Experienced Person
SRD	Safety Requirements at Design Level
SRM	Safety Reference Material
SRS	Safety Requirements at Service Level
SW	Software
SWAL	Software Assurance Level
SYSMAN	Systemised Airspace Management Tool
TA	Transition Altitude
TC	Terminal Control
TMA	Terminal Manoeuvring Area
ToW	Take Off Weight
TWR	Tower
UML	UMLAT (SID profile)
ULT	ULTIB (SID profile)
VCS	Voice Communication system
VLD	Very Large Demonstration
VS	Vertical Separation
WTA	Wake Turbulence Induced Accident

Table 8: Acronyms

Term	Definition
Extended Optimised Separation Delivery (OSD)	Extended version of the Optimised Separation Delivery tool developed in PJ.02-01-02 to provide support to the Tower Runway Controller for the application of refined, more granular route spacings on departure, as well as wake turbulence separations.
Pairwise Separation (PWS)	Procedure designed for use between arrivals on final approach or between departures from the runway, based on an optimum adjusting of the needed separation between two aircraft taking into account their respective characteristics and giving Controllers more dynamic separation options.
Systemised Airspace Management (SYSMAN)	Based on the iACM (Indra Airspace Capacity Manager), the product that aims to help ANSPs to adapt demand and capacity strategically, enabling ANSPs to optimize operational and environmental performances, the SYSMAN “Systemised Airspace Manager” prototype is an extension with new functionality aiming at the balancing of demand among routes on a Systemised airspace.

Table 9: Glossary of Terms

6 References

Safety

- [1] PJ.37-W3-01B DEMO Plan Part II Safety Assessment Plan - latest edition accessible in STELLAR Program Library
- [2] SESAR Safety Reference Material - latest edition accessible in STELLAR Program Library
- [3] Guidance to Apply SESAR Safety Reference Material - latest edition accessible in STELLAR Program Library
- [4] STELLAR Slideboard, Safety part (complementary guidance)
- [5] (EU) No 2017/373 laying down common requirements for service providers and the oversight in air traffic management/air navigation services and other air traffic management network functions, repealing Regulation (EC) No 482/2008, Implementing Regulations (EU) No 1034/2011 and (EU) No 1035/2011 and amending Regulation (EU) No 677/2011 (and associated AMC and GM)
- [6] SESAR P16.01.04, Final Guidance Material to Execute Proof of Concept, Ed00.04.00, August 2015
- [7] MATS Part 2
- [8] CAP 493 MATS Part 1, Tenth Edition, 28 March 2022.
- [9] SESAR PJ.37-W3-ITARO DEMO Plan Part I.
- [10] SESAR PJ.37-W3-ITARO DEMO Report Part I.
- [11] SESAR PJ.37-W3-01B DEMO Report Part III
- [12] SESAR Solution PJ.02-01 SPR-INTEROP/OSED for V3 – Part 1, D1.1.01, 31st January 2020

Appendix A. Analysis of Safety Objective

A.1. Analysis of OBJ-37-W3-DEMOP-SAF1-0008

Objective	OBJ-PJ.37-W3-003-SAF-0008: To assess the impact of the ITARO Departures Solution on operational safety in the Tower compared to the Reference Scenario
Success criterion	CRT-37-W3-DEMOP-004-SAF-001: There is evidence that the level of safety for the Tower controllers' operations is maintained and not negatively impacted with the ITARO Departures Solution compared to the Reference Scenario. CRT-37-W3-DEMOP-004-SAF-002a: There is evidence that the ITARO Departures Solution does not increase the number of minor wake under-separations and decreases the number of large wake under-separations (i.e. those with potential for severe wake encounters and / or loss of separation) compared to the Reference Scenario CRT-37-W3-DEMOP-004-SAF-002b: There is evidence that the ITARO Departures Solution does not increase the number of route under spacing events relative to the target distance spacing and compared to the Reference Scenario.
Analysis result	The overall feedback from ATCOs was that safety was not compromised as a result of the concept and the specific data analysis and discussions provided evidence to support the success criterion. The data did highlight a number of issues and areas where improvements could be incorporated into the concept to progress the concept for future iterations, these are detailed below this table and recommendations suggested as required. Data Analysis – Detailed data analysis has been undertaken using data created in the validation simulations. This analysis focuses on the effects of the concept on wake separations, route under spacings and under separations and potential catch-up in the TMA. The analysis has produced evidence to support the success criterion and has also highlighted certain areas where the concept can be further developed, and therefore, relevant recommendations have been suggested. End of run / day discussion – Generally, the safety discussion post-simulation exercises gave positive and encouraging feedback regarding the concept, however there were instances where ATCOs felt that some spacings and / or separations that the extended OSD tool gave were less than what they expected. Additionally, comments were received about the potential increase of traffic delivered into the TMA due to the increase in efficiency of departing traffic and importantly whether this would result in an increase in tactical conflicts or radar separation infringements.

Safety Questionnaire – Overall, results from the safety questionnaire were positive with half of the ATCOs indicating that the concept would have a positive impact on safety and the remaining half commenting that it would be the same as current operations. Furthermore, the majority of the controllers felt that the probability of experiencing an under separation when using the extended OSD tool would be the same as current operations. Issues were raised concerning under separations and spacings which were then collated and discussed in post validation simulation workshop.

Post Validation Simulation Workshop. Controllers re-iterated that they felt the concept had a positive impact on safety. The issues surrounding possible wake infringements and under separations were discussed, outcomes were derived, severity classifications attached to each outcome and actions and mitigations suggested.

Safety Issue	Recommendation
To ensure Reduced Separation is recorded correctly and accurately.	REC-37-W3-SAF-R1.1: During future testing of this solution in future projects, more robust procedures should be created to ensure all forms of Reduced Separation that ATCOs apply are recorded accurately and correctly in the simulation environment.
To ensure accuracy amongst all SID profile combinations.	REC-37-W3-SAF-R1.2: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.
Effects of simulated weather conditions on the algorithm	REC-37-W3-SAF-R1.3: Further investigation should be undertaken regarding the MET conditions used in simulations and its interaction with the algorithm in order to refine the calculation of the route time spacing required.
To ensure realistic departure speed profiles are inputted in the simulation environment.	REC-37-W3-SAF-R1.4: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (Note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).
Reduce the probability of under separations on certain route pairings.	REC-37-W3-SAF-R1.5: Further investigations should be undertaken in future projects to examine the use of 'safety buffers' on certain route pairings.

To understand differing aircraft speed data and performance.	REC-37-W3-SAF-R1.6: A larger sample size of differing aircraft types should be utilised in future projects to deduce whether improved departure speed profiles are required and if there are any issues with specific aircraft speed data.
To ensure that the target distance separations used in the extended OSD tool are sufficiently accommodating of all traffic operating in the wider TMA environment.	REC-37-W3-SAF-R1.7: Additional simulations should be undertaken to explore the interactions of Heathrow departures with all traffic movements both through the TMA and into and out of the major airports in the London TMA, with a consideration to include unfavourable wind profiles at all levels.
To understand whether other parameters need to be included in the solution to increase accuracy.	REC-37-W3-SAF-R1.8: Further investigation should be undertaken in future projects to ascertain whether other significant parameters need to be included in the Solution (e.g., Airline, destination, and air pressure.)
To understand of what impact the Solution has on traffic above the Controlled Traffic Region.	REC-37-W3-SAF-R1.9: Further investigations should be undertaken in future projects regarding same SID pair departures, catch-ups and potential wake encounters above the Controlled Traffic Region.
To ensure wake separations are clearly displayed to the ATCO	REC-37-W3-SAF-R1.10: The HMI needs to clearly display when there is wake separation.
To understand the impact of the extended OSD tool on catch-ups in the TMA.	REC-37-W3-SAF-R1.11: Further investigations should be undertaken to assess the impact of the extended OSD tool on catch-up occurring in the TMA and if the defined spacing delivery points for the leader and follower aircraft are appropriate on a SID pair basis.
To assess the target distance spacings for SID pair combinations.	REC-37-W3-SAF-R1.12: Further investigations should be undertaken to assess whether the target distance spacings assigned to SID pair combinations are sufficient.
To assess the differences in aircraft performance, particularly the planned distances to be flown and associated differing	REC-37-W3-SAF-R1.13: An investigation into whether a destination reference table should be an input to the extended OSD tool should be carried out.

	Take-Off Weights for differing aircraft.	
Results	OK	

Table 10: Extended results of OBJ-37-W3-DEMOP-SAF1-0008.

Appendix A contains detailed analysis from the validation simulation, end of day discussions, controller questionnaires, post validation simulation workshop and internal analytical reports on the data collated from the exercises. In order to collate the relevant information together this section will be structured as follows:

Appendix A.1.1 – Analysis and detailed discussion on Wake Under Separations (provides for success criteria CRT-37-W3-DEMOP-004-SAF-002a)

Appendix A.1.2– Analysis and detailed discussion on Route Under Separations (provides for success criteria CRT-37-W3-DEMOP-004-SAF-002b)

Appendix A.1.3 – Analysis and detailed discussion on TMA catch up (provides for success criteria CRT-37-W3-DEMOP-004-SAF-002a and 002b)

A.1.1 Analysis of impact of Extended OSD tool on Wake Under Separations and Change in Wake Encounter Risk.

A.1.1.1 Analysis of Wake Encounter Risk.

The evidence to support the safety objective of assessing the impact of the ITARO Departures Solution on operational safety in the Tower compared to the Reference Scenario in respect of wake turbulence encounter risk is provided through the qualitative argument in this section.

A Wake Turbulence Encounter (WTE) can occur between any pair of aircraft whether separation is designed to mitigate against severe wake turbulence encounter or mid-air collision risk, i.e. WTEs can occur for both wake and non-wake pairs.

Wake risk is the combination of both the likelihood and the severity of the encounter. Reducing spacing between aircraft can lead to an increase in both of these factors.

The likelihood of a WTE could increase when the spacing between a pair of aircraft reduces as there is less time for the vortex from the lead aircraft to be transported out of the path of the follower, as well as less time for the vortex to decay to background turbulence levels.

The severity of a WTE could increase when the spacing between a pair of aircraft reduces as the follower aircraft could encounter a younger vortex which has not had sufficient time to decay to smaller turbulence levels.

The following safety criteria has been defined to enable a measure of change in terms of wake risk for the extended OSD tool concept.

- **SAC#6** (See Appendix D.7): *The probability per departure of severe and or extreme wake turbulence events shall be no greater in operations using the extended OSD tool compared to operations with the Reference scenario OSD tool.*

It is not possible to predict wake encounters in the simulated environment of an RTS, however actual WTE data from operations can be used to provide evidence of the likely change in wake risk between the Reference and Solution scenarios. WTEs occur and are reported on departure in current operations which allows analysis to be conducted to understand the conditions in which WTEs are more or less likely. There is limited objective severity data for WTEs on departure, however, subjective data exists in the form of pilot narratives of the event.

Assessment of the pairs of aircraft which have reported WTEs on departure (see Figure 1) shows that while both wake and non-wake pairs have reported WTEs, the majority are by non-wake pairs.

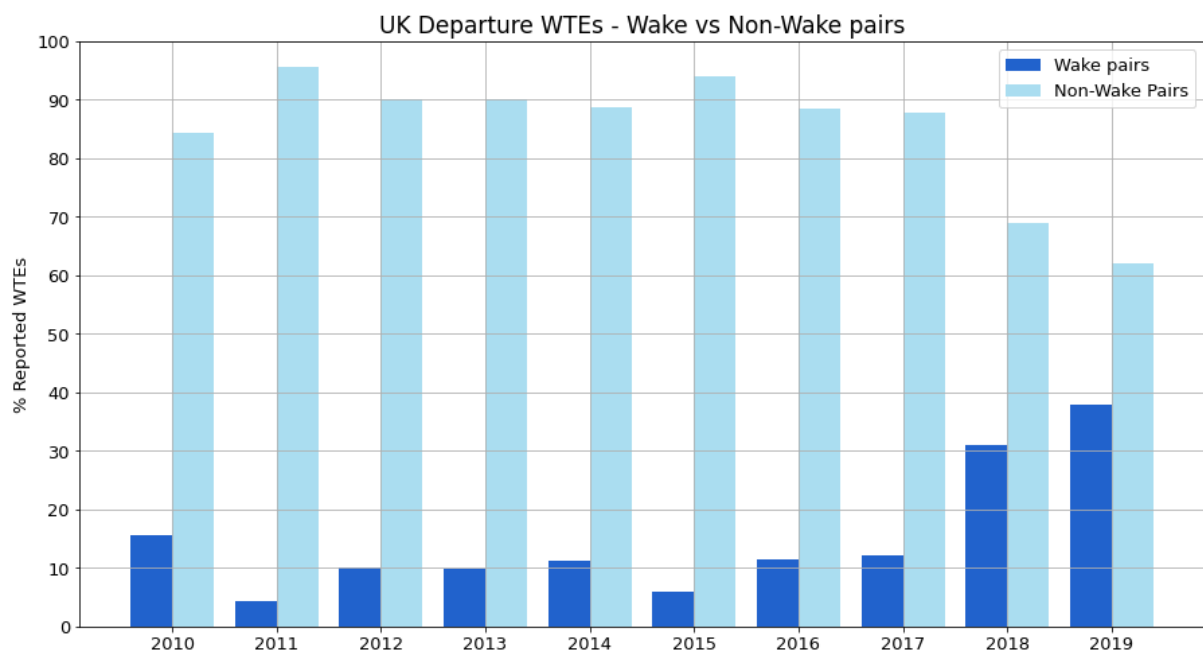


Figure 1: WTEs reported by wake separated and non-wake separated/spaced pairs for UK departures as a percentage of reported WTEs.

There are a number of different separations/spacings being applied on departure, some of which remain the same between the Reference and Solution scenarios: wake turbulence separations, 60s procedural spacing for those SIDs which diverge early and those utilising RSVA (or other forms of permitted reduced separation, such as the 3NM and increasing procedure for diverging SID pairs). Therefore, the change in spacing between the Reference and Solution scenarios only applies to those SID pairs for which there was a procedural separation of at least 2 minutes in the reference scenario for which conditions did not allow RSVA. These are therefore a sub-set of the non-wake pairs.

Analysis of the SIDs flown for the non-wake pair WTEs enables an assessment of the change of wake risk in terms of the solution over the reference. Taking all reported WTE from 2017 to 2019 at Heathrow, and matching them to the SIDs flown, shows that 80% of the WTEs were for those on early

diverging SIDS, i.e. not affected by the extended OSD tool concept and hence there would be no change between the Reference and Solution scenarios. Of the remaining 20%, a number of these may have been using reduced spacing through the use of RSVA, a spacing practice which again would not change between the Reference and Solution.

The above analysis showing that the majority of WTEs are reported from early diverging SID pairs combined with internal analysis on separation/spacing which shows that few WTEs for non-wake pairs have spacing more than 80 seconds, suggests that the majority of WTEs occur on the initial common departure path.

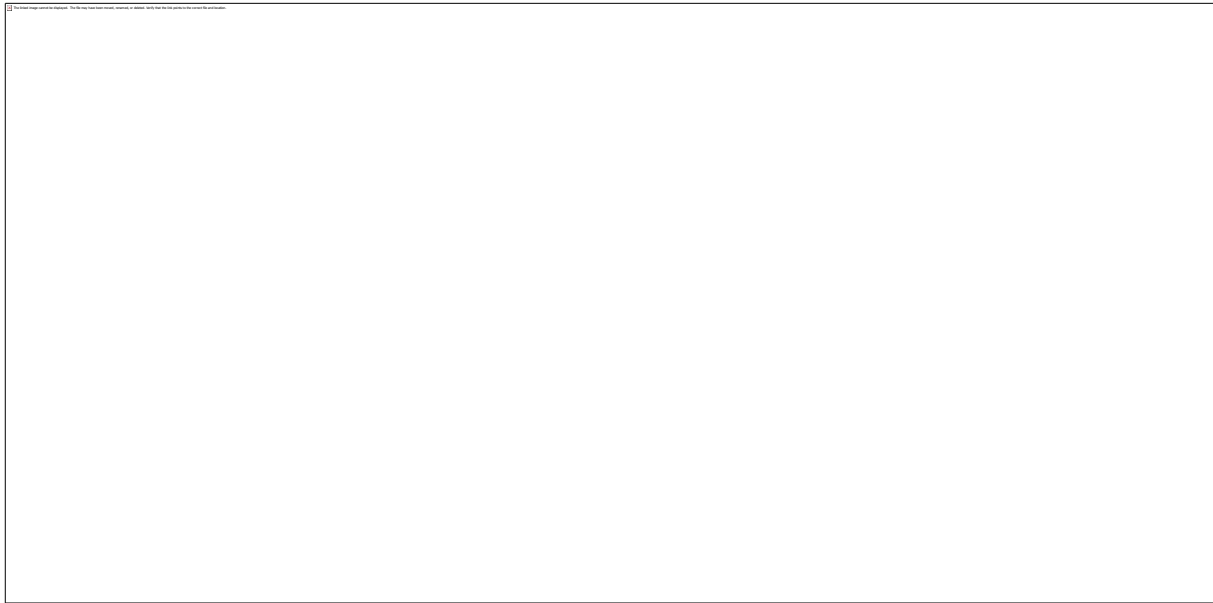


Figure 2: Altitude of reported WTEs on departure as a percentage of the population of non-wake pairs (all SIDs).

Confirmation that the majority of WTEs occur on the initial common departure path can be seen from Figure 2, which shows the altitude of WTE on departure for all SIDs. Almost 30% of encounters occur below 200ft and approximately 50% occur at 600ft¹ or less, when the follower aircraft is on the common initial departure path and the lead aircraft has not turned onto the SID. The initial common departure path would be the same for both aircraft on SIDs with diverging as well those with later diverging tracks. However, for the SIDs with later diverging tracks and hence those being changed by the extended OSD solution, the time separation would generally be larger than those on divergent tracks and therefore the wake would have more time to decay. Therefore, it would be expected that in the Solution scenario, the severity of an encounter would be no worse than that seen for divergent track WTEs which remain unchanged between the Reference and Solution.

In terms of the likelihood of encounter on departure, it would be expected that as the extended OSD tool is providing spacings generally smaller than those used in the Reference scenario, then there is

¹ A number of airports do not allow turns below 500ft QFE, which can be approximated to 600ft in terms of altitude across airports.

less time for the wake vortex to be transported out of the path of the follower and hence the likelihood of encounter may increase. However, as has been demonstrated in A.1.1.2 and A.1.2.1 the extended OSD tool may provide a benefit in terms of fewer under-spacing and under separations compared to the Reference scenario. As these under-spacings/under-separations could lead to a WTE due to the wake not having sufficient time to being transported out of the path of the follower and less time to decay, then for these pairs the extended OSD tool would have a benefit.

Overall, it would therefore be expected that the distribution of spacing with the Solution compared to the Reference would not only remove the longer spacing times through more consistent and efficient delivery of SID spacings, but also remove those which may be under spaced. This change in spacing distribution would lead to the following in terms of the wake risk:

- Reduced spacings (from integer minute procedural separations to a target spacing) would increase the likelihood of WTE but with a severity not above that seen in current operations with diverging SID pairs,
- Fewer under spaced pairs would lead to a lower likelihood of encounters with small time separations leading to fewer severe encounters.

With consideration to these 2 concluding points it gives the following result: **Partial evidence to support CRT-37-W3-DEMOP-004-SAF-002a.**

A.1.1.2 Analysis of Wake Under Separation based on Validation Simulation Exercise Results.

Introduction

Whilst the previous section (Appendix A.1.1.1) provided a qualitative argument for why the extended OSD tool should not increase the risk of WTEs compared with the current operation, this section provides quantitative evidence from the Validation Exercise on the impact of the extended OSD tool on the number of wake under-separations.

The validation simulations consisted of 40 exercises which included 13 Reference runs and 27 Solution runs. Incorporated into both Reference and Solution runs were exercises using the two wake separations standards as detailed below:

13 Reference Runs	RECAT-EU with OSD tool support (no SID separation tool support) = 8 runs
	PWS-D with OSD tool support (no SID separation tool support) = 5 runs
27 Solution Runs	Time-Based RECAT-EU with extended OSD (extended OSD) tool support with a TMA data-feed = 9 runs
	Time-Based PWS-D with extended OSD tool support with a TMA data-feed = 8 runs
	Time-Based RECAT-EU with extended OSD tool support without a TMA data-feed = 4 runs

Time-Based PWS-D with extended OSD tool support without a TMA data-feed
 = 6 runs.

(Note – RECAT -EU uses the 6 categories of wake time separations standards and PWS-D uses the 103x103 matrix /20 categories of wake time separation standards. Both indicate the minimum separation distance required in order to reduce the risk of a wake encounter to an acceptable level.)

Furthermore, incorporated into six of the Solution runs (see Appendix B for details on runway use and exercise number) were non-nominal (abnormal scenarios). These consisted of the following scenarios:

1. Aircraft undertaking Missed Approach Procedures (MAP) for both arrival and departure runways
2. Aircraft departing on a different SID than what was communicated.
3. Aircraft reports 'not ready' for take-off after the take-off clearance has been issued and waits for 2 minutes before getting airborne.
4. Aircraft refuses take off clearance and returns to stand.
5. Aircraft aborts take off and returns to stand.

In order to fully understand the analysis and the data presented the following explanations have been included:

1. The time separation applied by the Tower Controller between the leader and follower aircraft has been calculated from the scientific data logs recorded from the validation simulations and is based on the system time from the point at which the aircraft became airborne. This will be referred to as the 'delivery time' for the purpose of this analysis.
2. Aircraft pairs requiring wake separation (known as 'wake pairs') have been identified using the data logs from the validation simulations together with the wake separation time that was displayed to the Tower ATCO on the wake countdown timer.
3. A comparison has been drawn between the applied delivery time and required wake separation time to obtain the number of wake under-separations during all exercise runs.
4. A wake under-separation is defined as the case when the time separation delivered by the Tower Controller between a leader-follower pair is less than the required wake separation minimum.

(Note: the wake countdown timer has been validated in validation exercise RTS 5 in Solution PJ.02-01-02 and therefore this study investigates any change in the likelihood of wake under-separation occurring due to the introduction of a second countdown timer (route)).

Limitations of the Wake Encounter Analysis

Limitation 1 -During the Solution runs, there were two instances when RSVA/RS was indicated by the ATCO, however, both of these events occurred when the SID/route spacing countdown timer was not applicable. Furthermore, one instance was indicated during a Reference run when there was no SID/route spacing countdown timer.

Limitation 2 - The effect of the simulation environment can be observed when examining the frequency of aircraft types where a wake under-separation was recorded. Some aircraft types were more frequently involved in a wake under-separation, suggesting that their take-off performance in the simulation was unrealistic. This was further supported by the feedback provided by the ATCOs where they identified the GLF4 aircraft type to have an unrealistic take-off roll time and departure speed profile. Subsequently, this has affected the ATCOs delivery conformance to the wake countdown timer causing an over-estimation of the roll time of some aircraft. This had a more prominent effect on the follower aircraft than the leader.

Limitation 3 – There were instances where the wake separation timer reset itself to display the required wake separation time relative to the next departing aircraft before it had reached zero. This meant that the participating ATCOs could not learn from experience when they were over-estimating the roll time.

Limitation 4 - It is challenging to establish the risk of whether an ATCO mistakenly read the SID/route spacing countdown timer instead of the wake separation countdown timer. There is some indication that this might have been the case in at least one instance, which can be found in Table 19 where the delivery time was significantly lower than the wake separation target time.

Analysis of Total Number of Wake Under Separations (Solution vs Reference Runs).

Figure 3 shows that there were a total of 124 wake under-separations across all of the exercise runs, including Solution and Reference runs. The wake under separations are shown below and have been colour coded to highlight whether they occurred during a Reference, Solution or Abnormal run.

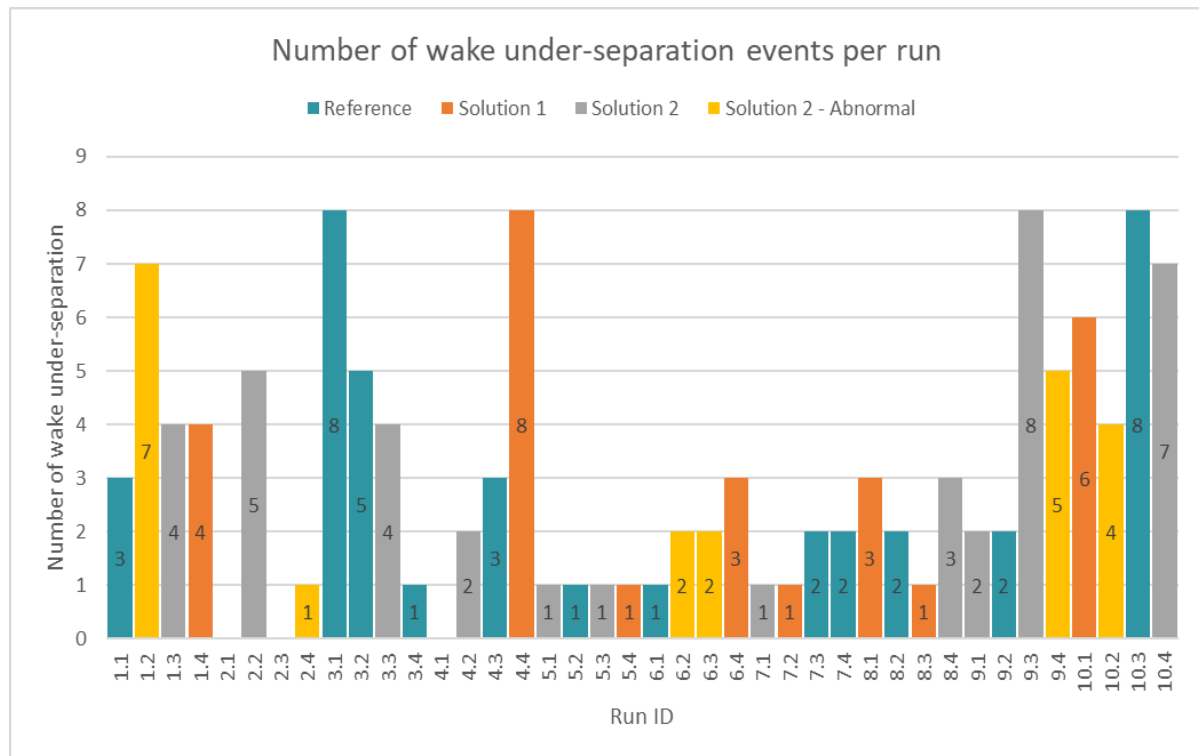


Figure 3: Number of Wake Under Separations per run.

Table 11 below, shows the breakdown of wake under-separations per scenario type and by the magnitude of the under-separation (0 to 10 seconds, 11 to 20 seconds, and 21 seconds and above, depicting the time below the target wake separation time).

Time below the wake separation [seconds]	Reference Run	Solution 1	Solution 2	Solution 2 Abnormal	Total
0-10s	35	19	31	19	104
11-20s	2	8	5	1	16
≥21s	1	0	2	1	4
Total					124

Table 11: Breakdown of the number of wake under-separations per scenario type and per time range below the wake separation target (seconds).

The number of wake under-separations across the Reference, Solution 1, Solution 2 and Abnormal exercise runs show little variation, and hence there is little evidence to suggest that the addition of the SID/ route countdown timer in the Solution runs might contribute to the increase in the number of wake under-separations, especially those that are equal to or over 21 seconds below the target separation time. This result therefore gives **Evidence to support CRT-37-W3-DEMOP-004-SAF-002a.**

Table 12 shows the percentage of wake under-separations relative to the number of wake pairs throughout the Reference and Solution runs. The percentages of wake under-separations show similar trends and consistency between Reference and Solution runs, especially when considering the total percentages are between 31% and 38%. The highest discrepancy is between 0 and 10 seconds below the target wake separation time with Solution 1 showing the lowest percentage of wake under-separations.

Time below the wake separation target [seconds]	Percentage of wake under-separations [%] relative to the number of wake pairs			
	Reference	Solution 1	Solution 2	Solution 2 Abnormal
0-10	28	19	30	34
11-20	2	8	5	2
≥21	1	0	2	2
Total	31%	27%	37%	38%

Table 12: Breakdown of the percentage of wake under-separations relative to the number of wake pairs per solution type and per time range below the wake separation target (seconds).

(Using the data from Table 12 above, Figure 4 has been generated to visually represent the difference between the Reference and Solution runs.)

Figure 4 below shows the percentage of wake under-separations for the Reference, Solution 1, Solution 2 and Abnormal scenarios. The results have been divided into categories showing the degree of under-separation below the minimum wake separation time.

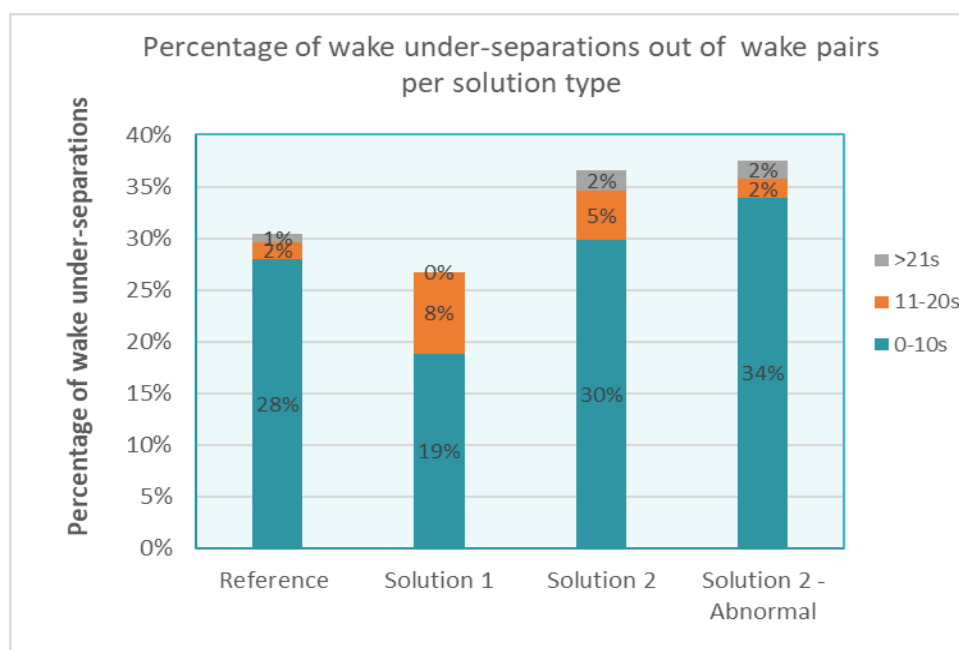


Figure 4: Percentage of wake under separations for each scenario type.

Figure 4, highlights that for Reference runs, 31% of wake pairs had a wake under-separation, but only 3% of wake under-separations were in excess of 10 seconds (shown in orange and grey). Solution runs show a similar trend, where the majority of wake under-separations were within the 10 seconds below the target wake separation time. During the Solution runs, between 19% to 34%, of the total number of wake pairs were under-separated by up to 10 seconds, and between 4% and 8% were under-separated by over 10 seconds with the lowest percentage for Abnormal runs. From Figure 4 it can be deduced that there is no strong evidence for an increase in the proportion of wake under-separations when the extended OSD tool was in use.

Table 13 below shows the breakdown of the percentage of wake under-separations relative to the number of wake pairs per scenario (percentages for Solution 1 and Solution 2 have been combined).

Time below the wake separation target [seconds]	Percentage of wake under-separations [%] relative to the number of wake pairs	
	Reference	Solution 1 & 2 combined
0 – 10	28	26
11 – 20	2	5
≥21	1	1
Total	31	32

Table 13: Breakdown of the percentage of wake under-separations relative to the number of wake pairs per scenario type, where solutions were combined, and per time range below the wake separation target (seconds).

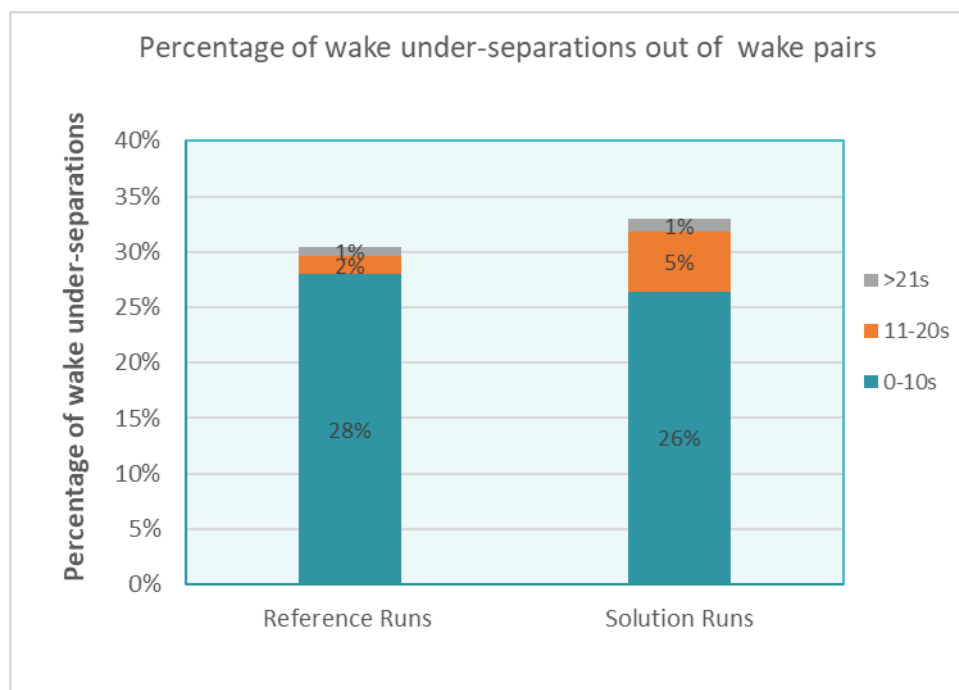


Figure 5: Percentage of wake under-separations, reference vs solution runs (combined Solution 1, Solution 2, and Solution 2 - Abnormal).

Figure 5 has been derived from data in Table 13 to provide a direct pictorial comparison of the ratios between the Reference and Solution runs combined together.

Overall, the Reference and Solution runs have a very similar total percentage of wake under-separations relative to the total number of wake pairs (125 for Reference runs, 261 for Solution runs).

Solution runs have a slightly lower number of wake under-separations within the range of 11 to 20 seconds, but a slightly higher number of wake under-separations that were equal or over to 21 seconds. This difference is considered to be negligible.

The data shown in Figure 5 further supports the conclusion from Figure 4 that there is little difference in the overall percentage of wake under-separations between Reference and Solution runs and the difference in the distribution between the time ranges can be considered negligible.

This data suggests that the introduction of a SID / Route spacing countdown timer had no effect on the percentage of wake under-separations with no increase to the number of minor wake under separations resulting in: **Evidence to support CRT-37-W3-DEMOP-004-SAF-002a.**

Causal factors for Observed Wake Under Separation in Validation Simulation Exercises.

Controller Delivery Performance using the Wake Countdown timer.

Based on the ATCO feedback noted in both the Reference and Solution runs during the validation simulations, the largest contributing factor to the observed wake under-separations was the ATCOs' over-estimation of the follower aircraft take-off roll time and the follower aircraft becoming airborne before the countdown timer reached 0s.

For example, if the wake countdown timer shows 100s (Heavy – Medium wake pair in RECAT-EU mode) and the Tower Controller anticipates a roll time of 40s, then the ATCO will clear the aircraft for take-off when the timer shows 40s with the expectation that the follower aircraft will become airborne when the countdown timer ticks down to 0s. However, if the follower aircraft only takes 30s to become airborne in the simulator, it will become airborne when there are still 10s remaining on the timer to satisfy the required wake separation, and hence a wake under-separation will occur.

This is corroborated by ATCO feedback during the end-of-run debrief sessions that aircraft frequently became airborne earlier than expected.

It is therefore a reasonable expectation that ATCOs have overestimated the roll-time on a number of occasions and thus, these instances can be considered to be within the 10 seconds below the wake separation target. By examining Table 16, and the data presented in Figure 6 below, it is noted that out of 124 wake under-separations, 104 instances were within 10 seconds of the target wake separation time. This suggests that the ATCO was following the wake countdown timer, but the aircraft became airborne earlier than expected in the simulator.

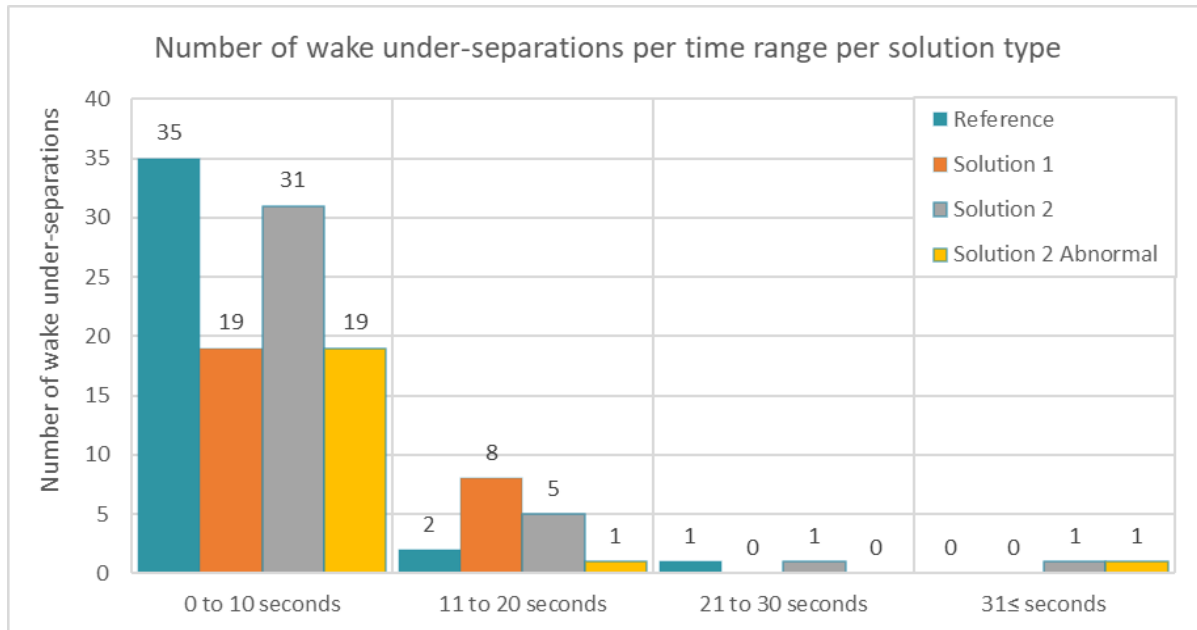


Figure 6: Number of wake under-separations per time range per solution type.

Since both the Reference (OSD tool) and Solution Scenarios (extended OSD tool) utilise the same wake countdown timer and the same aircraft take-off performance parameters, it is expected that the proportion of wake under-separations due to the controller's estimation of the roll time described above should be approximately the same between Reference and Solution Scenarios. Any significant difference in the proportion of wake under-separations between the Reference and Solution Scenarios could then be attributed to other causal factors, e.g., extended OSD tool (addition of second countdown timer) or HMI design.

Figure 7 below, shows the number of wake under-separations by aircraft type split by the follower and leader aircraft, showing some aircraft types had a higher number of wake under-separations.



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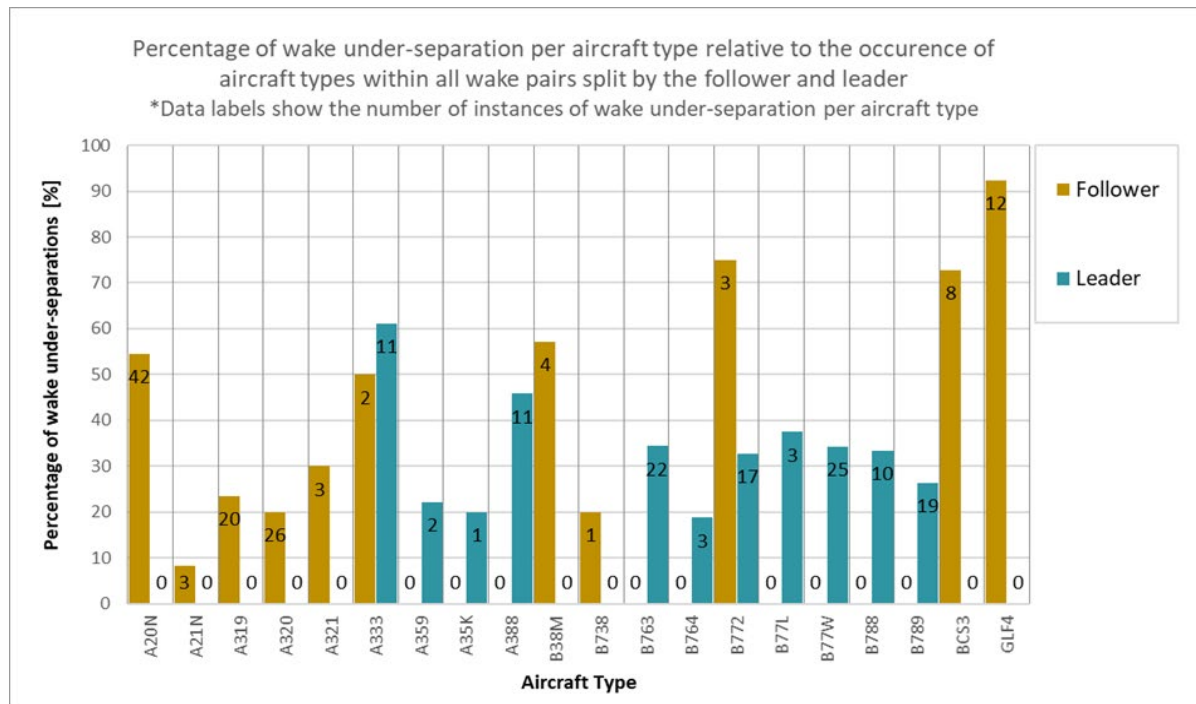


Figure 7: Percentage of wake under-separations per aircraft type relative to the occurrence of aircraft types within all wake pairs split by follower and leader (data labels show the number of instances of wake under-separations per aircraft type.)

It can be observed that by percentage, the GLF4, followed by the BCS3 and the B772 were the most common aircraft to be wake under-separated from their leader. However, it should be noted that the B772 was a follower only in only 3 wake pairs, and as such this result may have also been created by chance.

A very frequently under-separated aircraft in terms of wake was the A20N, it was a follower in 42 instances of wake under-separations, most of which were within 10 seconds below the wake separation target time.

The B77W was a leader in 25 instances of wake under-separations, most of which occurred within 10 seconds below the wake separation target.

This evidence suggests that the ATCOs frequently over-estimated the roll time of these aircraft in the validation simulations, i.e., their delivery performance was affected by unrealistic aircraft behaviour in the simulator environment.

This evidence is further supported by Tower Controllers frequently stating in the debrief sessions that the GLF4 aircraft type had a particularly unrealistic departure behaviour in the simulated environment as it was observed to become airborne very quickly.

The described wake under separated events, especially those within the '10 seconds and below' category could therefore be attributed to the simulated departure speed profiles associated with specific aircraft types; the simulation uses a simplified departure speed profile, whereas the algorithm uses real historical data. This leads to **Recommendation REC-37-W3-SAF-R1.4**: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an



input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).

Due to the possibility of some of the results being attributed to the simulated departure speed profiles and that ATCOs may have overestimated the roll-time on a number of occasions, it is difficult to fully conclude that the extended OSD tool has increased or decreased the number of wake under separation events. It can be noted however, that 84% of the wake under separation events were within the '10 seconds and below' category and thus, it could seem reasonable to presume that these events could be attributed to these issues. Until this can be ascertained, this gives the following result: **Partial evidence to support CRT-37-W3-DEMOP-004-SAF-002a.**

Tower Controller did not notice / forgot the Wake Separation Requirement.

A possible cause of wake under-separations in the Solution scenarios could be that the ATCO mistakenly followed the SID/ route countdown timer instead of the wake countdown timer. To investigate whether this may have caused any of the recorded wake under-separation events in the Solution runs, instances of wake under-separation during Solution runs were analysed to identify the events when the separation delivery time was closer to the time displayed on the SID/ route countdown timer than on the wake countdown timer.

Note that in this scenario, only the wake countdown timer would be displayed by default as the largest constraint, but some ATCOs elected to toggle on both the route and wake countdown timers (see Figure 27 and Figure 29 for photographs of the wake and SID Route timer displayed on ADIS.)

There were 40 instances (see Appendix B.2) when the wake separation time was the greatest constraint and there was an underlying SID/ route spacing time, i.e. the wake countdown timer showed a time that was larger than the SID/ route countdown timer, of which 30 were within the 10 seconds below the wake separation target (highlighted in blue in Appendix B.2). Out of the 30 occurrences, all had delivery times that were similar² between the two target times (SID/route spacing and wake separation), or they were closer to the wake separation target time than the SID/route spacing target time. This demonstrates that the wake separation countdown timer was likely followed, but as described previously, there was an overestimation of the roll time during the delivery.

Table 14 (see below) details the 10 instances of wake under-separation events that were in excess of the 10 seconds below of the wake separation target time and where the wake separation time was the greatest constraint.

² In those 30 instances, delivery time was either: (a) very close to both timers as they had similar countdown timer displayed (i.e. 89 seconds on route countdown timer and 90 seconds on wake countdown timer) hence impossible to determine whether one was followed over the other or (b) delivery time was closer to the wake separation countdown timer over the route timer

Run ID	Follower Callsign	Follower Aircraft Type	Leader Callsign	Leader Aircraft Type	RSVA Applied	Delivery Time [s]	Wake Separation Time [s]	=Delivery Time Wake Separation Time [s]	=Delivery Time –Route Spacing Time [s]	Route Spacing Time [s]	Solution Type
5.3	'N588TN'	GLF4	'AAL21'	B789	No	88	100	-12	-2	90	Solution 2
5.4	'N588TN'	GLF4	'BAW9CG'	B772	No	88	100	-12	-7	95	Solution 1
6.3	'N588TN'	GLF4	'BAW9CG'	B772	No	89	100	-11	-5	94	Solution 2 - Abnormal
6.4	'N588TN'	GLF4	'AAL21'	B789	No	86	100	-14	-4	90	Solution 1
7.2	'SWR33U'	BCS3	'BBC202'	B77W	No	86	100	-14	26	60	Solution 1
8.1	'SWR33U'	BCS3	'AAL729'	B788	No	74	90	-16	9	65	Solution 1
9.1	'N588TN'	GLF4	'BAW9CG'	B772	No	98	120	-22	8	90	Solution 2
9.3	'N588TN'	GLF4	'AAL21'	B789	No	67	120	-53	-23	90	Solution 2
9.4	'N588TN'	GLF4	'BAW9CG'	B772	No	84	120	-36	-6	90	Solution 2 - Abnormal
10.1	'N588TN'	GLF4	'AAL21'	B789	No	100	120	-20	10	90	Solution 1

Table 14: Instances of wake under-separations when the SID/ route separation timer was displayed that were over 10 seconds below the wake separation target.

- Four of the instances had a separation delivery time that was greater than the SID/ route countdown timer (highlighted in blue).
- Five of the instances had a separation delivery time within 10 seconds below the SID/ route countdown timer (highlighted in purple).



- One instance had a separation delivery time significantly below both the SID/ route and wake timers: 53 seconds below the wake separation target, and 23 seconds below the SID/ route spacing target respectively (highlighted in yellow).

As six of the wake-under-separations listed in Table 14 were within 11 to 16 seconds of the wake time separation target, it is difficult to establish whether the root cause was the ATCO mistakenly following the SID/Route timer over the wake timer, or whether it was an over-estimation of the roll-time by ATCO who still followed the wake timer. For the instances where the separation delivery time was significantly less than the wake timer, it is likely that the Tower Controller forgot about the wake separation requirement.

It is noted that from the 10 occurrences of wake under separations listed in Table 14, 8 of them involved the GLF4 aircraft type. As previously detailed the performance of GLF4 was noted to be unrealistic by ATCOs and thus this reinforces **Recommendation REC-37-W3-SAF-R1.4**: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part I [10]).

Conclusions and Recommendations of the Wake Under Separation Analysis

Conclusion 1 - The number of wake under-separations as a percentage clearly show that there is a minimal overall difference between Reference runs and Solution runs (combined).

Conclusion 2 - The highest percentage of wake under-separations were within 10 seconds of the wake separation time, which may be a result of ATCOs following the wake countdown timer but over-estimating the roll time of the follower aircraft, hence the aircraft becoming airborne before the wake countdown timer reached 0s. This conclusion is supported by ATCO feedback.

Conclusion 3 - There is an indication that there were a few occurrences when the SID/ route spacing countdown timer might have been followed instead of the wake separation countdown timer when the delivery time was significantly lower than the expected wake separation target time, i.e. 53 seconds below the target. This leads to **Recommendation REC-37-W3-SAF-R1.10**: The HMI needs to clearly display when there is wake separation.

A.1.1.3 Analysis of Wake Under Separations based on Safety Questionnaires and Post Validation Simulation Workshop.

This sub section provides qualitative evidence for wake under separations based on ATCO feedback in the questionnaires and post validation simulation workshop. At the end of each day of validation exercises, ATCOs were asked to complete a safety questionnaire regarding the exercises they had undertaken. The results were then collated together with any pertinent comments.

ATCOs were asked 'Using your own experience and judgement, please tick the relevant box according to the probability of wake separation infringement occurring when using this concept in comparison to current operations'.



Figure 8: Pie Chart showing ATCOs responses to question regarding the probability of wake separation infringement when using this concept in comparison to current operations.

The pie chart above clearly shows that nearly half of the ATCOs (6 out of 15) thought the probability of a wake under separation would be the same as current operations, with the remaining 8 suggesting that under separations are less likely to occur when using the concept / extended OSD tool (note, this is reliant on the extended OSD tool using realistic departure speed profiles).

ATCO who marked 'same as current operations' further stated.

'Tool will benefit controllers understanding of the large number of separations that will be in the future'.

During discussions controllers highlighted potential issues with skill fade caused by reliance on the tool, system failures and the likelihood of noticing any errors (these issues have been discussed in Appendix A.2.1)

Although this evidence could be classed as subjective, it highlights that after only a short amount of time utilising the tool, ATCOs felt confident with the output with regards to wake under separations, however, system failures and associated skill fade in manual calculations are an area of concern (recommendations have been suggested in Appendix A.2.2). The responses would therefore provide **Partial Evidence, although of a subjective nature to support CRT-37-W3-DEMOP-004-SAF-002a.**

A.1.2 Analysis of Impact of Extended OSD Tool on Route Under-Separations and Under-Spacings.

A.1.2.1 Analysis of Route Under-Separations and Under-Spacings based on Validation Simulation Exercise Results.

Introduction

To consider whether the solution increased or decreased the number of route under-separation and under-spacing events, specific data analysis of each of the validation simulations was undertaken, this includes data from Solution and Reference runs. These can be summarised as follows (the complete list of validation runs can be found in Appendix B):

13 Reference Runs:	RECAT-EU with OSD tool (RWY 27R) = 5 runs
	RECAT-EU with OSD tool (RWY 09R) = 3 runs
	PWS-D with OSD tool (RWY 27R) = 3 runs
	PWS-D with OSD tool (RWY 09R) = 2 runs
27 Solution Runs:	RECAT- EU with extended OSD tool & TMA data feed (RWY 27R) = 5 runs
	RECAT- EU with extended OSD tool & TMA data feed (RWY 09R) = 4 runs
	RECAT-EU with extended OSD tool (RWY 27R) = 3 runs
	RECAT-EU with extended OSD tool (RWY 09R) = 1 runs
	PWS-D with extended OSD tool & TMA data Feed (RWY 27R) = 7 runs
	PWS-D with extended OSD tool & TMA data Feed (RWY 09R) = 1 runs
	PWS-D with extended OSD tool (RWY 27R) = 3 runs
	PWS-D with extended OSD tool (RWY 09R) = 3 runs

Furthermore, incorporated into six of the Solution runs were non-nominal (abnormal scenarios) (Details of these scenarios have been detailed in A.1.1.2 and Appendix B).

The following parameters have been applied throughout the analysis to determine which aircraft were under-separated or under-spaced and thus, the definitions which have been used are as follows:

Under-separation is when the distance between the leader and the follower is less than 3NM (where 3NM equals minimum radar separation at Heathrow) measured at the point when the follower aircraft is at 1.5NM from the stop end of the departure runway.

Under-spacing is when the distance between the leader and the follower is greater than or equal to 3NM and under the target distance spacing (either 3.5NM or 5NM for diverging and same/similar SIDs, respectively) measured when the follower aircraft is at 1.5NM from the stop end of the departure runway.

- For a target spacing of 5NM (same/similar SID pairs), it would be greater or equal to 3NM and less than 5NM.
- For a target spacing of 3.5NM (diverging SID pairs), it would be greater or equal to 3NM and less than 3.5NM.

Reduced Separation Procedures

Another key factor to understanding the data for aircraft pairs that achieved less than 3NM at the Delivery Points, is that ATCOs can apply Reduced Separation (RS) procedures on departure if certain conditions exist. There are two forms of RS which shall be discussed:

Reduced Separation in the Vicinity of an Aerodrome (RSVA)³ is a permitted form of reduced separation within the immediate vicinity of aerodrome provided that:

- (1) adequate separation can be provided by the aerodrome controller when each aircraft is continuously visible to this controller;
- (2) **or** each aircraft is continuously visible to the pilots of other aircraft concerned and the pilots report that they can maintain their own separation;
- (3) **or** when one aircraft is following another, the pilot of the succeeding aircraft reports the other aircraft is in sight and can maintain their own separation.

Alternatively, an ATCO can apply a time spacing that will achieve '3NM and increasing' on the Aerodrome Traffic Monitor (ATM) radar for **diverging** pairs. This can be used instead of applying a 2-minute procedural time separation for certain SID pairs.

The data from the validation simulations has been split, where RS has been applied (and identified) by the ATCO and where there was no documentation of RS being applied. This will show the effect of RS on the final distance separations achieved in the RTS.

Furthermore, any early diverging SID pairings with a procedural 60 second separation time have been excluded from the analysis as the extended OSD tool does not support these (i.e., no route countdown timer available).

Limitations and Assumptions of the Route Under Separation / Under Spacings Analysis

Limitation 1 - The under-separation distance has been measured from the point when the follower aircraft reaches 1.5NM from the stop end of the departure runway. There are some departure pairs (2.26%) where the follower does not reach 1.5NM from the stop end due to a tight turn shortly after take-off for their respective SID profile, therefore, the separation distance has not been measured for these cases.

Limitation 2 - When comparing ATCO's delivery time versus the time given by the extended OSD tool route countdown timer, only the instances where the ATCO delivery time was equal to or exceeded the route countdown timer have been included (to remove the effect of controller delivery performance where possible).

Assumption 1 - There are occasions during the Reference runs where it is believed that the use of RS was not recorded or indicated by the ATCO and subsequently the data showed that certain departure pairs were under-spaced / under-separated (according to the definitions provided above). To enable a more accurate comparison of under-spacings and under-separations between the Solution and Reference run occurrences, feedback has been sought and provided by ATCOs which has indicated that for DET – MAX departures, RSVA is most frequently and routinely applied when conditions allow. By using this evidence and comparing when RSVA was applied to DET – MAX departures in the Solution Runs with similar weather conditions, it has been assumed, that any recorded under-separation or under spacing for DET – MAX departures in the Reference runs has been due to the use of RSVA and was thus omitted from the analysis.

³ CAP 493 [9] Chap 3 Para 3A.

Assumption 2 - There are occurrences of under-spacing and under-separations where the time spacing applied by the ATCO was below that advised by the extended OSD tool and there was no indication of RS being applied. In these cases, it is assumed that the controller either did apply RS, but did not indicate it during the run, or did attempt to follow the route countdown timer, but over-estimated the roll time of the follower aircraft in the simulation so that it became airborne before the countdown timer reached zero. These occurrences have been omitted from the analysis.

Assumption 3 - The Solution run data for PWS and RECAT-EU wake separation schemes have been combined as the wake scheme in use should not impact the likelihood of a route under-separation or under-spacing event occurring.

Analysis of Total Number of Route Under-Separations / Under-Spacings (Solution vs. Reference Runs)

From the initial analysis of the data, there were a total of 262 under spacings and under-separations recorded over the 40 validation runs; however, further investigations into these events (detailed in Table 15), showed that the majority of these were due to the use of permitted Reduced Separation (RS) procedures as detailed below.

Furthermore, in order to provide relevant evidence for the success criterion CRT-37-W3-DEMOP-004-SAF-002b⁴, the following occurrences (Table 15 in grey) have been omitted from further analysis:

- (1) Those where ATCOs have applied RS (RSVA procedures).
- (2) Those where the ATCO delivery time was below the time displayed on route countdown timer. These instances could be due to either the controller not following the tool and not indicating on EFPS they had applied RS or they over-estimated the roll time of the follower aircraft in the simulation and it became airborne before the timer reached zero. In these cases, it would appear that the ATCO decided to override the tool information with their own decision making based on their experience and knowledge. As previously described in Assumption 2, these occurrences have been omitted from the analysis for this success criterion CRT-37-W3-DEMOP-004-SAF-002b.
- (3) Through feedback gathered from the ATCOs, a DET-MAX departure pair has RSVA applied most routinely in clear conditions. After examination of the data, there were 11 x DET-MAX departure pairs that had MET conditions that were suitable for RSVA or other form of Reduced Separation to be applied during exercise Reference runs 2.3, 4.3, and 6.1., therefore, as previously described in Assumption 1 these occurrences have been omitted from the analysis for this success criterion CRT-37-W3-DEMOP-004-SAF-002b.

Thus, the analysis for this report will focus on the 16 occurrences from the Reference runs which will be compared with the 8 occurrences from the Solution runs to help validate the criterion. These have been highlighted in bold in Table 15.

⁴ CRT-37-W3-DEMOP-004-SAF-002b: There is evidence that the ITARO Departures Solution does not increase the number of route under spacing events relative to the target distance spacing and compared to the Reference Scenario.



	Reference	Solution 1	Solution 2	Solution 2 – Abnormal ⁵	Total Across all runs
Total number of under-spacings and under-separations	84	65	71	42	262
Of Which:					
Reduced form of separation was applied	57	47	50	28	182
ATCOs delivery time was less than time dictated by the extended OSD tool	N/A	16	18	11	45
Under-separations/under-spacings most likely to have had RS applied but not indicated based on feedback from ATCOs (i.e., DET-MAX SID pairs in clear conditions)	11	N/A	N/A	N/A	N/A
Number of separations not affected by applied reduced form of separation or ATCO's delivery time	16	2	3	3	24

Table 15: Number of under-spacings and under-separations across each solution and reference run and breakdown of the effects on the results.

Type of Run	Tool Used	TMA data feed
Reference	OSD	No
Solution 1	extended OSD	No
Solution 2	extended OSD	Yes

Table 16: Annotation references for each solution

Figure 9 shows the number of under-spacings and under-separations and indicates which run these occurred in.

⁵ Solution 2 – Abnormal refers to those exercise runs which incorporated abnormal scenarios into the simulation as previously described.

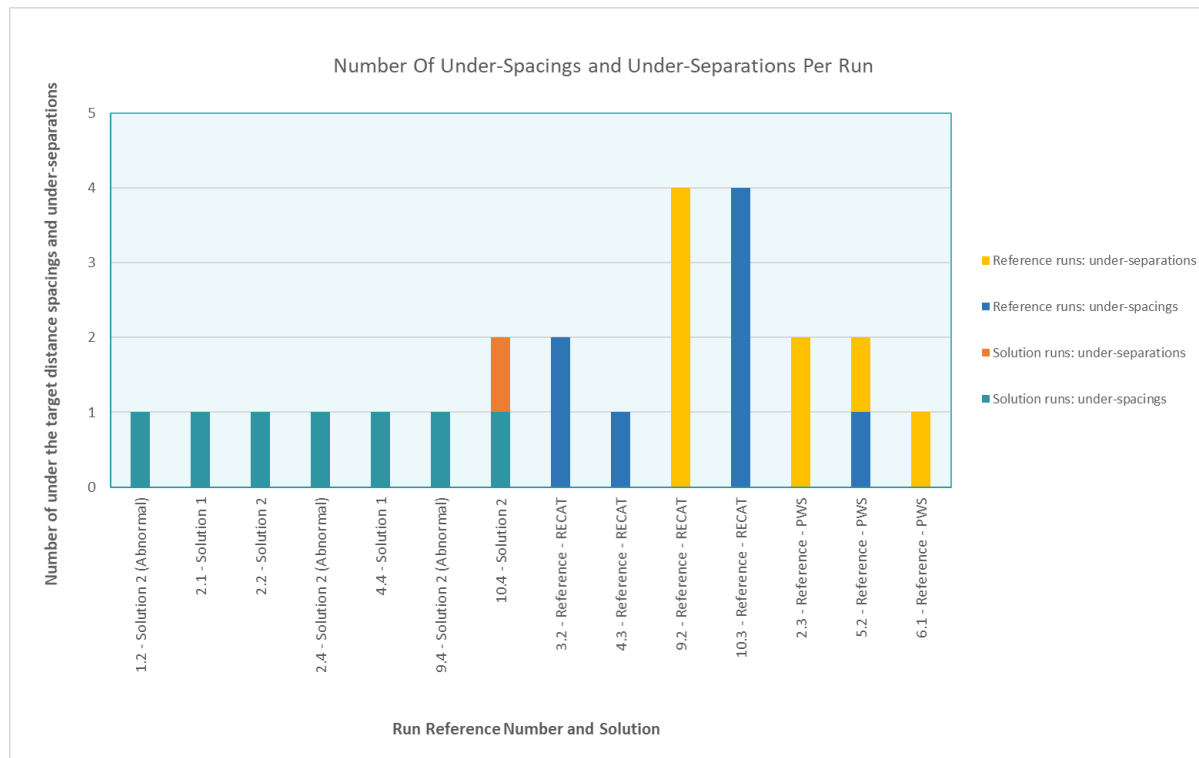


Figure 9: Number of Under Spacings and Under Separations per run.

The following summarises the data shown in Figure 9:

- 8 occurrences of under-spacing during the Reference runs.
- 8 occurrences of under-separation during the Reference runs.
- 7 occurrences of under-spacing in the Solution runs*
- 1 occurrence of under-separation in the Solution runs*

(*where the time achieved by the ATCOs was equal or greater than that given by the tool as per Limitation 3).

From the data presented, it can be seen that the Reference runs have a higher number of under-spacings and under-separations than the Solution runs (16 occurrences versus 8 occurrences).

The single under-separation that occurred during the Solution runs occurred during Run 10.4 when Solution 2 was tested (extended OSD tool with TMA data feed). This under separation was calculated to be under 3NM during Run 10.4 when Solution 2 was tested (extended OSD tool with TMA data feed). The distance achieved by the extended OSD tool was 2.98NM, whilst the applicable target distance spacing was 3.5NM and Minimum Radar Separation was 3NM. The extended OSD tool advised a 67 second separation, and the ATCO applied 70 seconds; this therefore suggests that the ATCO's delivery time was not an issue.

The under-separation for the Solution run occurred on the MAX-GOG SID pair (see Figure 25 for Heathrow SID chart). The MET conditions were a low tailwind with constant cloud at a ceiling of 500ft throughout the exercise, and the MDI (Minimum Departure Interval) was set to 4 minutes separation

for DET departures only. It is suggested that the MDI was not a factor in causing the under-separation event as the aircraft was departing on a different SID to that which the MDI was allocated.

The remaining 7 under-spacings for the Solution runs achieved a distance of above 3NM, however, they did not achieve the target distance of 3.5NM (for diverging SID pairs) or 5NM (for same SID pairs). The full details regarding the 8 occurrences for Solution runs can be found in Table 17 below (Run number 1.2, 2.4 and 9.4, which are highlighted in aqua contained abnormal scenarios as detailed in Appendix B).

Run Ref Number	Leader Callsign	Follower Callsign	Leader SID	Follower SID	Distance Separation Achieved	Distance Separation Target	Distance Difference Between Achieved and Target	Time Separation Achieved	Time Given by the Tool
1.2	AAL141	BAW2600	GAS	GAS	4.70	5	-0.30	91	91
2.1	BAW542	EIN15N	MAX	CPT	3.48	3.5	-0.02	77	69
2.2	BAW542	EIN15N	MAX	CPT	3.38	3.5	-0.12	74	69
2.4	BAW542	EIN15N	MAX	CPT	3.26	3.5	-0.24	70	69
4.4	MSR778	BAW314S	MAX	MAX	4.62	5	-0.38	99	90
9.4	MSR778	AUA4MG	MAX	MAX	4.64	5	-0.36	98	90
10.4	BAW9271	BAW704W	MAX	DET	4.23	5	-0.77	94	94
10.4	MSR778	BAW3576	MAX	GOG	2.98	3.5	-0.52	70	67

Table 17: Full Details of Under Spacings and Under Separations whilst using the extended OSD tool (Solution Runs).

A point to note whilst examining Figure 9, is the unequal number of runs in the Reference runs compared to the Solution runs; there were 13 Reference runs compared to 27 Solution runs. To achieve a direct comparison between the types of runs, a simple percentage comparison between the number of occurrences and the number of departures has been undertaken in Table 18.

Number of Departure pairs per run: Solution run = 1399 / Reference run = 676

Number of Under Spacings: Solution run = 7 / Reference run = 8

Number of Under Separations: Solution run = 1 / Reference run = 8

	Reference Runs	Solution Runs (with & without TMA data feed)	Difference
% of departures Route Under-Separated	1.18%	0.07%	1.11% decrease
% of departures Route Under-Spaced	1.18%	0.5%	0.68% decrease

Table 18: Table to show the percentage departures which were Under Separations and Under Spacings for both Solution and Reference Runs.

The calculated percentages in Table 18 show a decrease in both route under-separations and route under-spacings when using the extended OSD tool. However, consideration and thought should be taken with regards to whether the ATCOs had indicated RS had been applied during the Reference runs (Assumption 1) and Solution runs and additionally, where it has been assumed that the ATCO did not follow the tool and did not indicate RS correctly (Assumption 2). This leads to **Recommendation REC-37-W3-SAF-R1.1**: During future testing of this solution in future projects, more robust procedures should be created to ensure all forms of RS that ATCOs apply are recorded accurately and correctly in the simulation environment.

The data presented in Table 18 highlights that during the Solution runs where the extended OSD tool is being used by ATCOs, the percentage of under-separations and under-spacings have decreased resulting in: **Evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

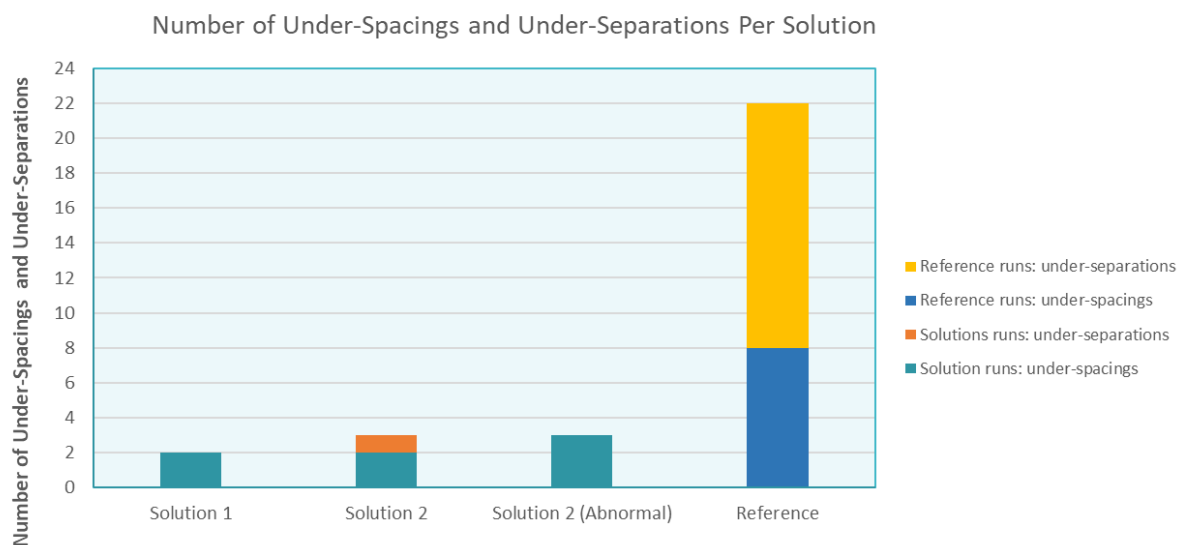


Figure 10: Sum of number of under-spacings and under-separations for each Solution and Reference runs.

Figure 10 shows the total number of under-spacings and under-separations for each solution.

Solution 1 – extended OSD without the TMA data feed.

Solution 2 – extended OSD with TMA data feed.

Reference – OSD without data feed.

The flow restriction is not found to have impacted the likelihood of route under-spacings and or under-separations as the MDI was applied to differing SIDs to where the under-spacings and under-separation occurred.

It can be seen that the under-separations and under-spacing occurrences for the Solution runs (including abnormal runs) are evenly distributed, highlighting that there is little correlation between occurrences with or without the TMA data feed. However, it is evident there is an increase in occurrences during Reference runs, which indicates that the use of the extended OSD tool in the Solution runs does decrease the number of under-separations and under-spacings, thus providing **Evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

Analysis of Rate of Route Under-Separations / Under-Spacings per 100 000 Departures (Solution vs. Reference Runs)

A total of 40 exercises were undertaken during the validation simulations: 13 Reference runs compared with 27 Solution runs. In order to compare and contrast the number of under-spacings and under-separations of both the Solution and Reference runs, a rate of under-spacings and under-separations per 100 000 departures has been produced. This figure has been calculated by using the sum of departures throughout all Solution 1, Solution 2, Abnormal and Reference runs (see Appendix B.1– Number of Departure pairs) and by determining the ratio of under-spacings to total number of departures. The ratio was then used to calculate a rate per 100 000 departures.

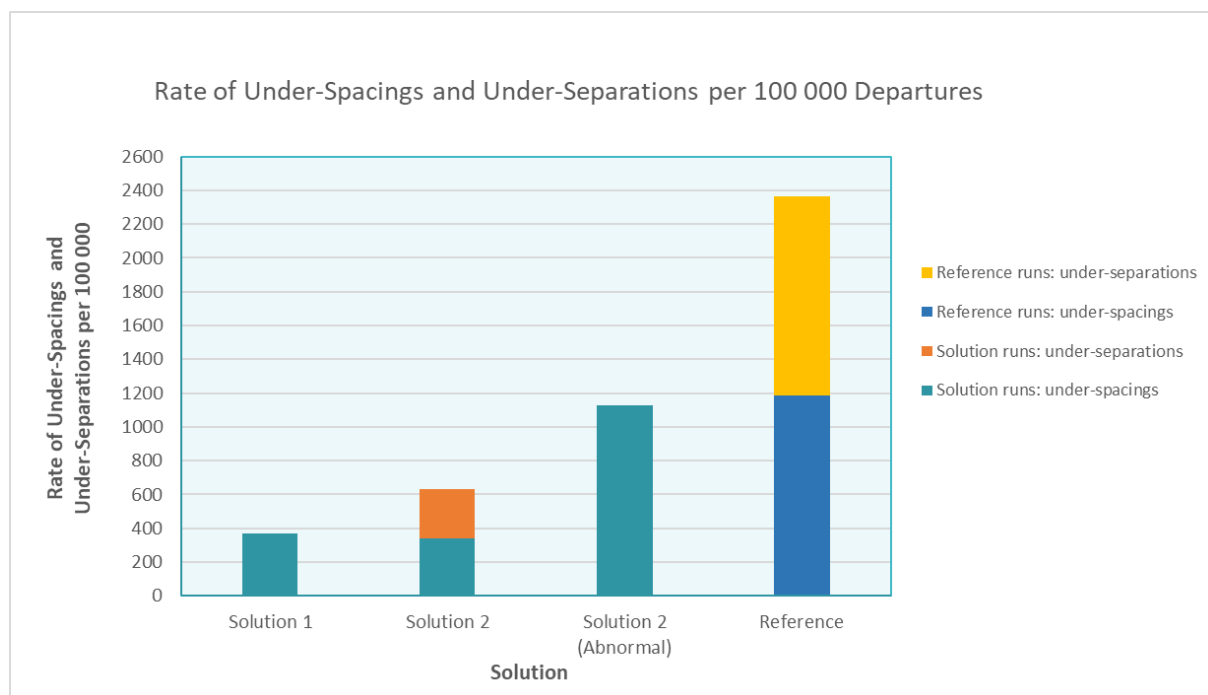


Figure 11: Rate of Under Spacing / Separations per 100 000 departures per each Solution and Reference Run.

As previously stated, the flow restriction / MDI is not found to have impacted the likelihood of an under-spacing or under-separation as the MDI was applied to different SIDs to where the under spacings and under separation occurred.

It can be seen in Figure 11: that the number of Reference run under-spacings are nearly equal to the number of under-spacings occurring when using Solution 2 (Abnormal). It should be noted that in live operations the number of abnormal incidences would be considerably less than what was experienced in the validation simulations (the abnormal runs were incorporated into the exercises to test the system and the ATCOs reactions rather than replicate the number of occurrences which would normally occur). Furthermore, since the solution scenario does not introduce any additional under-separations or under-spacings even in abnormal conditions when compared to the Reference Scenario, it is concluded that the extended OSD tool does not present a negative impact in terms of this success criterion.

By discounting the result for abnormal situations, the use of the extended OSD tool in the Solution runs has reduced the number of under-separations and under-spacings when compared to the Reference runs per 100 000 departures and thus provides **Evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

Analysis of Under Separations / Under- Spacings per SID Pair (Solution vs Reference Runs)

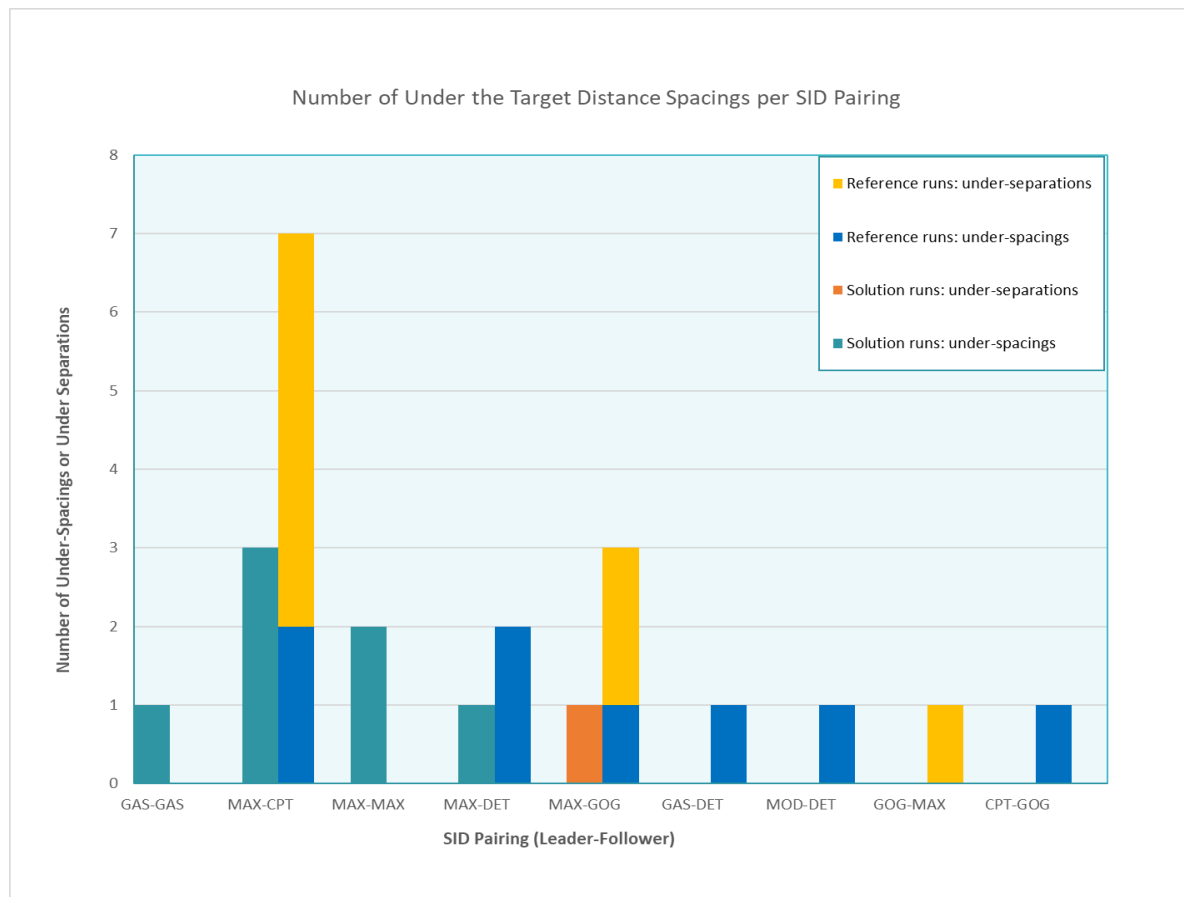


Figure 12: Number of under-spacings and under-separations per SID pairing.

Figure 12 shows the number of under-spacings and under-separations per SID pairing for both Reference runs and Solution runs.

- MAX – CPT was the SID pairing with the highest number of under-spacings (3) for the Solution runs.
- MAX – CPT was the SID pairing with the highest number of combined of under-spacings (2) and under-separations (5) for the Reference runs.

The high number of under-spacings and under-separations during the Reference runs could be related to the ATCOs not indicating when they used a form of RS. As described previously and detailed in Assumption 1, the DET-MAX departure profile is where RSVA is most frequently applied if weather conditions permit. The use of RS is however not permitted for MAX-CPT, MAX-DET, MAX-GOG, GAS-

DET, GOG-MAX or CPT-GOG (see Figure 25 for Heathrow SID chart); therefore, these departure profiles are most likely to be the legitimate under-spacings and under-separations during the Reference runs.

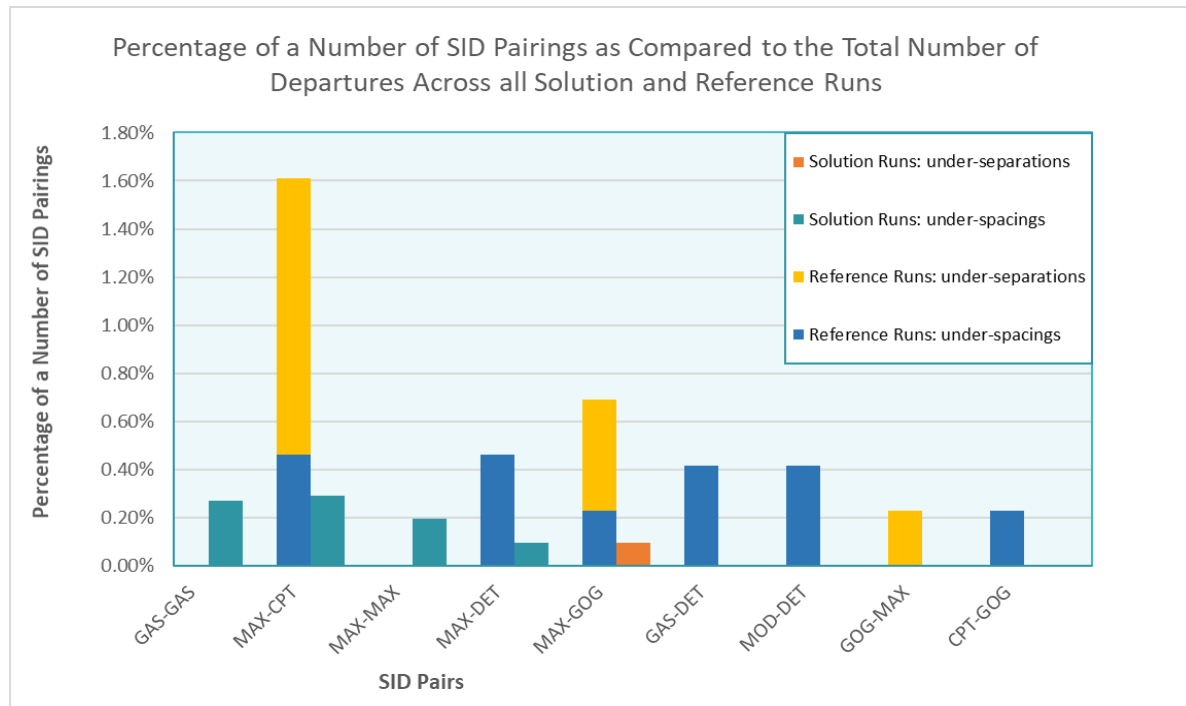


Figure 13: Number of under-spacings and under-separations per SID pairing displayed as a percentage of total number of departures.

Figure 13 shows each SID pairing as a percentage of the total number of departures where the pairing was possible (runway dependant), for both Solution & Reference runs. It is worth noting, that through all the Solution runs, the GAS-GAS departure profile only occurred once, and this resulted in an under-separation. Furthermore, under spacings seem to be more prominent with MAX leaders during the Solution runs.

In the Solution runs, the extended OSD tool performance seems to be worse with certain SID pairs, such as GAS-GAS where 1 under-spacing occurred out of 1 flight pair, and the MAX-MAX pairing where 2 under-spacings occurred out of 4 flight pairs, however due to the small number of pairs it is not possible to conclude whether this is statically significant.

The under-spacings for the Solution runs are more prominent with MAX leaders (7 out of 8 of the under-separation / spacing occurrences). However, in contrast MAX leaders are not as consistently associated with under spacings or under separations in the Reference runs as in the Solution runs. This leads to the **Recommendation REC-37-W3-SAF-R1.2**: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.

It can be seen from the data that by using the extended OSD in the Solution runs, there has been a reduction of under-separations and under-spacings across the spread of SID pairings (5 SID pairings for Solution runs compared to 7 SID pairings for Reference runs). However, as detailed above, there

appears to be issues in the Solution runs with those departures involving MAX leaders and those which were a same SID pair, GAS – GAS and MAX – MAX. Note there were no under-spacing or under-separations for same SID pairs in the Reference runs. Due to the presence of these contrasting results, it is concluded that there is **Partial evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

Analysis of Under Separation / Under- Spacings per MET Condition (Solution vs Reference Runs).

Figure 14 shows a sum of under-spacings and under-separations per each MET sample that was applied to both Solution and Reference runs. It shows a comparison between the Solution and Reference runs, and a split between under-spacings and under-separations.

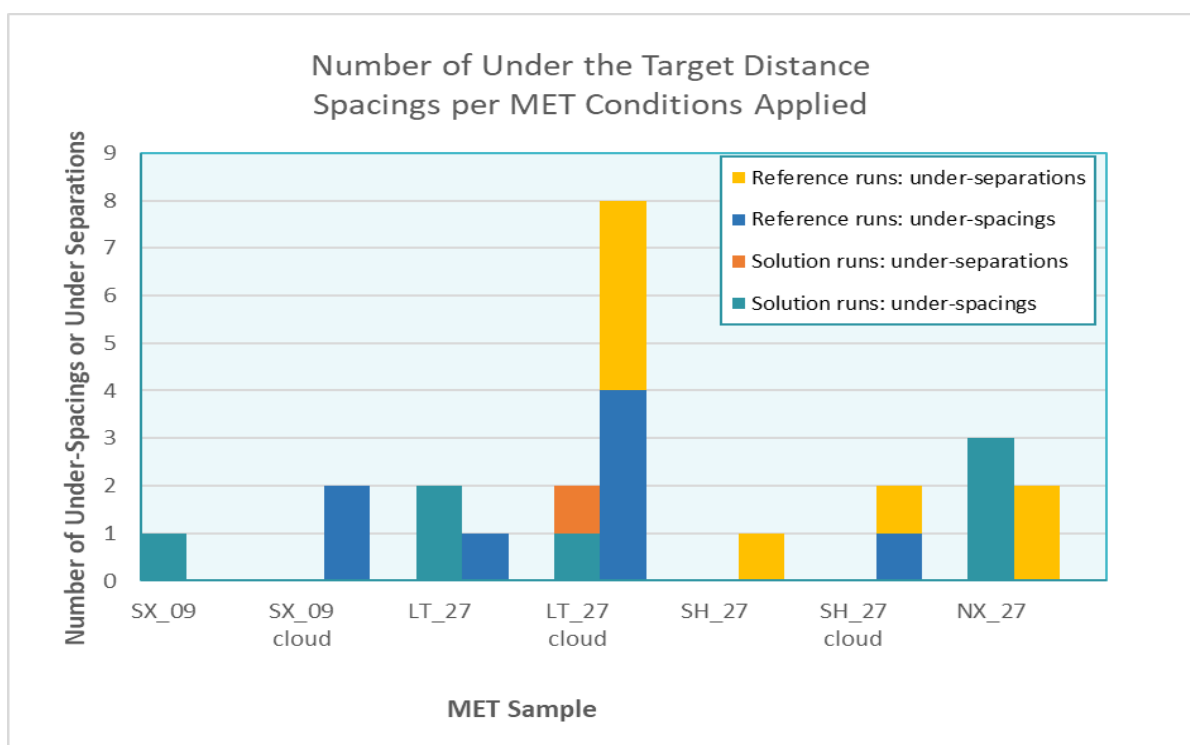


Figure 14: Number of under spacings and Under separations per MET sample during the solution runs. In scenarios where there was cloud indicated, it was static at 500ft.



Sample	Conditions	Direction
<i>SX_09</i>	Southerly Crosswind	09 (Easterly)
<i>SX_09 cloud at 500ft</i>	Southerly Crosswind static scenario; 35 mins transition into low cloud; 50mins transition out of low cloud	09 (Easterly)
<i>LT_27</i>	Low Tailwind	27 (Westerly)
<i>LT_27 cloud at 500ft</i>	Low Tailwind static scenario; low clouds at 500 feet for entire exercise	27 (Westerly)
<i>SH_27</i>	Strong Headwind	27 (Westerly)
<i>SH_27 cloud at 500ft</i>	Strong Headwind static scenario; low clouds at 500 feet for entire exercise	27 (Westerly)
<i>NX_27</i>	Northerly Crosswind	27 (Westerly)

Table 19: Summary of MET Samples used in Solution and Reference runs with corresponding Runway Direction.

For both the Solution and Reference runs, the highest number of under-spacings and under-separations occurred when using RWY 27.

	Runway 09	Runway 27
Total Number of Departure Pairs	608	1467
Number of Under Spacings / Under Separations	3	21
Number of Under Spacings / Under Separation as a percentage of the total number of Departure pairs	0.49%	1.43%

Figure 15: Summary of Under Spacings and Under Separation using MET conditions per Runway.

There were a total of 3 occurrences on RWY 09 (which equates to 0.49% of the departures) compared to 21 occurrences on RWY 27 (which equates to 1.43% of the departures), this could give some explanation to the higher number of events occurring on RWY 27.

When a light tailwind (LT_27) was applied on RWY 27 in the RTS, this resulted in the highest number of under-spacing and under-separation occurrences compared with the other MET conditions (Reference & Solution runs combined). Furthermore, when a static low cloud scenario at 500ft was added to the light wind conditions of LT_27, it resulted in the largest number of occurrences in the Reference Runs (8) and the only occurrence of an under-separation when using the extended OSD tool in this exercise. It is possible that the algorithm over-estimated the effect that the tail wind will have on reducing the leader's time to fly to its Delivery Point. However, the extended OSD is agnostic to the cloud conditions/visibility when calculating the route spacing time, so this is not expected to have contributed to the under-separation event for the Solution Scenario.

Consideration should also be taken regarding the difference between simulated weather and actual weather conditions. It is known that it is difficult to accurately replicate actual weather conditions into a simulated environment and thus these results may not fully demonstrate a true and accurate picture; however, it can provide evidence of certain departure profiles and wind conditions where the extended OSD tool can provide safety benefits to the ATCO and potentially reduce occurrences of under-separations. In this case and as highlighted in the data above, light tailwind conditions were found to be associated with the largest impact of the use of the extended OSD tool on the number of under-spacing and under-separations.

This evidence and analysis leads to **Recommendation REC-37-W3-SAF-R1.3**: Further investigation should be undertaken regarding the MET conditions used in simulations and its interaction with the algorithm in order to refine the calculation of the route time spacing required.

From the data it can be seen that the number of under-separations and under-spacings have reduced whilst using the extended OSD tool and as detailed above, it can provide safety benefits to the ATCO, however due to the simulated nature of the MET conditions it is unclear whether these results fully demonstrate a true and accurate picture therefore resulting in only **Partial evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

Analysis of Under Separation / Under-Spacings per Aircraft Pair (Solution vs Reference Runs)

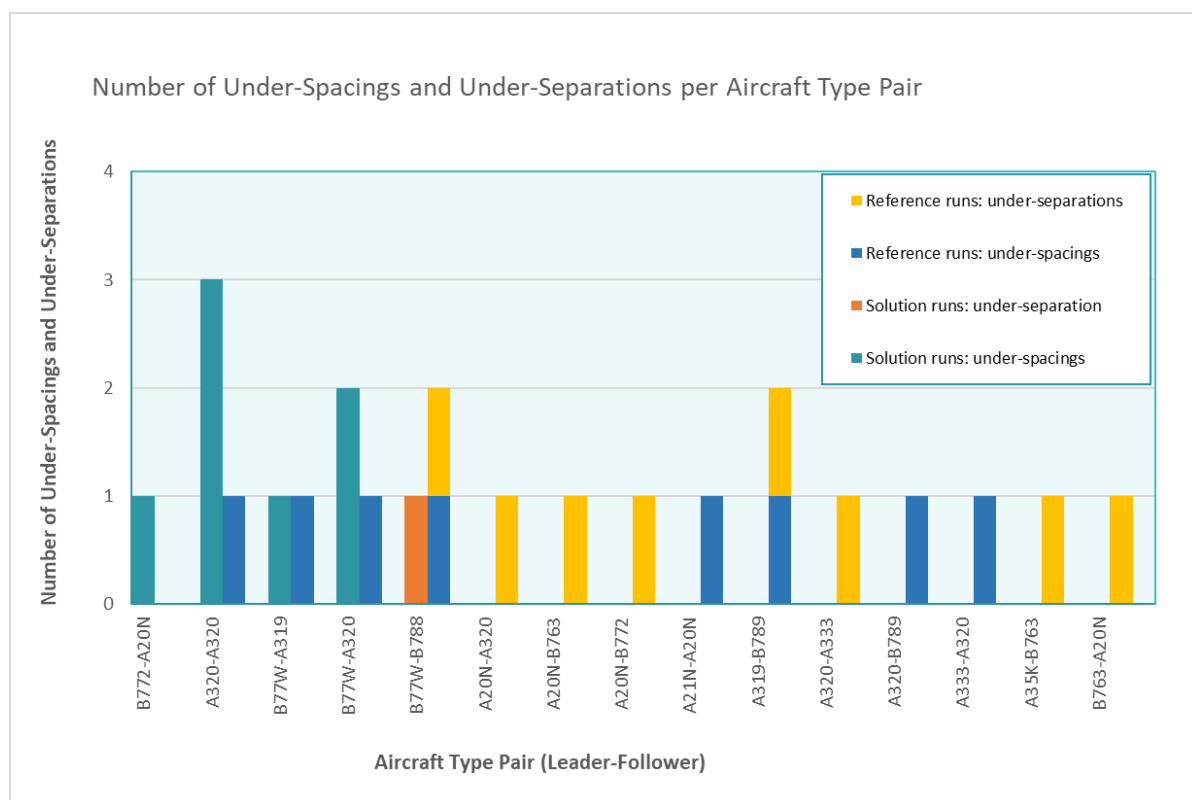


Figure 16: Number of under-spacings and under-separations per aircraft type pair for the Solution & Reference Runs.

Figure 16: shows the number of under-spacings and under-separations per aircraft type pair for the Reference and Solution runs. The following summarise the key points:

- Reference runs - There are a number of reoccurring under-spacings and under-separations where A20N and A320 are the leader aircraft.
- B77W as a leader resulted in 3 under-spacings and 1 under-separation for both the Solution and Reference run.

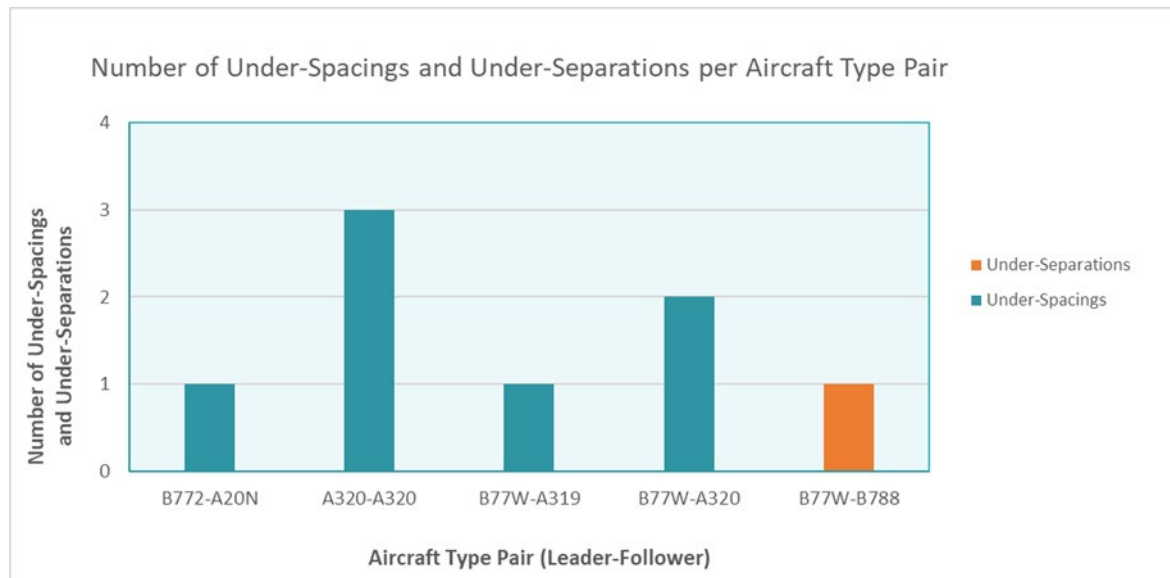


Figure 17: Number of under-spacings and under-separations per aircraft type pair for the Solution Run.

The under-separation for the Solution run (highlighted in orange) occurred when there was a wake pair with two category B aircraft (as per RECAT-EU). All under-spacings were B-D or D-D (Leader-Follower) pairings, where B-D is a wake pair and D-D is a non-wake pair. It is worth noting that four of the wake-constrained pairs in the distance under-separation analysis were also below the minimum wake separation requirement for the pair. However, these pairs are still of interest for the route under-separation analysis and the definitions of distance under-spacings and under-separations have been maintained.

The four pairs that were under-separated with respect to wake all achieved more than the Minimum Radar Separation (3NM) but were below the target route distance spacing and were therefore classed as under-spaced. In all four instances, the times displayed on the route and wake countdown timers were within 10s of each other, but in each case the route timer was lower than the wake timer.

(Note that an analysis of wake under-separations is provided in Section A.1.1.2.)

Figure 17: Figure 17-shows a slight correlation for certain types and under-spacing / under-separation occurrences for the Solution runs. These occurrences may be attributed to the simulated departure speed profiles associated with these aircraft types; the sim uses a simplified departure speed profile, whereas the extended OSD tool algorithm uses observed historical aircraft departure speed data.

Recommendation REC-37-W3-SAF-R1.4: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).

Although these results do not directly contribute to the success criterion, they support the overall results as they provide insight into the under-separations and under-spacings therefore, resulting in **No evidence to support CRT-37-W3-DEMOP-004-SAF-002b.**

Conclusions and Recommendations of the Route Separation / Under-Spacings Analysis.

Conclusion 1 – The percentage of under-separations and under-spacing where the extended OSD tool has been used in the Solution runs has decreased in comparison to the Reference Runs.

Conclusion 2 – In the Solution runs where the extended OSD tool, with and without the TMA data feed was used, the number of under-separation and under-spacings are evenly distributed and low in numbers. However, in the Reference runs, where TMA data feed was not used the number of under-separation and under-spacings occurrences increased.

The analysis has shown that there is reduction of under-separation and under-spacing occurrences when using the extended OSD tool in the Solution runs in comparison to the Reference runs, however, the following recommendations have been suggested for future iterations. These should improve the accuracy of the extended OSD tool and thus provide more robust evidence to support the concept to reach full maturity.

Recommendation REC-37-W3-SAF-R1.1: During future testing of this solution in future projects, more robust procedures should be created to ensure all forms of RS that ATCOs apply are recorded accurately and correctly in the simulation environment.

Recommendation REC-37-W3-SAF-R1.2: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.

Recommendation REC-37-W3-SAF-R1.3: Further investigation should be undertaken regarding the MET conditions used in simulations and its interaction with the algorithm in order to refine the calculation of the route time spacing required.

Recommendation REC-37-W3-SAF-R1.4: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment.

A.1.2.2 Analysis of Route Under-Separations / Under-Spacings based on Safety Questionnaires and Post Validation Simulation Workshop.

This sub section provides qualitative evidence for route under separations and under spacings based on ATCO feedback in the questionnaires and post validation simulation workshop. At the end of each day of validation exercises, ATCOs were asked to complete a safety questionnaire regarding the exercises they had undertaken.

ATCOs were asked *‘Using your own experience and judgement, please tick the relevant box according to the probability of an **under separation** (SID / Route separation) occurring when using this concept in comparison to current operations’*



Figure 18: Pie Chart showing ATCOs responses to question regarding the probability of under separations when using this concept in comparison to current operations.

The pie chart above clearly shows that two thirds of the ATCOs (10 out of 15) thought the probability of under separation would be the same as current operations, with another 4 suggesting that under separations are less likely to occur when using the concept / tool.

The ATCO who marked 'more likely to occur' further stated.

'Entered more likely ONLY if MDI restrictions not on system'.

With another stating that:

'The tool highlights when you are under separating and therefore draws attention to this fact'.

Although this evidence could be classed as subjective, it highlights that after only a short amount of time utilising the extended OSD tool, ATCOs felt confident with the tool output with regards to under separations, and indeed, if the MDI restrictions were displayed at all times, the responses would support the success criterion, this therefore provides **Evidence, although of a subjective nature to support CRT-37-W3-DEMOP-004-SAF-002b.**

Post Validation Simulation Workshop

During the post validation simulation workshop, ATCOs were asked to consider the issue of under separations when using the tool and in particular the possible outcomes which would occur if this did happen. Once these were established, the ATCOs then assigned a severity to each (the severity allows the reader to understand the severity of the outcome from the ATCO's perspective). The following summarises the discussion:

- Loss of Separation (Benign geometries) **Severity 3⁶**
- Increase in workload (Significant) **Severity 3**
- Increase in workload (Minor) **Severity 4⁷**

⁶ - Severity 3 – a situation from which opportunity for recovery is available within the ATC System and this recovery likely to be effective.

⁷ - Severity 4 – a situation which might result in confusion or non-optimal performance

The severities which were discussed and decided upon are no different to those when an under separation is experienced in operations today, therefore, providing some **(albeit subjective) evidence to support CRT-37-W3-DEMOP-004-SAF-001.**

Continuing the conversation with regards to the possible under separations, ATCOs were asked if an under separation did occur, what actions would be undertaken to recover the under separation and reduce the risk of a serious incident. Their actions would be:

- Issue a vector / control instructions to gain vertical separation of 1000ft or lateral 3 NM separation.
- Contact TC Controller for co-ordination and planning.

These actions would be no different than those undertaken in operations today, therefore, providing some (albeit subjective) evidence to support CRT-37-W3-DEMOP-004-SAF-001.

Result from the discussion with ATCOs – Partial evidence due to subjective nature of evidence to support CRT-37-W3-DEMOP-004-SAF-001.

ATCOs present in the workshop suggested that refinements of the algorithm may be required which re-iterates **Recommendation REC-37-W3-SAF-R1.2:** For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.

Furthermore, ATCOs proposed that safety buffers were applied on certain SID routes where the most under separations occur in both today's operation and those routes highlighted from the data analysis. This leads to **Recommendation REC-37-W3-SAF-R1.5:** Further investigations should be undertaken in future projects to examine the use of 'safety buffers' on certain route pairings.

A.1.3 Analysis of Departure Catch-ups in the TMA.

Due to the constraints of the project, a specific simulation to understand the impact of the solution on the TMA was not able to be undertaken. To help clarify any potential safety issues, a TMA controller observed four of the validation simulation exercises and took part in the post validation simulation workshop where, with their experience and knowledge, was able to provide some safety feedback which is detailed in Sections A.1.3.3.

Furthermore, to gain a deeper understanding of the potential impact of the extended OSD tool on the potential for catch ups in the TMA (after the spacing delivery points) two internal pieces of analysis were undertaken by NATS. The aim of the first analytical study (see Section A.1.3.1) was to examine aircraft performance in the TMA in general with a focus on aircraft catch-ups; it included quantitative analysis of existing catch-ups hotspots in the TMA, followed by a discussion with ATC experts, and utilised a representative sample of Heathrow departures traffic from pre-COVID-19 Operations focusing on SID pairs for which there was a procedural separation (as defined in MATS Part 2 [7]) of at least 2 minutes⁸. The second analytical study (see Section A.1.3.2) examined the critical catch ups that

⁸ In many cases an alternative form of reduced separation can be applied to these pairs, such as Reduced Separation in the Vicinity of the Aerodrome (RSVA), such that less than two minutes is delivered in practice. This depends on many variables including the SID pair, weather conditions and aircraft performance.

were identified in the first report and compared the time spacings that would have been advised by the extended OSD tool against the actual spacings that were delivered.

By using the evidence from both the NATS internal analysis reports as per the paragraph above, and the TMA controller feedback during and after simulation exercises, a high-level view was formulated of the likely impact of the extended OSD tool on the potential for catch-ups and under-separations in the TMA. Whilst the analytical data provides an accurate snapshot of departures at Heathrow for the time period assessed, it doesn't incorporate interactions from other airports in the vicinity of Heathrow, nor the effects of traffic congestion once established en-route within the airways structure in TC. For this, the experience and knowledge from the TC controller has been exploited.

A.1.3.1 Analysis of Current Departure Catch-Ups in the TMA

Introduction

The following section summarises the findings from an internal NATS report, which provided a departure separation analysis to assess whether aircraft pairs experience catch-ups in the **current operation** after the follower aircraft reaches a 1.5NM radial distance from the stop-end of the runway (which corresponds to the Spacing Delivery Point for the follower aircraft used by the extended OSD tool). The rationale behind this study is as follows:

- To ensure safe operation, there is a need to confirm that reducing spacings at the extended OSD tool delivery point does not lead to an increased number of under-separations in the TMA.
- It is not expected that deployment of the extended OSD tool will change aircraft performance in the TMA.
- Therefore, it is necessary to analyse existing operations to determine whether any “catch up hotspots” or conditions contributing to catch ups exist.
- For the identified hotspots and conditions, it is necessary to determine whether spacings at the point of delivery should be made more conservative to avoid catch-ups leading to under-separations in the TMA.

The key findings from this analysis highlight when and where in the departure phase catch ups are more likely to occur. An investigation into the causal factors for catch-ups beyond this delivery point has also been conducted to understand the extent that the spacing applied on departure contributed to these catch-ups.

Analysis was performed using radar data representing typical pre-Covid Heathrow departure operations from 1 Oct 2018 to 30 Sept 2019, i.e., a 12-month analysis period to encompass seasonal variations in weather and traffic.

Analysis Assumptions

1. For this analysis, a catch-up was defined as follows:
 - The lateral separation was less than the target distance separation for that SID pair (i.e., 5 NM for same/similar SID pairs and 3.5 NM for diverging SID pairs), and
 - The vertical separation was less than 1,500 feet, and

- The lateral separation between a departure pair decreased over the three preceding radar sweeps (including the current radar sweep).

Note that any given departure pair can experience multiple catch-ups. Where this was the case, the analysis considered catch-ups involving the same departure pair to be distinct if the catch-up instances were separated by more than 4 seconds. This enabled the analysis to distinguish between catch-ups that may be occurring at different phases of the departure.

2. It was assumed that catch-ups while Reduced Separation in the Vicinity of the Aerodrome (RSVA) procedures had been applied by the Tower Runway Controller were not of primary interest in the study. In order to make sure events where RSVA could have been applied were not included in the assessment, and not skewing the results, radar points that are typically within the visual range of the Tower were excluded from the assessment (London Control Region was assumed to represent the vicinity of the aerodrome). Excluding these radar points was considered necessary because dates / times with RSVA conditions are not recorded, and it is not possible to identify from historical data whether RSVA could have been applied to specific flights.
3. Only aircraft pairs flying on SIDs subject to a 2-minute (or above) procedural departure time separation were included in the analysis since these are the pairs which the extended OSD tool will provide support for.

Results

The analysis showed that 40 catch-ups (according to the definition above) occurred beyond the point to which the extended OSD tool provides spacing delivery support (i.e., when the follower reaches 1.5NM radially from the stop-end of the runway) during the 12-month study period. The analysis revealed that these events were infrequent with fewer than two catch-ups per 10 000 departures. Furthermore, none of the catch-ups resulted in a Loss of Separation.

Figure 19 shows the percentage of catch-ups as a function of the SID pair type, i.e. same, similar and diverging. As the extended OSD tool treats same / similar and diverging SIDs differently by applying different target distance separations, it was necessary to determine whether any particular SID type was generally associated with more catch-up instances.

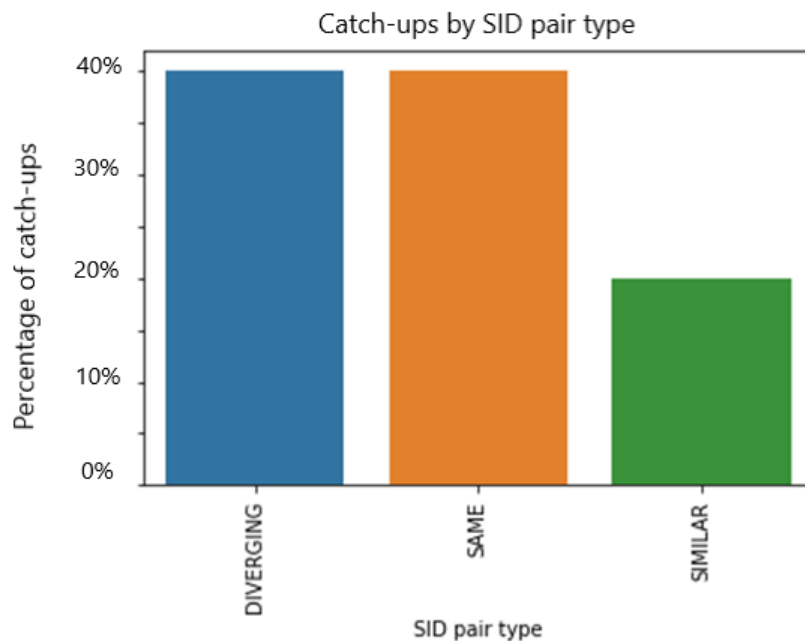


Figure 19: Catch up by SID Pair Type.

Figure 19 shows that 40% of the catch-ups occurred on same SID pairs and diverging SID pairs, respectively, whilst 20% occurred on similar-SID pairs. This percentage split is in line with the SID usage at Heathrow during the study period. Therefore, there is no evidence that SID type influenced the prevalence of catch-ups during the study period.

More than 65% of catch-ups involved departures from RWYs 27L and 27R, which was in line with the approximate 70:30 split between westerly and easterly operations at Heathrow during the study. Therefore, there is no evidence that the direction of the Heathrow runway operation (westerly or easterly) influenced the prevalence of catch-ups during the study period. It may also be inferred that the different geometries of SID pairs for the easterly and westerly runways have not had a notable effect on the prevalence of catch-ups.

Figure 20 shows the altitude distribution of where catch-ups occurred for both leader and follower aircraft (a Kernel Density Estimation is used).

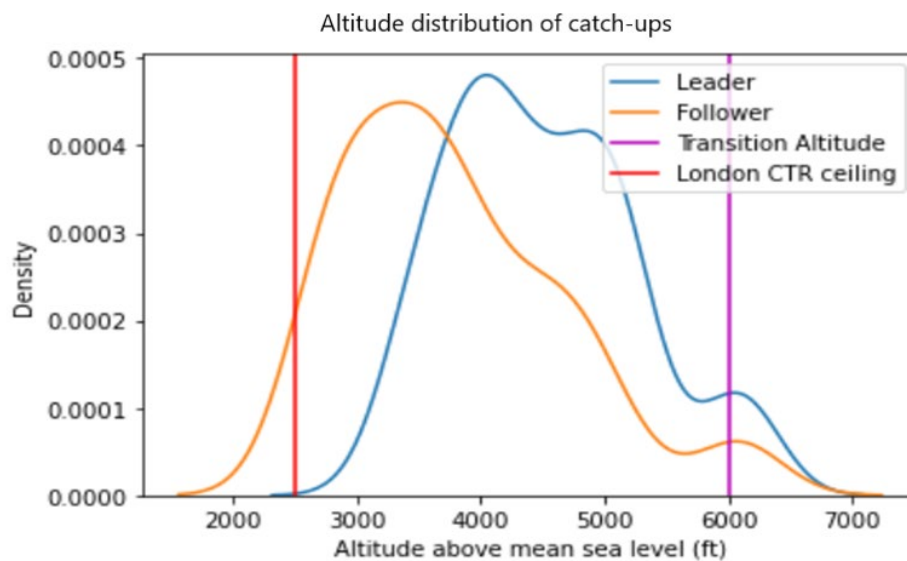


Figure 20: Altitude distribution of catch-ups.

In addition to the analysis of the altitude distributions of where catch-ups occurred, analysis of the locations of catch-ups was also performed. Figure 21 shows the locations of leader aircraft during identified catch-up events for aircraft departing on northerly SIDs from Runways 27L and 09R.

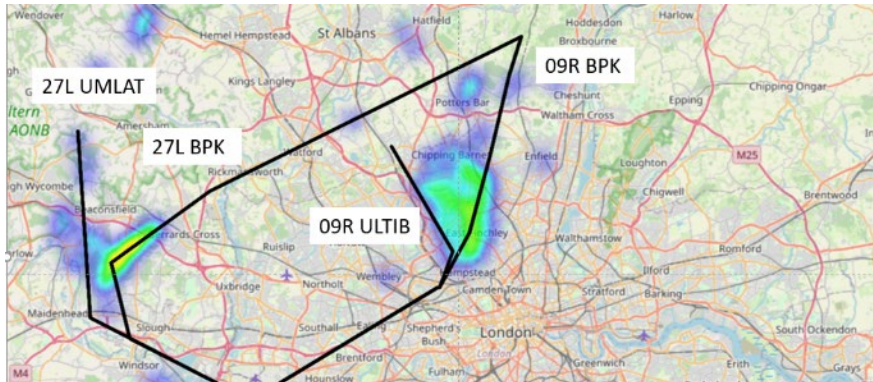


Figure 21: Heatmap showing locations of leader aircraft on northerly SIDs from 27L and 09R during catch-up events.

Figure 21 highlights two main areas where the follower exhibited a catch-up with its lead aircraft. Considering the western area first, which coincides almost perfectly with the simplified trajectory of the Brookmans Park (BPK) SID in westerly operation, it is found from publicly available SID charts that this section of the SID is associated with altitude requirements ranging from 4000 to 5000 feet. The finding of catch-ups in this area is supported by the altitude distribution of catch-ups in Figure 20, which shows a maximum of the distribution of leader altitude during catch-up also between 4000 to 5000 feet.

Considering the eastern area, which is located mainly between the BPK SID in easterly operation and the ULTIB SID, association to leaders on a specific SID is more uncertain due to the spread of catch-up locations. This is most likely to be an effect of the aircraft being vectored off the SIDs for a more direct routing, which is supported by statements from locally valid ATCOs. There are some indications of particularly high catch-up density on the easterly BPK SID at the point the BPK and ULTIB SIDs diverge. In reference to SID charts, this section of the BPK SID is again associated with altitude requirements in excess of 4000 feet, which is in agreement with the earlier conclusion drawn from the western area as well as Figure 21 Figure 20: .

The analysis indicates that SID geometry, particularly with strict altitude requirements, may be causal to the occurrence of catch-ups. While the highly localised appearance of the westerly SID catch-up area appears to indicate that a relatively sharp turn is the main contributor to a catch-up, the lack of catch-up for leaders on the easterly ULTIB SID seems to contradict this based on the available data. As such, the main causal factor is concluded, based on the available data, to be the period of climb as enforced by the altitude requirements after the first turn on the BPK and ULTIB SIDs.

In addition to the location of catch-up instances, their duration was also analysed to better understand potential impact on operation. Figure 22 shows the distribution of the catch-up durations recorded.

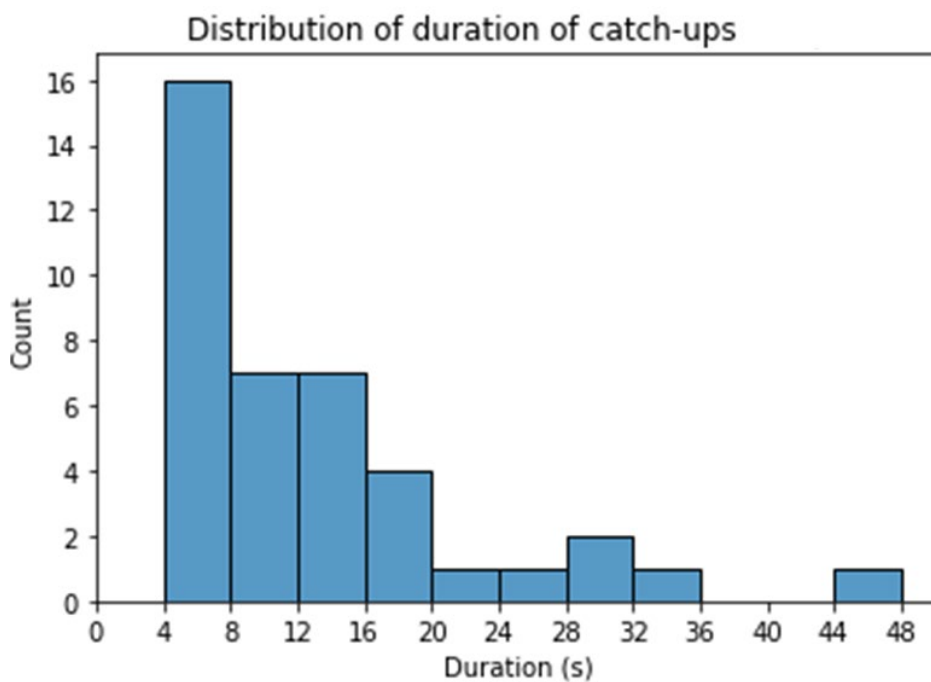


Figure 22: Distribution of catch-up durations

Figure 22 shows that 40% of the catch-ups satisfied the catch-up conditions for just 4 seconds i.e. one radar sweep. As such it is concluded that a majority of catch-ups are resolved rapidly, likely without ATCO intervention considering the time scales involved.

Additional assessment was conducted to investigate catch-up instances in excess of 30 seconds. This analysis showed they typically occurred within the lateral boundary of the London CTR, but above the vertical ceiling of 2500 feet above mean sea level.

Figure 23 shows the rate of catch-ups per 1000 departures by RECAT-EU category pairs.

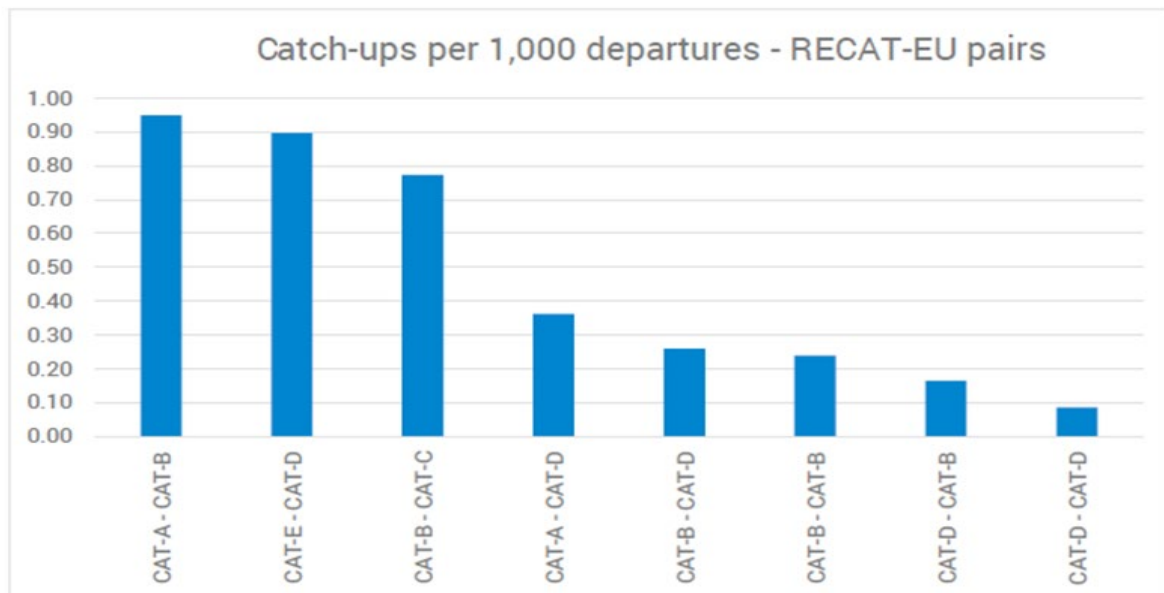


Figure 23: Catch-Ups per 1000 departures by RECAT-EU pair

Figure 23 shows that the rate of catch-ups per 1,000 departures was greatest for the following three RECAT-EU category pairs: CAT-A – CAT-B (0.95), CAT-E – CAT-D (0.90) and CAT-B – CAT-C (0.77). These pairings were disproportionately represented versus the RECAT-EU category mix at Heathrow, which is dominated by CAT-B – CAT-B, CAT-B – CAT-D and CAT-D – CAT-D departure pairs. This provides evidence that there are greater performance differentials between the aircraft types within these leader and follower wake categories, resulting in a greater probability of catch-up.

Causal Factors for Catch Ups

Following discussions with ATC experts, the following causal factors are considered most likely to have contributed to the occurrence of a catch-up:

- Differences in aircraft performance.
 - Differences in the performance of different generations of a given aircraft type.
 - Heavy, slow and low leader (e.g. an Airbus A380 flying ultra-long-haul and non-stop) versus a more agile follower (note this can be seen in Figure 20 where CAT-A – CAT-B aircraft are shown to have the highest probability of catch-ups occurring).
 - Certain aircraft types having poor climb and speed performance (e.g. the Airbus A340-300 series).
 - It is also possible that, in rare instances, the leader could have a minor technical problem (e.g. undercarriage not retracting, a flap malfunction) early in their departure that causes them to reduce their climb rate.

- Behavioural factors including:
 - ATCO variation in delivery of procedural departure time separations on same/similar SID pairs.
 - The Tower Runway Controller not fully accounting for aircraft/flight operations performance differences between the leader and follower aircraft.
- Differences in leader/follower flight crew familiarity with Heathrow departure operations.
 - Airlines leasing non-standard aircraft relative to their fleet mix and consequently using a non-standard flight crew that's unfamiliar with the Heathrow departure operation.

Conclusions and Recommendations.

- The analysis provides evidence that catch-ups can occur in the current operation beyond the spacing delivery point considered by the extended OSD tool (although none resulted in a Loss of Separation). This leads to **Recommendation REC-37-W3-SAF-R1.11**: Further investigations should be undertaken to assess the impact of the extended OSD tool on catch-up occurring in the TMA and if the defined spacing delivery points for the leader and follower aircraft are appropriate on a SID pair basis.
- Although there was no evidence that the type of SID pairing (i.e., same, similar or diverging) affected the probability of a catch-up occurring, catch-ups were more frequent on SID pairs where the leader aircraft's SID contained a turn shortly after take-off. This may be explained by the presence of altitude constraints requiring the leader to climb after a previously executed turn, which constrains the speed of the leader whilst the follower is accelerating during the initial climb-out phase and can thus result in a catch-up scenario. This leads to **Recommendation REC-37-W3-SAF-R1.12**: Further investigations should be undertaken to assess whether the target distance spacings assigned to SID pair combinations are sufficient.
- There is evidence that catch-ups in the TMA are more likely for certain wake pairings. This is likely to be due to the performance differentials between the aircraft types in those categories. For example, catch-ups were observed to be most likely between CAT-A (A380) and CAT-B pairs, which can be explained by the slow acceleration and climb rate of the A380 aircraft relative to aircraft types within the CAT-B category. As the extended OSD tool takes observed aircraft speed into account when calculating the departure time spacing, this should help to mitigate against catch-ups due to aircraft performance differentials.
- The suggestion from ATC experts that some TMA catch-ups are a result of ATCO variation in the delivery of procedural departure time separations for same/similar SID pairs would be mitigated by the extended OSD tool, which is expected to increase consistency between controllers. Similarly, the extended OSD tool should mitigate against cases where the Tower Runway Controller does not fully account for aircraft/flight operations performance differences between the leader and follower aircraft.

A.1.3.2 Analysis of Extended OSD tool Impact on Departure Catch-Ups in the TMA

Introduction

The following section details the findings from an internal NATS report, which assesses the expected impact of the extended OSD tool on the departure catch ups at Heathrow that were identified and analysed in Section A.1.3.1 and compares the time spacings that would have been advised by the extended OSD tool against the actual spacings delivered.

For the purpose of this study, the definition of a catch-up remains the same:

- The lateral separation was less than the target distance separation for that SID pair (i.e., 5 NM for same/similar SID pairs and 3.5 NM for diverging SID pairs) and
- The vertical separation was less than 1,500 feet and
- The lateral separation between a departure pair decreased over the three preceding radar sweeps (including the current radar sweep).

Results

There were 40 catch-ups identified between 1st October 2018 and 30th Sep 2019 (as previously described in Section A.1.3.1).

Of the 40 catch-ups, there were 35 unique departure pairs (where 5 departure pairs experienced two catch-ups). Of the 35 unique departure pairs, the route spacing calculated by the extended OSD tool was lower than the minimum wake separation in 4 cases (i.e., the wake separation would have been displayed by the extended OSD tool as it is the most constraining factor), and thus have been removed from the analysis. The remaining 31 departure pairs have been analysed by comparing the delivered spacing against the spacing suggested by the extended OSD tool.

The spacing suggested by the extended OSD tool was greater than the delivered spacing in 20 of the 31 catch-ups. From the data sample available, this indicates that the extended OSD tool would reduce the number of catch ups that occur; however, further investigation into the spacings of the 11 catch-ups where the extended OSD tool would suggest a smaller time spacing than that delivered operationally is required.

Result - Evidence to support CRT-37-W3-DEMOP-004-SAF-002b.

Spacings by Runway

Catch-ups occurred in all three departure runway modes currently in operation at Heathrow.

Runway	Extended OSD Tool Suggests Reduced Spacing Count	Extended OSD Tool Suggests Increased Spacing Count
09R	2	6
27L	6	3
27R	3	11

Table 20: Number of spacings of catch-ups increased / decreased by the extended OSD tool by Runway.



Runway 27L has the highest proportion of catch-ups, potentially exacerbated by the extended OSD tool at 67%, with RWY 09R at 25% and RWY 27R at 21%. However, the data available doesn't provide sufficient evidence to conclude that the extended OSD tool performs differently across departure runways and therefore there is **No evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.

Spacings by SID

Breaking the catch ups down by the SID of the leader and follower provides greater insight into where the extended OSD tool is suggesting reducing the spacings that led to catch ups historically. Due to the small sample size, many SID pairs had one or no catch ups in the study, making it difficult to ascertain any significant patterns in the data.

SID Pair	extended OSD Tool Suggesting Reduced Spacing Count	extended OSD Tool Suggesting Increased Spacing Count
BPK-BPK	6	2
BPK-UML/ULT ⁹	1	4
CPT-CPT	-	1
DET-CPT	-	2
DET-DET	-	1
DET-MID	-	2
GAS/GOG-DET	-	1
GAS/GOG-MID	-	1
MID-CPT	1	3
MID-DET	1	1
MID-GAS/GOG	-	1
UML/ULT-BPK	1	1
UML/ULT-UML/ULT	-	1

Table 21: Number of departure time spacings of catch-ups increased / decreased by the extended OSD tool by SID pair.

The extended OSD tool appears to reduce the chances of catch ups where the leader is on a CPT, DET, or GAS/GOG SID. Where the leader was on a MID¹⁰, or UML/ULT SID, the extended OSD tool increases the departure time spacing of the catch-up pairs in the majority of cases, but also has some catch-ups where the departure time spacing is reduced by the tool compared with what was applied operationally, i.e. it has the potential to make the catch-up worse.

⁹ BPK -UML – Runway 27 Departure in a northerly direction, BPK -ULT – Runway 09 Departure in a northerly direction. Figure 25 shows SIDs at Heathrow

¹⁰ - MID was used as a proxy for MAXIT and MODMI given that MAXIT and MODMI did not exist during the study period (1st Oct 2018 – 30th Sept 2019)

Particular attention should be given to BPK-BPK SID pairs. 75% of catch-ups on these SID pairs may have been exacerbated by the extended OSD tool since the departure spacing time suggested would be less than that delivered operationally. In fact, out of the 8 BPK-BPK catch-up pairs affected by the extended OSD tool as given by Table 21, 5 departed from RWY 27L and were assigned reduced spacing values. One of these cases suggested the same time as delivered but only after rounding up. Conversely, for BPK-BPK from Runway 27R, there were 3 catch ups and 2 of the spacings would have been increased by the extended OSD tool. Therefore, it is reasonable to deduce that the extended OSD tool is reducing spacings for BPK-BPK SID pairs that experienced critical catch ups specifically on Runway 27L.

Given the BPK-BPK SID pair has a larger sample size than the other SIDs and displays a clear and opposite pattern to the others, it can be concluded, and also leads to an addition into **Recommendation REC-37-W3-SAF-R1.2**: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.

Result -No evidence to support CRT-37-W3-DEMOP-004-SAF-002b.

Spacings by Aircraft Type

Catch ups occurred across 25 aircraft type pairs in the study. Figure 24 aggregates the aircraft type pairs by wake as categorised by RECAT-EU definitions:

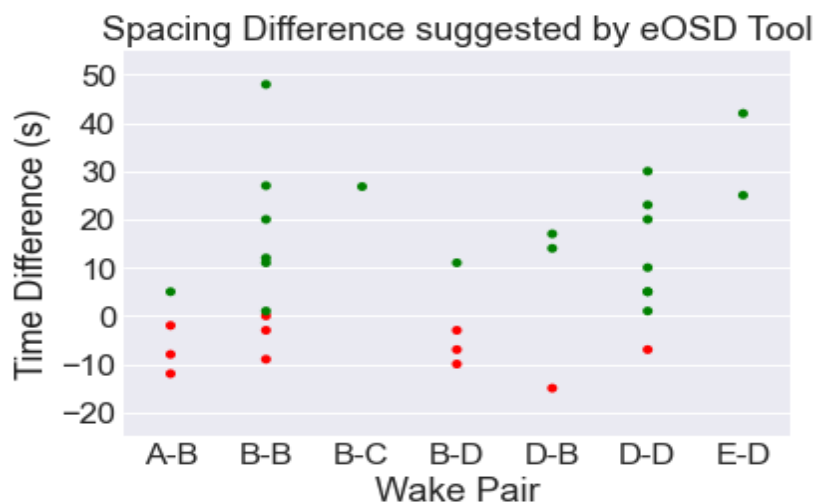


Figure 24: Number of departure route spacing times increased / decreased by the extended OSD tool for pairs that experienced catch-ups grouped by Aircraft Type (aggregated by Wake Pair).

75% of A-B and B-D wake pairs would have reduced spacings suggested by the extended OSD tool compared with the time spacing that was delivered operationally. Note that:

- All A-B pairs are an A388 followed by a B77W.
- The extended OSD tool would have advised a departure time spacing that was lower than that applied operationally for three B-D pairs:

- One spacing advised was exactly two minutes on BPK-BPK SIDs which equalled the procedural route separation outlined in MATS Part II for this SID pair. Therefore, the extended OSD tool did not suggest a smaller spacing than is currently advised.
- The other two were both A332s followed by A319/A320 from Runway 27L where the SID pair was BPK-BPK. It is therefore possible that the driving factor in the reduced spacings from the extended OSD tool is the Runway and SID pair rather than the wake pair. A larger sample size is necessary to deduce whether A332s followed by A319/A320s require improved departure speed data.

It is worth highlighting an A343 followed by A359 (B-B) where the extended OSD tool would have reduced the spacing by 9 seconds, an A320 followed by a B772 (D-B) where the spacing would be reduced by 15 seconds, and a A321 followed by A20N (D-D) where the spacing would be reduced by 7 seconds. There are no other data points of these aircraft type pairs in the sample of critical catch ups to discern whether there are issues with these aircraft.

This data analysis involving the differing aircraft types leads to **Recommendation REC-37-W3-SAF-R1.6**: A larger sample size of differing aircraft types should be utilised in future projects to deduce whether improved departure speed profiles are required and if there are any issues with specific aircraft speed data.

Result -No evidence to support CRT-37-W3-DEMOP-004-SAF-002b.

Summary of the Key Findings of the Analysis

- The extended OSD tool suggests an increased departure time spacing for the approximately 65% of catch ups that occurred at Heathrow between 1st October 2018 and 30th September 2019. This would result in the number of catch-ups reducing; however, it is possible that the severity of others could be increased.
- The sample size of 31 departure pairs experiencing a catch-up where the route spacing was the largest constraint is insufficient to draw firm conclusions on whether there is a correlation between specific SID pairs/aircraft types and when a smaller departure time spacing than delivered operationally was advised by the extended OSD tool where a catch-up occurred. This highlights that in this scenario there is **No evidence to support CRT-37-W3-DEMOP-004-SAF-002b**.
- There is evidence that the extended OSD tool algorithm needs refining to increase the spacing delivered for BPK-BPK SID pairs for departures on RWY 27L. Further analysis would be required to deduce whether the BPK-BPK target distance spacings also need reviewing on other departure runways. This supports **Recommendation REC-37-W3-SAF-R1.2**: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft. **Recommendation REC-37-W3-SAF-R1.9**: Further investigations should be undertaken in future projects regarding same SID pair departures, catch-ups and potential wake encounters above the Controlled Traffic Region.
- A388s followed by B77Ws appear to have a smaller departure time spacing advised by the extended OSD tool compared with what was delivered operationally where catch-ups occurred. Further investigation is required to deduce whether the departure speed profiles

associated with these aircraft types used by the extended OSD tool need refining. This re-enforces **Recommendation REC-37-W3-SAF-R1.4**: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).

- Further investigation into the appropriateness of the departure speed profiles for A343-A359, A320-B772, and A321-A20N aircraft type pairs is recommended as the extended OSD tool advised a smaller departure time spacing for these pairs compared with what was applied operationally when a catch-up occurred. This further re-enforces **Recommendation REC-37-W3-SAF-R1.4**: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).
- With the data available, it is difficult to determine whether cases where the extended OSD tool would advise a route spacing that the operational data suggests would result in a catch-up is due to a single input needing refining, e.g. runway, SID, or aircraft type, or whether it is a combination of these parameters that need refinement. There are other parameters that are not currently considered in the extended OSD tool prototype which may impact the delivered spacing including airline, destination, and air pressure. This leads to **Recommendation REC-37-W3-SAF-R1.8**: Further investigation should be undertaken in future projects to ascertain whether other significant parameters need to be included in the Solution (e.g., Airline, destination, and air pressure.)
- Only surface wind data was available for the analysis of catch ups in during 2018. The surface wind was therefore applied across all altitude bands to formulate the wind profiles for the 2018 catch-ups that were input into the extended OSD tool. This reduced accuracy of wind speed/direction at altitude for these 2018 incidents. However, changing a wind profile doesn't significantly alter the spacings advised unless direction and speed are altered significantly so it is unlikely that only using surface wind will have led to notable differences in results.

A.1.3.3 Key Insights Following Discussion with TMA ATCO

Whilst observing the simulations in the Tower environment, the TMA controller confirmed that it was difficult to accurately confirm whether any under separations between aircraft would occur in the TMA as a result of the solution (no TMA radar was available, and the assumption was made based on the simulated Tower radar screen and their personal experience and knowledge). In the post-validation simulation discussion, it was commented that if the extended OSD tool was refined and tuned correctly then the aircraft reaching the TMA should be adequately separated in accordance with ATC regulations and in theory, the number of under separations would be the same or if not, less than in today's operation (i.e., the extended OSD tool should reduce the behavioural causal factors which were highlighted in Appendix A.1.3.2). However, there was concern over whether this would still be the case when an aircraft was established in the TC area combined with certain unfavourable weather trends, especially strong winds and specific traffic / departure mixes.

The TMA controller described a potential unfavourable scenario which comprised of a strong upper wind combined with a steady stream of westerly same-SID departure pairs (CPT GOGSI from either Runway 27 or 09 – Figure 22). If the extended OSD tool was utilised during these conditions, the aircraft departing Heathrow could catch up once established in the TMA / TC as the tool only takes

into account the strong upper wind conditions up to the spacing delivery point and thus there could be potential catch-up issues if the wind changed significantly beyond this point. This potential catch-up issue and possible erosion in spacing was deemed by the TMA controller to cause both a minor increase in workload and a LoS (minor geometries). Currently, aircraft departing on this profile generally transit into the TMA with a separation of approximately 7 miles, this provides additional spacing on top of the required minimum radar separation for these pairs, thus allowing the ATCO to act accordingly if conflicts arise and maintain separations effectively with minimal increase in workload or LoS. If this scenario occurred and the aircraft were under separated, an additional issue which may need to be considered is that the likelihood of an en-route wake encounter in the upper airspace could increase. This situation could be impacted further by some, if not all of the following occurrences:

- i. Differing aircraft types / ToW (take off weight)*
- ii. Differing aircraft performance and flight crew performance*.
- iii. Operating Procedures unique to each airline*.
- iv. Interactions of other movements into and out of major airports in the London TMA which are utilising the same airways and reporting points*.

(cited at A.1.3.1 of the initial NATS Analysis as causal factors for catch ups)*

In order to account for the potential issue with differences in aircraft performance, especially when considering the planned distance to be flown and associated differing Take-Off Weights for different aircraft (e.g., extra take-off weight due to additional fuel for ultra-long-haul flights) it leads to the following **Recommendation REC-37-W3-SAF-R1.13** : An investigation into whether a destination reference table should be an input to the extended OSD tool should be carried out.

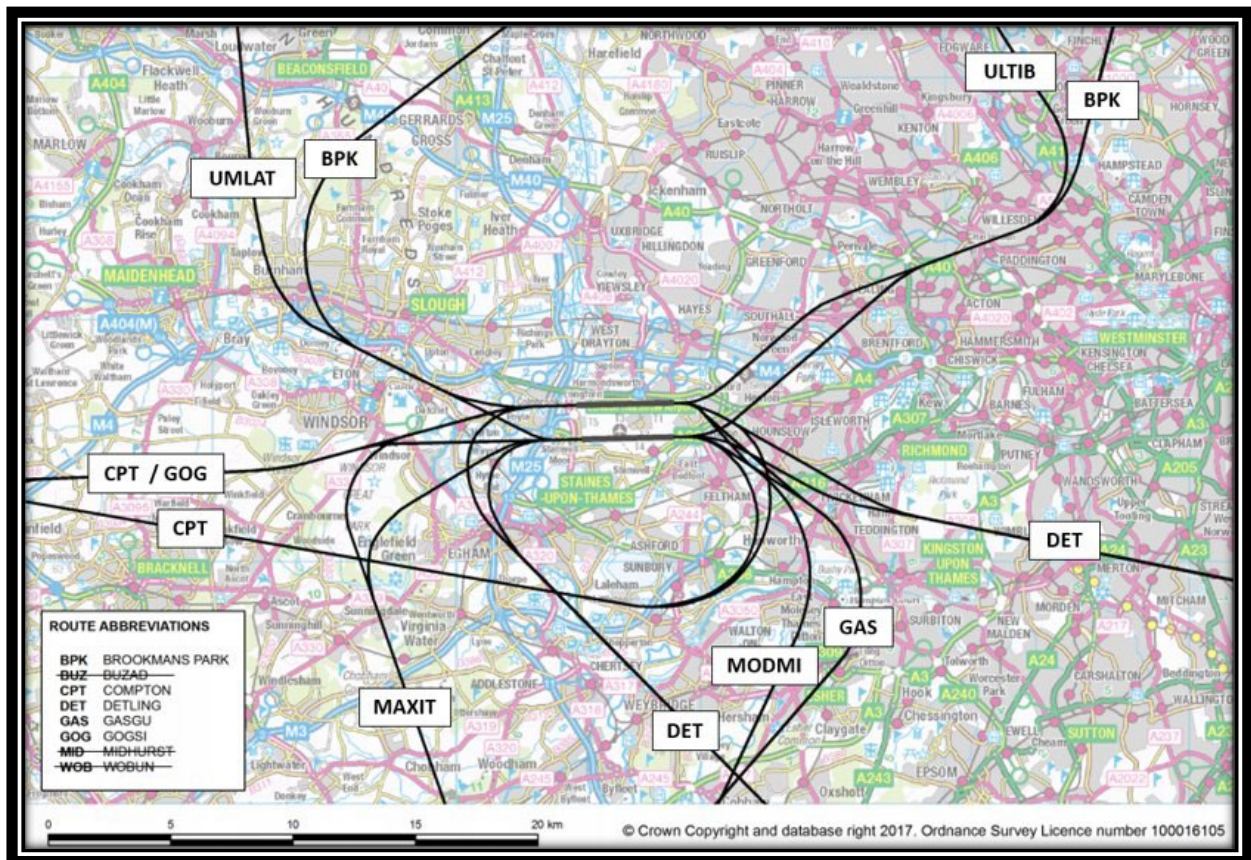


Figure 25: Standard Instrument Departures (SID) at Heathrow

The potential deployment of the extended OSD tool enables all departures to be delivered into the TMA with a more accurate spacing than is observed in today's operation¹¹. Considering this benefit and then applying the unfavourable scenario as described in above (a strong upper wind combined with a steady stream of westerly same-SID departure pairs), known areas of congestion / high traffic density could be congested further (e.g., in the London TMA, Compton (CPT) is at a confluence where multiple departure routes from alternate airports meet resulting in high traffic density and congestion). This congestion and possible ensuing safety issues could be seen by ATCOs by potential increase in tactical conflicts and or MRS infringements and a potential increase in en-route wake encounters above the transition altitude.

By considering the analysis presented in the internal NATS analysis report (see Sections A.1.3.1 and A.1.3.2) and the discussion with the TMA Controller, it leads to **Recommendation REC-37-W3-SAF-R1.7**: Additional simulations should be undertaken to explore the interactions of Heathrow departures with all traffic movements both through the TMA and into and out of the major airports in the London TMA, with a consideration to include unfavourable wind profiles at all levels. This exploration should

¹¹ The extended OSD tool is designed to give a 5-mile spacing between same and similar SID pairs

uncover if there any issues regarding the target distance spacings used in the extended OSD tool and the complexities of all traffic operating within the TMA environment.

In today's operation, the issue of congestion in certain areas and potential 'catch up' is managed by utilising a suitable flow management tool and controllers tactically managing the situation, accordingly, giving effective and timely deconfliction advice where appropriate. Furthermore, when possible, the practice of interleaving same SID pairs departures with northerly (e.g., UMLAT, ULTIB and BPK) or southerly departures (e.g., DET, MAX, MOD or GAS) can at times reduce this congestion (see Figure 29 SIDs at Heathrow).

The issue of same SID pairs was also raised in the internal NATS analysis of current TMA catch-ups (see Section A.1.3.1) when the same SID pair departures, BPK – BPK and MID – MID, resulted in being in the top three of catch-ups. Furthermore, Figure 20 shows that from historical data, there is a higher distribution of catch-ups at altitude. Additionally, as summarised in the second internal NATS analysis key findings, it highlights a potential issue with same SID pairs. These discussions and evidence lead to **Recommendation REC-37-W3-SAF-R1.9**: Further investigations should be undertaken in future projects regarding same SID pair departures, catch-ups and potential wake encounters above the Controlled Traffic Region (CTR).

A.1.4 Results on Operational Safety from Questionnaires

This sub section provides qualitative evidence for operational safety based on ATCO feedback in the questionnaires. At the end of each day of validation exercises, ATCOs were asked to answer the following question regarding the exercises they had undertaken:

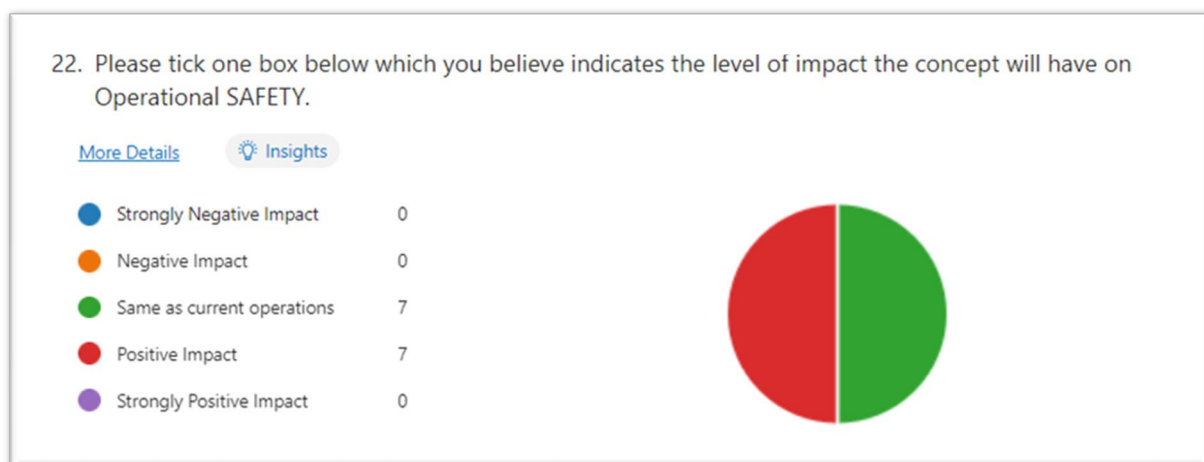


Figure 26: Pie Chart showing ATCOs responses to question regarding the level of impact the concept will have on Operational Safety.

The pie chart above clearly shows that all controllers felt that Operational Safety had **not** been impacted. 50% (7 out of 14) felt it was the same as current operations whilst the remaining 50% felt it had a positive impact.

ATCOs stated that the Solution:

‘Reduced workload’, and it gave a ‘more consistent operation’,

whilst another controller stated:

‘It had a positive impact providing that there were no failures’.

Furthermore, one controller specified that:

‘It gives confirmation to the ATCO that their plan is correct’.

Additionally, participants were also asked:

‘Are there any changes to procedures that you would like to see to improve the safety of this concept?’

Two controllers stated that the timer should be on EFPS and another specified that procedures should be designed in tandem with HMI (this is discussed in Section A.2.1 and recommendations suggested).

As previously mentioned, the evidence gathered from the questionnaires could be classed as subjective; however, it does highlight that in its present maturity the ATCOs who took part in the validation exercises felt positive about the extended OSD tool and its delivered benefits and confident that Operational Safety had not been impacted. This positive feedback provides **Evidence, although of a subjective nature, to support CRT-37-W3-DEMOP-004-SAF-001.**

A.1.5 Summary of Issues and Recommendations for CRT-37-W3-DEMOP-004-SAF-001, 002a & 002b.

A summary of the issues raised and potential mitigations / recommendations to assist in reducing occurrences of under spacing and under separation and their severity.

Safety Issue	Recommendation
To ensure Reduced Separation is recorded correctly and accurately.	REC-37-W3-SAF-R1.1: During future testing of this solution in future projects, more robust procedures should be created to ensure all forms of Reduced Separation that ATCOs apply are recorded accurately and correctly in the simulation environment.
To ensure accuracy amongst all SID profile combinations.	REC-37-W3-SAF-R1.2: For future iterations of the extended OSD algorithm, refinements are required to ensure accuracy of the input values to the extended OSD tool describing the SID profiles flown by aircraft.
Effects of simulated weather conditions on the algorithm.	REC-37-W3-SAF-R1.3: Further investigation should be undertaken regarding the MET conditions used in simulations and its interaction with the algorithm in order to refine the calculation of the route time spacing required.

To ensure realistic departure speed profiles are inputted in the in the simulation environment.	REC-37-W3-SAF-R1.4: Further investigation should be undertaken in future projects to ensure realistic departure speed profiles are used as an input in the simulation environment (note this aligns with Operational Feasibility REC-37-W3-OPF-R1 in the PJ.37-W2-01B Demo Report Part 1 [10]).
Reduce the probability of under separations on certain route pairings.	REC-37-W3-SAF-R1.5: Further investigations should be undertaken in future projects to examine the use of 'safety buffers' on certain route pairings.
To understand differing aircraft speed data and performance.	REC-37-W3-SAF-R1.6: A larger sample size of differing aircraft types should be utilised in future projects to deduce whether improved departure speed profiles are required and if there are any issues with specific aircraft speed data.
To ensure that the target distance separations used in the extended OSD tool are sufficiently accommodating of all traffic operating in the wider TMA environment.	REC-37-W3-SAF-R1.7: Additional simulations should be undertaken to explore the interactions of Heathrow departures with all traffic movements both through the TMA and into and out of the major airports in the London TMA, with a consideration to include unfavourable wind profiles at all levels.
To understand whether other parameters need to be included in the solution to increase accuracy.	REC-37-W3-SAF-R1.8: Further investigation should be undertaken in future projects to ascertain whether other significant parameters need to be included in the Solution (e.g., Airline, destination, and air pressure.)
To understand of what impact the Solution has on traffic above the Controlled Traffic Region.	REC-37-W3-SAF-R1.9: Further investigations should be undertaken in future projects regarding same SID pair departures, catch-ups and potential wake encounters above the Controlled Traffic Region.
To ensure wake separations are clearly displayed to the ATCO	REC-37-W3-SAF-R1.10: The HMI needs to clearly display when there is wake separation.
To understand the impact of the extended OSD tool on catch-ups in the TMA.	REC-37-W3-SAF-R1.11: Further investigations should be undertaken to assess the impact of the extended OSD tool on catch-up occurring in the TMA and if the defined spacing delivery points for the leader and follower aircraft are appropriate on a SID pair basis.
To assess the target distance spacings for SID pair combinations.	REC-37-W3-SAF-R1.12: Further investigations should be undertaken to assess whether the target distance spacings assigned to SID pair combinations are sufficient.
To assess the differences in aircraft performance, particularly the planned distances to be flown and associated differing Take-Off Weights for different aircraft.	REC-37-W3-SAF-R1.13: An investigation into whether a destination reference table should be an input to the extended OSD tool should be carried out.

Table 22: A Summary of Recommendations for OBJ-37-W3-DEMOP-SAF1-0008.

A.2. Analysis of OBJ-37-W3-DEMOP-SAF1-0009.

Objective	OBJ-37-W3-DEMOP-SAF1-0009	
Success criterion	CRT-37-W3-DEMOP-004-SAF-003: Evidence is gathered regarding the impact on safety and associated procedures that the ITARO Departure Solution has.	
Analysis result	A detailed analysis on this objective is provided below this table. It is summarised as follows: Safety Questionnaire: The main issues identified by the ATCOs on the questionnaires regarding the impact on safety was mainly surrounding both the HMI and the placement of the timer. Furthermore, there were some concerns surrounding the de-skilling of ATCOs manually calculating separations as they become reliant on the tool and that any changes to the procedures would need to be designed in tandem with the HMI. Post Validation Simulation Workshop. By utilising the main themes highlighted in the questionnaires and in the end of day discussions, the following safety issues were considered and deliberated amongst the participants, and suitable mitigations and recommendations suggested as follows:	
	Safety Issue	Recommendation
	Timer display	REC-37-W3-SAF-R2.1: A toggle switch should be provided to enable ATCO personalisation of the timer. (See also REQ-37-W3-HP-6)
	Placement of wake and SID countdown timer	REC-37-W3-SAF-R2.2: A HMI workshop should be held to discuss suitable placement of the extended OSD tool output. (See also REQ-37-W3-HP-7)
	Placement of MDI and TMA data feed information	REC-37-W3-SAF-R2.3: A HMI workshop should be held to discuss the suitable placement of the MDI and TMA data feed information
	Ability for ATCO to undertake other safety critical tasks	REC-37-W3-SAF-R2.4: During the next wave of this solution, more scenarios and tasks that ATCOs experience daily should be incorporated into the simulated exercises.
	Procedures when extended OSD tool fails	REC-37-W3-SAF-R2.5: A simple to follow separations matrix and immediate action procedures should be produced to enable safe operations to continue.

	Procedures to deal with skill fade	REC-37-W3-SAF-R2.6: HF, Safety and ATCOs should fully investigate the required procedures, tasks and possible ATCO training requirements in the event of tool failure.
	Future deployment and effect on current procedures	REC-37-W3-SAF-R2.7: All ATC procedures which will be affected by the deployment of the tool should be highlighted early in future projects to assess for any major safety issues.
	Refresher training to enable ATCOs to manually calculate separations if extended OSD tool fails.	REC-37-W3-SAF-R2.8: Further investigations are required to fully understand the content, duration and frequency of training required for ATCOs to sufficiently maintain currency and skills to manually apply accurate and efficient separations.
Results	OK	

Table 23: Extended results of OBJ-37-W3-DEMOP-SAF1-0009.

A.2.1 Key Insights following ATCO Feedback.

Procedures Relating to the Timers

The simulations utilised two different countdown timers: one timer gave the ATCO the wake separation between pairs (this feature has already been validated in Wave 1 – RTS5), and the second timer gave the SID / Route spacing between departing pairs to achieve the target distance spacing. Due to limitations of the available simulation equipment, it was decided that both timers were to be placed on the ADIS (see Figure 27 and Figure 29) to the left of the Tower controller.



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Figure 27: Picture showing SID/Route Timer on ADIS - (outlined in red).



Figure 28: Zoom-in of ADIS screen detailing the SID / Route timer.





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Figure 29: Picture showing Wake Timer on ADIS - (outlined in red).



Figure 30: Zoom-in of ADIS screen detailing the Wake Timer.





Figure 31: ATCO Simulated Tower position. ADIS to the left of the ATCO (outlined in Yellow)

In the post sim workshop discussion, the following point was raised regarding how the time was displayed on the equipment:

- During the simulated exercises both timers (wake & SID) displayed the required separation in minutes and seconds, however, from a safety perspective this could be confusing to some controllers.

For example, the ATCOs explained that a timer showing 1m40 could be read as either 100 seconds (60 seconds + 40 seconds) or 140 seconds. This confusion could result in the ATCO applying an incorrect separation, which may lead to a under separation, a wake infringement or worse, a wake encounter. With these possible safety incidents in mind, this leads to **Recommendation REC-37-W3-SAF-R2.1**:- A toggle switch should be provided to enable ATCO personalisation of the timer. (It is noted and assumed that all controllers would undergo training and become more familiar on using the extended OSD tool and its associated equipment and therefore this safety issue over how the time is displayed should reduce to nil.)

Placement of Timers, MDI information and TMA data feed.

Although more related to HF, the placement of the timers could prove an issue from a safety perspective. ATCOs stated that the timers need to be in a prominent position where the timings displayed would not be confused or misinterpreted with any other information already being displayed to controllers. If there was confusion or misinterpretation, this could lead to incorrect separation standards (both wake and SID) being applied when issuing take-off instructions. Whilst some controllers highlighted the timers should appear on the Electronic Flight Progress Strips (EFPS), others preferred them to be displayed on ADIS, as per the simulation exercises, whilst an option to have them

on both systems was also discussed. This leads to **Recommendation REC-37-W3-SAF-R2.2**: A HMI workshop should be held to discuss suitable placement of the extended OSD tool output.

In relation to the timers, and the potential for either an under separation or safety incident to occur, ATCOs cited that both the MDI information and the TMA data feed information needs to be in a format that can be easily understood and, in a position where the controller would be able to see it and use it effectively without confusion or misinterpretation.

One controller commented in the questionnaire *“without the MDI information you could be led into departing an aircraft with correct route and wake Separation but not MDI Separation”*.

With another ATCO highlighting *“Need to ensure all separations wake, route and MDI can be understood by the ATCO”*.

Whilst the issues relating to the timer, MDI and TMA data feed information are more related to the HMI design undertaken by HF (further discussion contained within the PJ37-W3-ITARO (01B) DEMO Report Part III [11]). It is important to note that the placement of the MDI and TMA data feed information would be critical in avoiding a safety incident. This leads to **Recommendation REC-37-W3-SAF-R2.3**: A HMI workshop should be held to discuss the suitable placement of the MDI and TMA data feed information.

Impact to other Safety Critical ATC Tasks and Procedures

During the workshop, a point was raised regarding other tasks that need to be completed by an ATCO in between departures (i.e., aircraft or vehicles crossing the runway, aircraft being towed, etc). The tool allows more refined, granular route spacing values compared to current operation, which in some cases, will reduce the time between departing aircraft, thus, by using the tool, there is then less time to complete these tasks. The ATCOs present in the workshop stated that these types of tasks generally occur 3 or 4 times per hour; however, it wouldn't be uncommon for this number to increase to perhaps 10 times in an hour, and they emphasised that the tool could assist in the management of these tasks. This assistance is because the tool gives a visual reminder and indication to the controller in minutes and seconds of the route/ flow separation between aircraft, the ATCO could then utilise this information to plan the best 'crossing slot' for an aircraft in between those aircraft that are departing. This could also assist the controller's mental capacity and workload, making their planning easier.

Although the validation simulations incorporated a very small number of 'runway crossers' into the exercises, it is apparent from this discussion that this was not a full representation of the other tasks undertaken by controllers in current operations. By considering this point and the above discussion into consideration, this leads to **Recommendation REC-37-W3-SAF-R2.4**: During the next wave of this solution, more scenarios and tasks that ATCOs experience daily should be incorporated into the simulated exercises.

Introducing a tool which assists the ATCO with calculating separations between aircraft can be of great benefit to the controller by reducing the mental workload and thus increasing their capacity to undertake other tasks; however, as stated by the ATCOs, this could have an adverse safety effect by introducing tool reliance and thus the potential of skill fade amongst the controlling cadre.

Failure of extended OSD tool & Impact on ATCO Procedures (Skill Fade)

If the tool was to fail (the equipment failure will be detailed and discussed in Appendix A.3), the result to the ATCO would be as follows:

1. No assistance or visual indication from the tool for the separations required between aircraft.
2. No TMA data feed or MDI information.

During the workshop, ATCOs stated that in the immediate realisation of the tool failing, a potential safety incident could occur, which may include incorrect separation being applied to departing aircraft whilst the ATCO both managed the unfolding situation and then aimed revert to undertaking manual calculations of the required separations. (The details of tool failure, its consequences and potential recommendations are covered in Appendix A.3.)

When asked whether the concept will have a safety impact on associated procedures in the post exercise questionnaire, one ATCO wrote:

‘Potentially, if an ATCO becomes over reliant on the timer and it fails, your workload could increase significantly to compensate and calculate’.

Using this evidence as a basis in the workshop, ATCOs were asked to clarify and explain their workload increase if the tool failed. The ATCOs split this increase into 2 phases as follows:

- There would be a major increase in workload for the first 5 minutes of the tool failing.
- This would reduce to a minor increase in workload for the next 5 minutes once the situation was understood, and emergency procedures retrieved and followed.

Workload increase for tool failure = Total time 10 minutes

The ATCOS in the workshop stated that during the early deployment phase of the tool (maybe first 6 – 12 months), the skill to calculate the separations manually should be remembered by all controllers (both experienced and new qualified) albeit, they may be slightly slower in calculating accurate separations and thus a more conservative separation may be delivered. It was noted, however, that over time and with an increasing reliance on the tool, the skill to accurately undertake these manual calculations (considering the introduction of more granular, refined route spacings) would be diminished and could lead to a more severe safety incident occurring including infringements of minimum radar separation standards.

To ensure safe separation between all aircraft could be achieved at all stages of future solution deployment if the tool failed, ATCOs suggested the following **Recommendation REC-37-W3-SAF-R2.5**: A simple to follow separations matrix and immediate action procedures should be produced to enable safe operations to continue. (From a commercial standpoint and key performance benefits, it was stated that that efficiency and capacity may be affected). Utilising this simple matrix in the very short term would provide assurance that aircraft would be correctly separated but with a reduced departure rate to the airport operations; however, if the tools’ un-serviceability was for a longer period, an alternative measure would need to be found.

From a safety perspective, a further consideration should be made to how long a controller’s currency in manually calculating separations would last. With increasing tool reliance, it is expected that the ATCO’s skill in manually calculating separations would fade, they would become less accurate, and thus would lose confidence in working without the tool.

One ATCO stated in the end of day questionnaires:

'After long term use and de-sensitisation to the timer/skill fade with separation, if the system failed workload could increase significantly. Also, if timer is wrong and you're used to it you could just blindly follow it'.

Controllers stated that with the introduction of the tool into operations, refresher training involving calculating manual separations should be included in the currency package for maybe 30-40 minutes per year per controller. In order to fully appreciate what the refresher training should include leads to **Recommendation REC-37-W3-SAF-R2.8**: Further investigations are required to fully understand the content and duration and frequency of training required for ATCOs to sufficiently maintain currency and skills to manually apply accurate and efficient separations.

Furthermore, deliberation is required into the feasibility that the task and training to manually calculate separations once the tool is deployed is removed and instead ATCOs rely on a simple matrix together with new procedures to obtain MDI and TMA data information by alternative means if the tool fails. Both of these scenarios lead to **Recommendation REC-37-W3-SAF-R2.6**: HF, Safety and ATCOs should fully investigate the required procedures, tasks and possible ATCO training requirements in the event of tool failure.

It was highlighted that if the solution was either progressed further and/or deployed, all the procedures within the Tower environment (and possibly TC environment) would have to be checked and possibly revised to incorporate new procedures and deliver new training to ATCOs. This leads to **Recommendation REC-37-W3-SAF-R2.7**: All ATC procedures which will be affected by the deployment of the tool should be highlighted early in future projects to assess for any major safety issues.

Potential Safety Issues in TMA and Surrounding Sectors

Following discussions in the post validation simulation workshop, the issue of potential increase in workload was raised. It was suggested that due to the possible increase of traffic that the extended OSD tool may deliver into surrounding sectors, this could impact workload for TC controllers. This increase would be due to the rise in the number of aircraft operating within their sectors, and or, managing any increase in the number of tactical conflicts (as discussed in Section A.1.4). As cited in Appendix A.1.4, the potential increase in workload was considered by the ATCOs to be minor and with the mitigations of an appropriate flow management tool and the proposed recommendations in Section A.1.5, this potential safety issue of workload should be successfully managed and reduced.

A.2.2 Summary of Issues and Recommendations for OBJ-37-W3-DEMOP-SAF1-0009

A summary of the issues raised and potential mitigations / recommendations to assist in reducing occurrences and their severity.

Safety Issue	Recommendation
Timer display.	REC-37-W3-SAF-R2.1: A toggle switch should be provided to enable ATCO personalisation of the timer. (See also REQ-37-W3-HP-6)
Placement of wake and SID countdown timer.	REC-37-W3-SAF-R2.2: A HMI workshop should be held to discuss suitable placement of the extended OSD tool output. (See also REQ-37-W3-HP-7)
Placement of MDI and TMA data feed information.	REC-37-W3-SAF-R2.3: A HMI workshop should be held to discuss the suitable placement of the MDI and TMA data feed information.
Ability for ATCO to undertake other safety critical tasks.	REC-37-W3-SAF-R2.4: During the next wave of this solution, more scenarios and tasks that ATCOs experience daily should be incorporated into the simulated exercises.
Procedures when extended OSD tool fails.	REC-37-W3-SAF-R2.5: A simple to follow separations matrix and immediate action procedures should be produced to enable safe operations to continue.
Procedures to deal with skill fade.	REC-37-W3-SAF-R2.6: HF, Safety and ATCOs should fully investigate the required procedures, tasks and possible ATCO training requirements in the event of tool failure.
Future deployment and effect on current procedures.	REC-37-W3-SAF-R2.7: All ATC procedures which will be affected by the deployment of the tool should be highlighted early in future projects to assess for any major safety issues.
Refresher training to enable ATCOs to manually calculate separations if extended OSD tool fails.	REC-37-W3-SAF-R2.8: Further investigations are required to fully understand the content and duration and frequency of training required for ATCOs to sufficiently maintain currency and skills to manually apply accurate and efficient separations.

Table 24: A Summary of Recommendations for OBJ-37-W3-DEMOP-SAF1-0009.

A.3. Analysis of OBJ-37-W3-DEMOP-SAF1-0010.

Objective	OBJ-37-W3-DEMOP-SAF1-0010: Understand the equipment requirements, e.g. software levels required, corrupt data, hardware failure									
Success criterion	CRT-37-W3-DEMOP-SAF-004: Evidence is gathered regarding equipment requirements and the ITARO Departure Solution									
Analysis result	Safety Questionnaire: The main areas of concern highlighted in the questionnaires was the issue of tool failure and incorrect data being displayed to the ATCO. These areas of concern then prompted statements regarding a potential increase in workload, skill fade in manual calculations when the tool fails and whether the tool was showing corrupt data. Post Validation Simulation Workshop: By utilising the main themes highlighted in the questionnaires and comments from the end of day discussions, relevant topics were raised in the workshop where the following safety issues were considered and deliberated, and suitable mitigations and recommendations suggested: <table><tr><th>Safety Issue</th><th>Recommendation</th></tr><tr><td>Tool error / failure messages</td><td>REC-37-W3-SAF-R3.1: A visual only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.</td></tr><tr><td>Interaction between existing ATC equipment (including back-up servers).</td><td>REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.</td></tr><tr><td>Tool Failure – Corrupt but believable data.</td><td>REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See also REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects.</td></tr></table>		Safety Issue	Recommendation	Tool error / failure messages	REC-37-W3-SAF-R3.1: A visual only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.	Interaction between existing ATC equipment (including back-up servers).	REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.	Tool Failure – Corrupt but believable data.	REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See also REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects.
Safety Issue	Recommendation									
Tool error / failure messages	REC-37-W3-SAF-R3.1: A visual only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.									
Interaction between existing ATC equipment (including back-up servers).	REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.									
Tool Failure – Corrupt but believable data.	REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See also REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects.									

		REC-37-W3-SAF-R3.5: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.
Results	OK	

Table 25: Extended results of OBJ-37-W3-DEMOP-SAF1-0010.

Failure of extended OSD Tool – Hardware

During the post validation simulation workshop, hardware failures were discussed amongst the participants and whilst the exact hardware and HMI of the solution is not fully specified at this maturity level, an initial dialog was undertaken to try and highlight any areas of concern.

Included in the validation exercises were the following failures:

1. **Complete extended OSD tool failure:** Both wake and route countdown timers disappear for the duration of the failure and the controllers revert to manually applying wake and route separations/spacings (as undertaken in current operation). Note - this was not an optimal way to indicate the failure (an obvious error message is preferable) but this was the only option available in the simulation due to lack of screen real estate on the ADIS to display an error message near the countdown timer tool failure.
2. **TMA data-feed failure:** The flow restriction functionality which is normally included in the route countdown timer failed. In this scenario, the ATCO has to manually factor in any additional time separation required to satisfy a flow restriction. An orange 'TMA FAILED' error message appeared in bottom righthand part of the screen – as described above this was not optimal, but the only option available due to limited ADIS screen real estate to place new information.

During the exercises it was observed that some controllers did not immediately notice the failure of the tools and at times had to be prompted by the PJ37-W3-ITARO (01B) observers. This issue could be due to unfamiliarity of the error message location and the extended OSD tool itself (as described above) but overall, no issues were raised in the exercise debrief or the questionnaires regarding the ability of the controllers to revert back to current procedures. (As noted in 0, discussions have been undertaken to understand and mitigate the skill fade and tool reliance post deployment and this has been detailed in OBJ-37-W3-DEMOP-004-SAF-0010).

In the end of day questionnaires one ATCO commented:

'The more reliant on the tool, the less likely you are to notice an error'.

The workshop highlighted that a total loss and failure of the extended OSD tool (and/or hardware) would initially produce a major increase in workload. Once realised and immediate action procedures undertaken, only a minor increase of workload would follow (as detailed in 0); however, there could be a potential safety incident of an under separation for an aircraft departing. There was unanimous agreement that the alerts and error messages used within the validation exercises were not robust enough for current operations. Thus, this leads to **Recommendation REC-37-W3-SAF-R3.1:** A visual only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures. (Further

recommendations which are relevant during a total loss and failure of the extended OSD tool include, using in situ back-up servers and compliance with ED153 which are detailed in the next sections of this Appendix.)

Interactions between existing ATC Equipment

A point was raised during the workshop which related to a potential safety issue being created from the interaction of the extended OSD system with current equipment used within the operation. With the introduction and deployment of the solution, it should be understood beforehand whether there is any interference with in-situ equipment already utilised in today's operation when either the tool was serviceable or if the tool failed. Further discussion followed regarding the failure of tool and in order to mitigate any failure of the tool, it was suggested to utilise the backup server system that would already be in place in the tower environment. This leads to **Recommendation REC-37-W3-SAF-R3.2**: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower. This investigation could assist in the assurance of the system in case of failure.

Tool Failure – Corrupt but Believable data

Discussions about the issue of corrupt but believable data being given by the tool was discussed in all forums and questions included on the questionnaire.

Figure 32 shows results from the following question raised in the questionnaire:

- If the extended OSD tool falsely indicated that the 2nd aircraft could be cleared for take-off, how likely are you to identify the error if the indication was.....?*

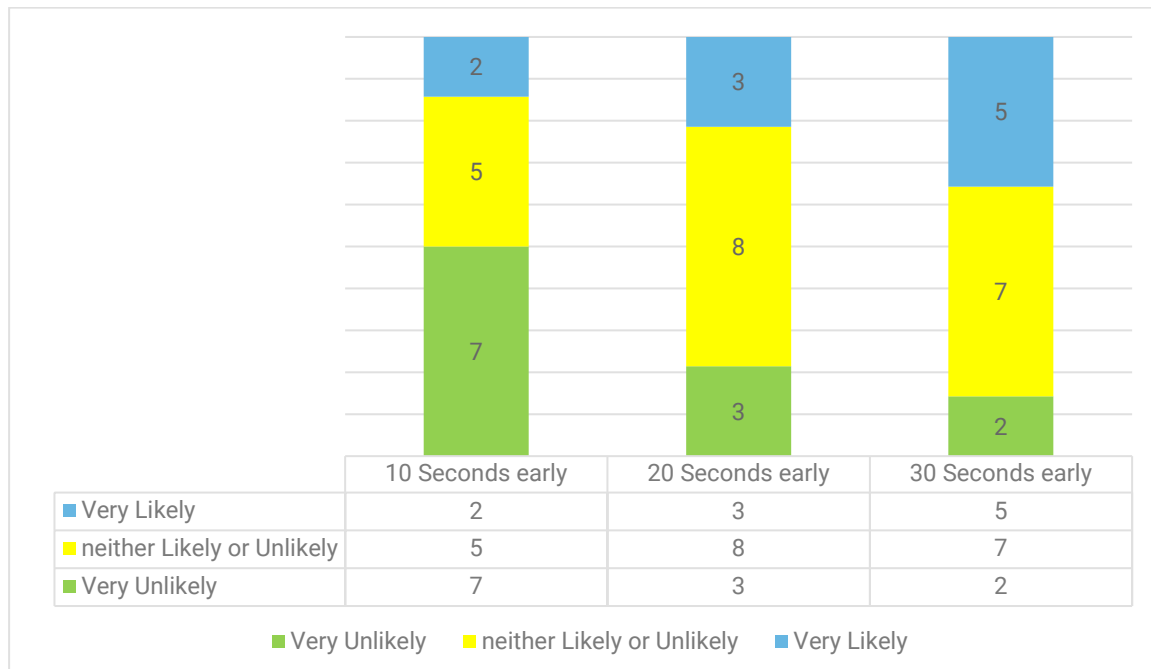


Figure 32: Graph showing ATCOs responses to identifying an incorrect time indication.

There were 14 respondents in total and the overall results illustrate that if the tool indicated a false clearance which was 10 seconds early, the percentage of ATCOs who would not notice (those in the

category very unlikely and neither likely nor unlikely) was 85%. This figure decreased slightly to 79% when the time increased to 20 seconds and a further reduction to 64% was seen when the timing increased to 30 seconds. From this evidence (albeit a snapshot of a potential error), it highlights that from a controller's perspective it is not easy to identify the issue of corrupt but believable data¹²

The ATCOs during the post validation simulation workshop suggested that perhaps a possible error could be noticed in the following circumstances:

- i. after a period of time had elapsed, and,
- ii. when the aircraft continually presented themselves at less than the minimum standard separation required, and,
- iii. in a time that was less than expected.

If these conditions were noticed, it could result in a Loss of Separation between aircraft (benign geometries). It was deliberated and agreed that this issue may be noticed by either the Tower Controller, the TC Controller or both.

As in today's operation, if an under separation/ loss of separation was observed, controllers (both Tower and TC) would tactically resolve the issue with suitable control instructions (e.g., further climb, turn/ vector etc) and/or co-ordination with relevant controllers /sectors. Whilst difficult to mitigate against, this leads to **Recommendation REC-37-W3-SAF-R3.3**: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. This would allow further investigations into the integrity of the system to be undertaken by technical staff and for the controllers to revert to failure procedures which would provide safe separations for operations to continue. This leads to **Recommendation REC-37-W3-SAF-R3.4**: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects. Furthermore, and leading to **Recommendation REC-37-W3-SAF-R3.5**: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.

¹² Considering that at the time the questionnaire was undertaken, the controllers are fully current on manually calculating the separations, if the tool was deployed and refresher training removed (as discussed in OBJ-PJ37-W3-003-SAF-0009) it could be expected that these figures of identifying an error would be higher due to skill fade and reliance on the tool.

A.3.1 Summary of Issues and Recommendations for OBJ-PJ37-W3-003-SAF-0010

A summary of the issues raised and potential mitigations / recommendations to assist in reducing any occurrences and their severity.

Safety Issue	Recommendation
Tool error / failure messages	REC-37-W3-SAF-R3.1: A visual only alert (not audible) of the status of the equipment is required to allow maximum time for controllers to identify the failure and then to quickly revert to the alternate procedures.
Interaction between existing ATC equipment (including back-up servers)	REC-37-W3-SAF-R3.2: Further investigations are undertaken regarding possible interaction between other ATC systems and the extended OSD tool system and the utilisation of any back up servers already in use in the Air Traffic Control tower.
Tool Failure – Corrupt but believable data	REC-37-W3-SAF-R3.3: A function should be introduced to allow the Supervisor only to switch off the system (either in certain elements or the whole extended OSD tool) in situations where there was any doubt about the integrity of the information being presented to the controller. (See also REQ-37-W3-HP-3) REC-37-W3-SAF-R3.4: Further investigation into the issue of corrupt but believable data and its impact to the system should be undertaken in future projects. REC-37-W3-SAF-R3.5: Further examination should be made into the assigning of the correct software assurance level to the system in association with compliance of ED153.

Table 26: A Summary of Recommendations for OBJ-37-W3-DEMOP-SAF1-0010.

Appendix B. Validation Simulations Runs with Tool & Runway Information

Run Reference Number	Tool.	Runway	TMA Data Feed
1.1	RECAT with OSD	09R	NO
1.2	RECAT with extended OSD - Abnormal	09R	YES
1.3	RECAT with extended OSD	09R	YES
1.4	RECAT with extended OSD	09R	NO
2.1	PWS with extended OSD	27R	NO
2.2	PWS with extended OSD	27R	YES
2.3	PWS with OSD	27R	NO
2.4	PWS with extended OSD - Abnormal	27R	YES
3.1	RECAT with OSD	09R	NO
3.2	RECAT with OSD	09R	NO
3.3	RECAT with extended OSD	09R	YES
3.4	PWS with OSD	27R	NO
4.1	PWS with extended OSD	27R	NO
4.2	PWS with extended OSD	27R	YES
4.3	RECAT with OSD	27R	NO
4.4	RECAT with extended OSD	27R	NO
5.1	PWS with extended OSD	27R	YES
5.2	PWS with OSD	27R	NO
5.3	PWS with extended OSD	27R	YES
5.4	PWS with extended OSD	27R	NO
6.1	PWS with OSD	27R	NO
6.2	PWS with extended OSD - Abnormal	27R	YES
6.3	PWS with extended OSD - Abnormal	27R	YES
6.4	PWS with extended OSD	27R	NO



7.1	PWS with extended OSD	09R	YES
7.2	PWS with extended OSD	09R	NO
7.3	PWS with OSD	09R	NO
7.4	PWS with OSD	09R	NO
8.1	PWS with extended OSD	09R	NO
8.2	RECAT with OSD	27R	NO
8.3	RECAT with extended OSD	27R	NO
8.4	RECAT with extended OSD	27R	YES
9.1	RECAT with extended OSD	27R	YES
9.2	RECAT with OSD	27R	NO
9.3	RECAT with extended OSD	27R	YES
9.4	RECAT with extended OSD – Abnormal	27R	YES
10.1	RECAT with extended OSD	27R	NO
10.2	RECAT with extended OSD – Abnormal	09R	NO
10.3	RECAT with OSD	27R	NO
10.4	RECAT with extended OSD	27R	YES

Table 27: Summarising the runway and tool used for each validation run.

B.1. Number of Departure Pairs per Run

Run Reference Number	Total Number of departure pairs per run	Tool
1.1	39	Reference
1.2	37	Abnormal Sol 2
1.3	41	Sol 2
1.4	43	Sol 1
2.1	52	Sol 1
2.2	57	Sol 2
2.3	58	Reference
2.4	25	Abnormal Sol 2
3.1	45	Reference



3.2	45	Reference
3.3	50	Sol 2
3.4	50	Reference
4.1	53	Sol 1
4.2	55	Sol 2
4.3	55	Reference
4.4	57	Sol 1
5.1	52	Sol 2
5.2	54	Reference
5.3	53	Sol 2
5.4	57	Sol 1
6.1	54	Reference
6.2	61	Abnormal Sol 2
6.3	53	Abnormal Sol 2
6.4	57	Sol 1
7.1	53	Sol 2
7.2	55	Sol 1
7.3	55	Reference
7.4	57	Reference
8.1	56	Sol 1
8.2	55	Reference
8.3	59	Sol 1
8.4	58	Sol 2
9.1	60	Sol 2
9.2	59	Reference
9.3	61	Sol 2
9.4	58	Abnormal Sol 2
10.1	52	Sol 1
10.2	32	Abnormal Sol 2
10.3	50	Reference
10.4	52	Sol 2

Table 28: Summary of Departure pairs per Simulation Run.

B.2. All wake under-separations where route spacing countdown timer was lower than the wake countdown timer.

<i>Run ID</i>	<i>Follower Callsign</i>	<i>Follower Aircraft Type</i>	<i>Leader Callsign</i>	<i>Leader Aircraft Type</i>	<i>RSVA Applied</i>	<i>Delivery Time [s]</i>	<i>Wake Separation Time [s]</i>	<i>=Delivery Time – Wake Separation Time [s]</i>	<i>=Delivery Time –Route Spacing Time [s]</i>	<i>Route Spacing Time [s]</i>	<i>Solution Type</i>
9.3	'N588TN'	'GLF4'	'AAL21'	'B789'	No	67	120	-53	-23	90	Solution 2
9.4	'N588TN'	'GLF4'	'BAW9CG'	'B772'	No	84	120	-36	-6	90	Solution 2 - Abnormal
9.1	'N588TN'	'GLF4'	'BAW9CG'	'B772'	No	98	120	-22	8	90	Solution 2
10.1	'N588TN'	'GLF4'	'AAL21'	'B789'	No	100	120	-20	10	90	Solution 1
8.1	'SWR33U'	'BCS3'	'AAL729'	'B788'	No	74	90	-16	9	65	Solution 1
6.4	'N588TN'	'GLF4'	'AAL21'	'B789'	No	86	100	-14	-4	90	Solution 1
7.2	'SWR33U'	'BCS3'	'BBC202'	'B77W'	No	86	100	-14	26	60	Solution 1
5.3	'N588TN'	'GLF4'	'AAL21'	'B789'	No	88	100	-12	-2	90	Solution 2
5.4	'N588TN'	'GLF4'	'BAW9CG'	'B772'	No	88	100	-12	-7	95	Solution 1
6.3	'N588TN'	'GLF4'	'BAW9CG'	'B772'	No	89	100	-11	-5	94	Solution 2 - Abnormal
1.2	'BAW2600'	'A20N'	'AAL141'	'B772'	No	91	100	-9	2	89	Solution 2 - Abnormal
10.1	'BAW342N'	'A20N'	'VIR137Y'	'A333'	No	92	100	-8	27	65	Solution 1

10.2	'BAW660'	'A20N'	'BAW31F'	'B789'	No	82	90	-8	22	60	Solution 2 - Abnormal
1.4	'BAW312'	'A20N'	'BAW7TG'	'B788'	No	94	100	-6	3	91	Solution 1
9.3	'BAW628'	'A20N'	'UAL919'	'B763'	No	74	80	-6	9	65	Solution 2
10.4	'BAW704W'	'A320'	'BAW9271'	'B77W'	No	94	100	-6	0	94	Solution 2
1.2	'N383LS'	'GLF4'	'AIC172'	'B788'	No	115	120	-5	95	20	Solution 2 - Abnormal
1.2	'IBE3161'	'A321'	'ACA857'	'B77W'	No	96	100	-4	2	94	Solution 2 - Abnormal
2.2	'BAW8PW'	'A20N'	'BAW15K'	'B77W'	No	96	100	-4	43	53	Solution 2
8.4	'DLH6U'	'A20N'	'BAW139'	'A35K'	No	96	100	-4	-1	97	Solution 2
9.3	'BAW952M'	'A319'	'AAL39'	'B77W'	No	96	100	-4	54	42	Solution 2
1.3	'BAW718'	'A320'	'BAW219V'	'B789'	No	97	100	-3	7	90	Solution 2
1.4	'SHT18E'	'A319'	'AAL141'	'B772'	No	97	100	-3	8	89	Solution 1
2.4	'SAS804'	'A20N'	'BAW26E'	'B789'	No	87	90	-3	39	48	Solution 2 - Abnormal
6.2	'BAW460M'	'A20N'	'ETD12'	'B788'	No	87	90	-3	16	71	Solution 2 - Abnormal
9.1	'BAW628'	'A20N'	'UAL919'	'B763'	No	77	80	-3	12	65	Solution 2

1.2	'SAS78C'	'A20N'	'BAW3576'	'B788'	No	98	100	-2	22	76	Solution 2 - Abnormal
1.3	'EWG7PY'	'A319'	'AIC172'	'B788'	No	98	100	-2	8	90	Solution 2
2.2	'SAS804'	'A20N'	'BAW26E'	'B789'	No	88	90	-2	19	69	Solution 2
4.4	'BAW704W'	'A320'	'BAW9271'	'B77W'	No	98	100	-2	9	89	Solution 1
4.4	'BEL6H'	'A320'	'IBE3163'	'A359'	No	98	100	-2	18	80	Solution 1
7.1	'BAW470'	'A20N'	'QTR01G'	'B77W'	No	98	100	-2	30	68	Solution 2
9.4	'AUA4MG'	'A320'	'MSR778'	'B77W'	No	98	100	-2	8	90	Solution 2 - Abnormal
10.1	'BAW704W'	'A320'	'BAW9271'	'B77W'	No	98	100	-2	4	94	Solution 1
10.2	'BAW48CU'	'A320'	'AAL109'	'B772'	No	88	90	-2	25	63	Solution 2 - Abnormal
3.3	'AUA6EH'	'A320'	'VIR539'	'B789'	No	99	100	-1	22	77	Solution 2
4.4	'BAW314S'	'A319'	'MSR778'	'B77W'	No	99	100	-1	22	77	Solution 1
8.1	'DLH8HH'	'A20N'	'BAW283'	'B772'	No	89	90	-1	21	68	Solution 1
10.2	'IBE31YZ'	'A320'	'THY6760'	'B77L'	No	99	100	-1	27	72	Solution 2 - Abnormal
10.2	'AAL141'	'B772'	'BAW57K'	'A388'	No	99	100	-1	10	89	Solution 2 - Abnormal

Table 29: All wake under-separations where route spacing countdown timer was lower than the wake countdown timer.

Appendix C. Bespoke Safety Assessment Report PJ37-W3-ITARO (01B) Departures Solution

C.1. Background

The PJ.37-W3-01B ITARO Departure Solution continues work conducted in CREDOS which related to crosswind-dependent suspension of wake separations and SESAR 2020 Wave 1 PJ.02-01-02 which developed the OSD tool.

In Wave 1, SESAR 2020 PJ.02-01, the distance-based S-PWS for departures concept, covering 96 of the most common aircraft types in Europe, was validated at the V3 level.

In Wave 2, the time-based S-PWS for departures matrix was extended to include an additional 7 aircraft and validated at the V3 level [5].

In addition, a 14-category scheme has been defined which covers > 90% of ICAO aircraft types and has been defined in terms of MTOW, wingspan and resistance to wake. For all aircraft types, the minima are specified by the RECAT 20-category scheme, which is a combination of the RECAT-EU 6-category scheme and the RECAT 14-category scheme. Additionally, with the development of the S-PWS 103x103 matrix (increased from the 96x96 matrix in SESAR 2020 Wave 2), which increases the complexity of the Tower Runway Controllers' work, it has been recommended that the S-PWS separation scheme can only be applied with the support of a separation delivery tool.

In SESAR 2020 Wave 1 PJ.02-01, NATS developed an Optimised Separation Delivery (OSD) tool, which uses information on when the lead aircraft is airborne to calculate the earliest airborne time for the follower aircraft for satisfying the wake separation scheme. This is the “Not Before Airborne Time” (NBAT) for the wake separation, which was displayed to the Tower Runway Controller on their electronic environment (EFPS display in the case of Heathrow). In addition to the NBAT display on the EFPS, the NATS Solution also included a digital automatic countdown timer, which was displayed on the ADIS in RTS5.

In parallel to the OSD tool developed by NATS in SESAR 2020 Wave 1 PJ.02-01-02 [12], EUROCONTROL developed an OSD tool which included options of a digital automatic countdown timer, known as the Dynamic Departure Indicator – Timer (DDI-T) and a distance indicator, known as the Dynamic Departure Indicator – Distance (DDI-D). The distance spacing indicator (in the form of a line/arc) was displayed per aircraft pair on the appropriate SID to support the application of all wake separation schemes.

Both DDI-T and DDI-D indicators took all time and distance spacing/separation constraints applicable for departures into consideration; this included Wake Turbulence (WT) whether PWS, WDS, RECAT-EU or ICAO, Minimum Radar Separations (MRS), Vertical Separation (VS), SIDs, Reduced Runway Separations (RRS) and ADI/MDI.

In Wave 2 PJ.02-W2-14.8 [7], EUROCONTROL developed an enhanced OSD for departures solution, which built on the OSD tool developed in PJ.02-01-02 Wave 1 (AO-0329). The enhanced OSD tool is a more efficient separation delivery tool that supports the application of complex separation schemes (e.g. PWS, WDS) using BD/ML techniques to make more accurate predictions of aircraft behaviour (e.g. trajectory/climb profile, speed profile) and wind on the initial departure path. The enhanced OSD tool

developed in Wave 2 also supports the application of existing non-wake spacing and separation constraints.

The PJ.37-W3-01B ITARO Departures Solution extends the OSD tool developed in SESAR 2020 Wave 1 PJ.02-01 by NATS and INDRA to provide support for reduced and more granular non-wake SID separations. The SID separations are no longer be defined in integer minutes and instead be dependent on several factors, this includes the SID pairing, runway, leader and follower aircraft types, and measured wind profile. As the ITARO Departures Solution increases the complexity of the Tower Runway Controller's work, the optimised non-wake SID separations can only be applied with the support of a separation delivery tool. The extended OSD tool provides support for both wake separations and SID separations.

2. Dynamic TMA/E-TMA for Enhanced Arrivals and Departures

The PJ.37-W3-01B ITARO Departures Solution incorporated an emulated TMA data-feed to ensure that the optimised SID separations do not put an excessive demand onto TMA sectors.

The PJ.37-W3-01B ITARO Departures Solution aligns with work being carried out in SESAR Wave 2 Project PJ.01: Enhanced Arrivals and Departures, Solution PJ.01-W2-08B (Dynamic TMA/E-TMA for Advanced Optimised Descent Operations) [8].

PJ.01-W2-08B follows up the work performed by SESAR Solutions, PJ.25, PJ.01-02 and PJ.01-03B in Wave 1 to continue development of optimised management of TMA and E-TMA airspace and routes.

PJ.01-W2-08B improves traffic management into and out of the TMA using dynamic lateral routes, speed and a broad range of climb/descent profiles. This is to help optimise TMA efficiency whilst managing demand and capacity.

A Systemised Airspace Management tool (SYSMAN) is being developed in solution 08B4 of PJ.01-W2-08B to help ATC depart traffic closer together and at shorter intervals than currently operating, whilst avoiding bunching along the multiple arrival and departure streams that exist in the TMA. A traffic flow prediction is provided via specific metering (or Reference) points to provide a useful representation of traffic in the TMA. The aim is for SYSMAN to smooth the flow of aircraft to reduce the level of tactical intervention required.

SYSMAN makes predictions about when a route will become overloaded based on the traffic count past a fixed Reference Point on the route and comparing it to a defined maximum threshold. In this scenario, an alternative offload route is offered. This threshold may also be suitable for determining when the departure flow rate from the airport needs to be reduced by increasing the applied departure separations. The operational feasibility of this approach has been investigated in the PJ.37-W3-01B ITARO Departures Solution

As described above, the PJ.37-W3-01B ITARO Departures Solution follows up on work already previously performed and thus the majority of elements have been safety assessed and validated; however, in this iteration there are two elements of the solution which are new and are being tested in the validation simulations. To ensure there is no safety delta introduced, these two elements are subject to this bespoke safety assessment which will only assess the following two elements:

- a) A data-feed from the TMA into the extended OSD (extended OSD) tool, which will indicate when the departure flow needs to be temporarily reduced in order to avoid putting an excessive traffic demand onto specific TMA sectors.
- b) A timer for SID / route spacing which will allow a more consistent and accurate delivery of aircraft into the TMA.

C.2. General Approach to Safety Assessment

This safety assessment is conducted as per the SESAR Safety Reference Material (SRM) [2], which itself is based on a twofold approach:

- A success approach which is concerned with the safety of the Solution operations in the absence of failure within the end-to-end Solution functional system, encompassing both Normal operation and Abnormal conditions,
- A conventional failure approach which is concerned with the safety of the Solution operations in the event of failures within the end-to-end Solution functional system.

These two approaches are applied to the derivation of safety properties at each of the successive lifecycle stages of the Solution development.

C.3. Scope of the Safety Assessment

The following parts of the safety assessment lifecycle are covered by the current issue of the bespoke Safety Assessment Report:

- **V1** - through initial identification of safety implications of the Change of the two new elements and the definition of Safety Criteria
- **V2** - through establishing **Safety Requirements at Service level (SRS)** to deliver the Safety Criteria and the derivation of **Safety Requirements at design level (SRD)** to satisfy the SRSs (based on combined safety analysis of the design, data analysis and safety-related measurements, observations and debriefing of the validation exercises). The safety assessment for Safety Requirements derivation will align with the design maturity (i.e. successive inclusion of Operational Improvements - OIs). The bespoke safety assessment will be conducted to the level of granularity decided by the Project for the design of the Functional system for the 2 new elements of the Solution (encompassing people, procedures & airspace and equipment if applicable).

The SRDs are derived during the V2 phase of the development lifecycle as initial SRDs. The purpose is to feed the SESAR Solution PJ37-W3-01B DEMOR Part II, with a complete and correct set of safety requirements for the 2 new elements.

This bespoke safety assessment addresses two elements incorporated into PJ.37-W3-01B, these are:

- a) A data-feed from the TMA into the extended OSD (extended OSD) tool, which will indicate when the departure flow needs to be temporarily reduced in order to avoid putting an excessive traffic demand onto specific TMA sectors.
- b) A timer for SID / route spacing which will allow a more consistent and accurate delivery of aircraft into the TMA.

C.4. Layout of the Bespoke Safety Assessment

Appendix C.1 to C.3 - Background of the solution, the general approach to safety assessment in SESAR and the scope of this safety assessment.

Appendix C.5 to C.7 - Setting the Scene of the Safety Assessment: The operational concept overview and the scope of the change, summarises the solution operational environment and key properties together with the stakeholders' expectations and derives the Safety Criteria.

Appendix D - Safety Specification at ATS Service Level: The definition of SRSs, covering normal and abnormal operating conditions.

Appendix E - Safe Design of the Solution Functional System: The safe design of the solution, through the derivation of SRDs and link to validation results. Safety Criteria Achievability.

Appendix F - Preliminary Safety Impact Assessment: Hazards inherent to aviation and the relevant accident/incident models.

Appendix G - Derivation of SRS (Functionality and Performance) for Normal Conditions: The methodology and the process used to derive the Functionality and Performance SRSs based on the NOV5 EATMA diagrams.

Appendix H - Risk Analysis of Abnormal Conditions and Derivation of SRS: The operational effect with mitigations, and the Risk Classification schemes for the relevant Accident/Incident Models.

Appendix I - Risk Analysis addressing Internal Functional System Failures and Derivation of SRS: The results from the HAZID workshop and derivation of mitigations and SRS/SRD.

Appendix J - Designing the Solution Functional System for Normal Conditions: The derivation of the SRDs from SRS involving both static and dynamic analysis.

Appendix K - Designing the Solution Functional system for Abnormal Conditions of Operation: The derivation of SRDs from SRSs.

Appendix L - Designing the Solution Functional System addressing Internal Functional System Failures: The deriving SRDs from the SRS (integrity/reliability) based on a top-down causal analysis. Bottom-up failure modes and effects analysis. Derivation of SRDs from the SRS (functional and performance) for protective mitigation.

Appendix M - Demonstration of Safety Criteria Achievability:

Appendix N - Assumptions.

C.5. Operational Concept Overview and Scope of the Change

C.5.1 Solution Operational Environment and Key Properties

This sub-section describes the key properties of the Operational Environment that are relevant to the PJ.37-W3-01B bespoke safety assessment.

Airspace and Airport Characteristics

Very Large Airport (more than 250k movements per year) and Large Airport (between 150k and 250k movements per year).

The runway configurations and modes of operations employed at Very Large and Large Airports include:

- Independent parallel runways operating in segregated mode operations.
- Dependent parallel runways operating in segregated mode operations with the option of some arrival aircraft landing on the designated departure runway.
- Closely spaced parallel runways operating in segregated mode operations.

Types of Airspace – ICAO Classification

Control areas around aerodromes are usually ICAO Class C or D:

- **ICAO Class C:** IFR and VFR flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect of other VFR flights
- **ICAO Class D:** IFR and VFR flights are permitted, and all flights are provided with air traffic control service, IFR flights are separated from other IFR flights and receive traffic information in respect to VFR flights, VFR flights receive traffic information in respect of all other flights.

Airspace Users – Flight Rules

In both the reference and solution scenarios, instrument and visual flight rules (IFR & VFR) are applied.

Traffic Levels and Complexity

In Reference scenario: level of traffic in peak hours as per the current runway throughput at the Very Large and Large airports.

With Solution scenarios: level of traffic in peak hours as per the increased runway throughput enabled by the Solutions.

Terrain Features – Obstacles

There is a need to ensure that there is no topography change between when the data (wind, wake, etc.) is used and when the solution is applied operationally.

Note that the local topography such as hangar buildings, terminal buildings and high ground in the vicinity of the aerodrome may impact both surface winds and winds aloft.

Separation Minima

In Reference scenario:

- The ICAO radar separation standards for departures include Minimum Radar Separation (MRS) which prevents aircraft collision and WT separation which is intended to protect aircraft from adverse Wake Turbulence Encounters (WTEs).
- The Reference Scenario is TB-RECAT-EU and PWS with OSD.
- For departing category pairs with no defined WT separation, the MRS is to be applied. This is typically 3 Nautical Miles (NM).
- Reduced Separation in the Vicinity of the Aerodrome (RSVA) can be applied, in addition to the 3NM and increasing procedure if required.

In Solution scenario:

- The solution scenario is TB-RECAT-EU and PWS with the extended OSD tool.
- Consideration to ensure the correct SID spacing, wake separation and MRS for the 1st and 2nd aircraft departing the runway is needed.
- Reduced Separation in the Vicinity of the Aerodrome (RSVA) can be applied, in addition to the 3NM and increasing procedure if required.
- Introduction of target distance spacings as an alternative to the procedural time separations on departure.

Ground ATM Capabilities

In Reference Scenario:

- Surveillance System (Initial Departure Path and TMA)
- Surveillance Radar – Primary and Secondary Surveillance Radar (SSR), (Mode S)
- Flight Data Processing System
- Advanced Meteorological Information
- Surveillance System for Surface Movement (e.g. Advanced Surface Movement Guidance and Control System (A-SMGCS))
- Tower CWP (Airport Tower Supervisor, Tower Runway Controller, Tower Ground Controller, Tower Clearance Delivery Controller or Apron Manager)
 - Electronic Flight Progress Strips
 - Traffic Situation View Display
 - Meteorological Information Display
 - ATC Voice Communications
- TMA CWP (TMA Supervisor, TMA Planning Controller, TMA Executive Departure Controller)
 - Flight Progress Strips (Either electronic or paper)
 - Radar Situation View Display
 - ATC Voice Communications

With Solution scenario:

The following ground ATM capabilities are considered in the operational environment:

- Local environment weather information and wind forecasting and monitoring capabilities.
- TMA data feed.

Aircraft ATM Capabilities

No change from Reference scenario, i.e.:

- Transponder (Elementary and Enhanced Mode-S Surveillance (ELS) (EHS) or Mode A/C)
- Flight Management System (FMS) Capability
- Air-Ground Voice Communication System (VCS).

CNS Aids

No Change from reference scenario.

C.6. Expected Benefits

See Section 2.2 for benefits associated with the whole solution PJ37-W3-ITARO (01B).

C.7. Safety Criteria

Safety Criteria (SAC) define the acceptable level of safety (i.e. accident and incident risk level) to be achieved by the Solution under assessment, considering its impact on the ATM/ANS functional system and its operation.

The SAC setting is driven by the analysis of the impact of the change on the relevant AIM models (identified in Appendix F.1).

The following section defines the SAC applicable to the operational scenario for the whole of the PJ37-W3-ITARO (01B) solution (described in the DEMOP Part I Section 4.3.2). Two sets of safety criteria are formulated:

- A first one aimed at ensuring an appropriate Separation design, i.e., definition of SID spacing minima which, if correctly applied in operation, guarantee safe operations on runway departure, on the initial common departure path and SID, respectively.
- A second one aimed at ensuring correct spacing delivery i.e., that the defined SID spacing minima are correctly applied for spacing delivery by ATC.

A Scoping and Change workshop was undertaken where the SACs from the previous work undertaken in PJ.02-01 were discussed. This ensured relevancy to the solution and consideration of the safety benefits, but importantly allowed for stakeholder agreement at this stage.

The PJ.37-W3-01B solution demonstrates the use of the extended OSD tool for Departures with support for SID/Route spacings and a TMA data-feed; the concept does not include WDS-D (as it did in PJ.02-01), instead the wind on the initial departure path is used by the extended OSD tool to convert the target distance spacing into a time spacing. With this in mind, the associated AIM models have been re-visited to confirm relevancy and applicability for each SAC and amended as deemed appropriate.

By extending the OSD tool to include support for SID/ route pairs, it is intended to improve runway throughput and the spacing applied will be more efficient and consistent for the aerodrome environment. Furthermore, this improvement should produce a more consistent delivery of traffic to the TMA controllers and may help to avoid ‘bunching’ along SIDs and thus reduce tactical conflicts.

In support of the above, the following SACs have been defined for the whole solution:

SAC#D1a: **Wording** There shall be no increase in imminent wake separation infringements which are induced by ATC to the 1st aircraft whilst on departure (2nd aircraft not yet airborne) in operations based on the extended OSD tool compared to operations with the Reference Scenario OSD tool (AO-0329).

Rationale On possibility of imminent wake separation infringement on departure induced by ATC and the second aircraft is not yet airborne (see WE7F.1.a in AIM Wake Induced Risk on Initial Departure).

SAC#D2a: **Wording** There shall be no increase in imminent wake separation infringements which are induced by ATC to the 1st or 2nd aircraft whilst on departure in operations based on the extended OSD tool compared to operations with the Reference Scenario OSD tool (AO-0329).

Rationale On possibility of imminent wake separation infringement on departure induced by ATC and the second aircraft is airborne (see WE7F.2 in AIM Wake Induced Risk on Initial Departure).

SAC#D3: **Wording** There shall be no increase in imminent minimum radar separation infringements (non-wake) on the initial departure induced by ATC for the 1st or 2nd aircraft whilst on departure in operations based on the extended OSD tool compared to operations with the Reference Scenario OSD tool (AO-0329).

Rationale On possibility of an imminent radar separation infringement on the initial departure path induced by ATC for either 1st or 2nd aircraft. (see ME7F.1 and ME7F.2 AIM MAC Risk on initial Departure).

SAC#D5a: **Wording** There shall be no increase in tactical conflicts (non-wake) in the TMA departing sectors induced by ATC for the 1st or 2nd aircraft whilst on departure in

operations based on the extended OSD tool compared to operations with the Reference Scenario OSD tool (AO-0329).

Rationale On possibility of tactical conflicts whilst in the TMA induced by ATC for either 1st or 2nd aircraft. (see MF7.1.1.2 and MF7.1.1.2.1 leading to MF7.1 in AIM MAC Risk in TMA).

SAC#D5b: **Wording** There shall be no increase in imminent minimum radar separation (non-wake) in the TMA departing sectors induced by ATC for the 1st or 2nd aircraft whilst on departure in operations based on the extended OSD tool compared to operations with the Reference Scenario OSD tool (AO-0329)

Rationale On possibility of an imminent minimum radar separation infringement whilst in the TMA induced by ATC for either 1st or 2nd aircraft. (see MF7 in output of MB14.2 in AIM MAC Risk in TMA).

Additionally, since the creation of the DEMOP Part II and the development of the demonstration exercises, it was considered necessary that a further SAC is required as follows:

SAC#D6: **Wording** The probability per departure of severe and/or extreme wake turbulence events shall be no greater in operations using the extended OSD tool compared to operations with the reference scenario OSD tool.

Rationale On possibility of severe and or extreme wake turbulence events on departure induced by ATC for either 1st or 2nd aircraft (see WE3 and WE2 in AIM WAKE ID).



Appendix D.

D.1. Mitigation of risks Inherent to Aviation – Normal Conditions

The purpose of this section is to present the Safety Requirements at ATS Service level (SRS) derived for Normal conditions of operation following Guidance F of Safety Reference Material and additional related SAF-GUI in STELLAR. The set of Safety Requirements at the ATS Service level (SRS) in this section specify the desired safety behaviour of the change at its interface with the operational context considering normal conditions.

The SRS are derived taking into account the EATMA Models at operational specification level.

D.2. Safety Requirements at ATS Service Level (SRS) for Normal Conditions of Operations

Table 30 shows the ATS operational services that are impacted by the two new elements of the solution (the SID /route timer and the TMA data feed information) in the relevant operational environment to address and mitigate the hazards inherent to aviation which were derived in the Scoping and Change Assessment.

ID	ATS Operational Service	Hazards inherent to aviation
ATS-01	Wake Encounter Avoidance (Ground – Air)	Hp#1a “Adverse Wake Encounter on Initial Common Departure Path”
ATS-02	ATC Collision Prevention Tactical Conflict Management Tactical Conflict Management	Hp#2a “Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict – Initial Common departure Path
ATS-03	ATC Collision Prevention Tactical Conflict Management Tactical Conflict Management	Hp#3 “Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict in the TMA”

Table 30: ATS Operational Services Potentially Impacted and Hazards Inherent to Aviation.

The following table collates all SRS in the document for normal operations, which are based on the output from Appendix D.2 and also derived from the Safety Criteria in Section C.7.



SRS ID	SRS for Normal conditions of operation	Related SAC
SRS-01	The SID / Route timer shall ensure that the data presented to the ATCO is in accordance with the relevant SID target spacings and ATC regulations.	SAC#D1a, SAC#D2a, SAC#D3, SAC#D5a, SAC#D5b, SAC#D6
SRS-02	TMA data feed to the ATCO shall be in accordance with ATC regulations	SAC#D5a, SAC#D5b

Table 31: List of SRS (functionality and performance) for Normal Conditions of Operations.

D.3. Additional SRS Related to Adjacent Airspace or Neighbouring ATM Systems

No impact on adjacent airspace or neighbouring ATM Systems has been identified

D.4. Mitigation of Risks Inherent to Aviation – Abnormal Conditions

The purpose of this section is to present the Safety Requirements at ATS Service level (SRS) derived for Abnormal conditions of operation. These are generated in a HAZID attended by Operational Controllers. Participants at the HAZID were asked for their opinions on what is an abnormal event (something that doesn't usually happen) for this solution.

No abnormal conditions were identified for the two new elements of the solution.

It should be noted however, that the validation simulations did include both abnormal and non-nominal events which have been detailed in 41A.1.1.2; however, these scenarios covered the whole ITARO solution rather than the two new individual elements. As detailed above, participants of the HAZID did not identify any specific conditions or events that would affect the two new elements.

D.5. Mitigation of System generated Risks (failure conditions)

The purpose of this section is to present the Safety Requirements at ATS Service level (SRS) associated to the operational hazards (caused by internal failures of the Solution functional system).

This includes 2 types of SRS:

- Additional SRS (functionality and performance) to mitigate against operational hazard effects (protective mitigation).
- SRS addressing integrity/reliability in order to limit the frequency with which the Solution functional system-generated operational hazards could be allowed to occur.

D.6. Operational Hazards Identification and Analysis

ID	Operational Hazard Description	Operational Effects	Mitigation of effects	Severity (most probable effect)
OH-01	Erroneous SID Route Timer Output	Potentially insufficient SID / Route separation if	SRD 101: The SID route timer shall be assessed and assured in accordance with ED153.	WK-ID-SC3b



	(This refers to the SID route timer providing erroneous or corrupt output, that would not be detected by the tower controller.)	timer provides incorrect time	SRD 102: The HMI shall display any failure of the SID route timer in a prominent location. SRD 103: Input data for the SID route timer shall be subjected to integrity checks to assure timeliness and accuracy. SRD 104: The Tower Supervisor shall have the ability to turn the SID route timer off if corrupt data is believed to be present.	MTFoO ¹³ (per Departure) – 1E-02
OH-02	Erroneous TMA data feed output. (This refers to the TMA data feed providing erroneous or corrupt output, that would not be detected by the tower controller)	Potentially aircraft being insufficiently separated into the TMA causing the TMA ATCO an increase in workload and potentially an increase of tactical conflicts	SRD 105: The TMA data feed shall be assessed and assured in accordance with ED153. SRD 106: The HMI shall display any failure of the TMA data feed in a prominent location. SRD 107: Input data for the TMA data feed shall be subjected to integrity checks to assure timeliness and accuracy. SRD 108: The Tower Supervisor shall have the ability to turn the TMA data feed off if corrupt data is believed to be present.	MAC-SC4b MTFoO (per flight hour) – 1E-02
-	Controller Error The only human error that was deemed if the controller misinterpreted the SID / Route times, wake timings with the TMA data feed times (Flow restrictions) thus clearing an aircraft to take off with less	Potentially insufficient SID / Route separation	SRD 109: All procedures shall be assured in accordance with existing ANSP standard practices. This includes procedure design, training needs analysis, sim assessments and APSAs SRD 110: The SID / Route timer on the HMI shall clearly differentiate between route times, wake times and flow restriction times (given by TMA data feed).	No new hazards. Assurance addressed by HF.

¹³ **MTFoO** stands for the Maximum Tolerable Frequency of Occurrence being the maximum probability of the hazard's effect.

	separation than required.		SRD 111: The SID Route timer shall indicate which SID pairing the separation time applies to.	
-	Unexpected Wind Conditions This refers to unexpected wind conditions occurring in the vicinity of the aerodrome. These could include gust fronts, microbursts and windshear, non of which can be forecasted or visually seen.	Potentially insufficient SID / Route separation on departure and into the TMA	SRD 112: The wind / meteorological data utilised by the extended OSD tool shall be suitably assessed and assured as accurate and current.	No new hazards.

Table 32: Operational hazards and operational effects associated with the two new elements.

D.7. Process Assurance of the Safety Specification at ATS Service level

Process Assurance of the two new elements assessed in Safety Specification at ATS Service Level has followed the SESAR Safety Reference Material [2] and the supporting Guidance Material [3], and SRSs and SRDs have been derived accordingly.

The supporting workshop was run in accordance with Guidance G in the SESAR Safety Reference Material [2] and was attended by Suitably Qualified and Experienced Personnel (SQEP) detailed at Appendix I.

The material presented in this document is subject to peer review before publication.

D.8. Safety Requirements at ATS Service level (SRS) associated to failure conditions

SRS ID	Safety Requirements at ATS Service level (integrity/reliability)	Related Operational Hazard	Severity & IM
SRS 101	The probability of the SID Route timer providing corrupt but believable data shall not exceed 2E-04 per departure.	OH 01	WK-ID-SC3b (1E-02) IM =10



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SRS 102	The probability of the TMA data feed providing corrupt but believable data shall not exceed 1E-05 per flight hour.	OH 02	MAC-SC4b (1E-02) IM =10
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Table 33: Safety Requirements at Service level - integrity/reliability.



Appendix E. Safe design of the Solution Functional System

E.1. Overview of the Activities Performed

This section addresses the following activities:

- Section F1.1- F1.2: Introduction of the functional system.
- Section F2.: Derivation of Safety Requirements (functionality and performance) at design level (SRD) in normal conditions of operation from the SRSs (functionality and performance) from Section E2 and supported by the analysis of the initial or refined design.
- Section F4: Assessment of the adequacy of the design (initial or refined) in the case of internal failures and mitigation of operational hazards (identified in section Section E8) through derivation from SRS (integrity and reliability), safety requirements (functionality and performance) and/or safety requirements (integrity and reliability) at design level.
- Section F4.3: Safety process assurance at the initial or refined design level.
- Section F4.4: Safety Criteria Achievability.

E.1.1 Design model of the Solution functional system

The European ATM Architecture (EATMA) Operational activity models are process models used to describe operational scenarios/use cases (could be produced per phase of flight if practical). They are hosted by the EATMA Operational layer, which contains the elements needed to describe the operational concepts. This includes process models and descriptions of how ATM actors collaborate

E.1.2 Description of the Design Model

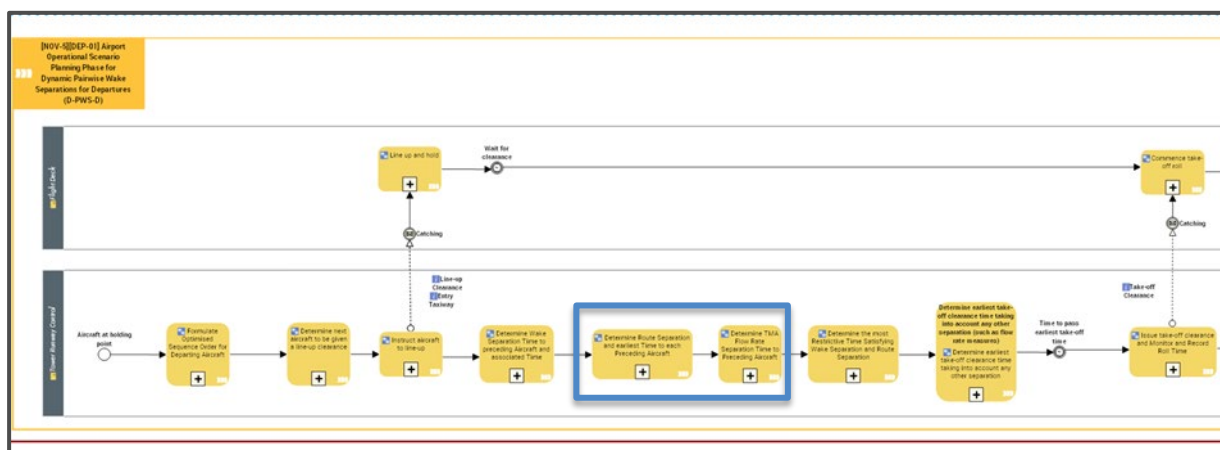


Figure 33: Cropped Diagram of the NOV-5 form the whole system of PJ37-W3-ITARO (01B).

The cropped NOV-5 model as shown in Figure 34 below shows the operational scenario activities from the point the aircraft arrives at the runway holding point to the point that the take-off clearance is issued.

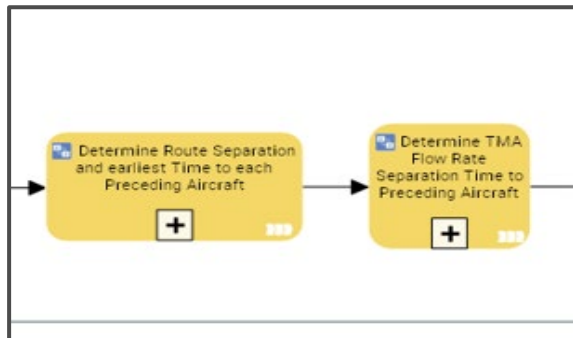


Figure 34: An expanded picture of the highlighted section of Diagram 2 showing the relevant area of the NOV05 diagram for the two new elements.

(A full NOV-5 EATMA diagram can be found in Appendix G.)

E.1.3 Task Analysis

A task analysis is conducted on the whole system by HP (normally included in the HPAP) which details the human operators' tasks and working methods. Due to this bespoke safety assessment only covering the two new elements and assessing any safety delta, a task analysis has not been undertaken and therefore is not available.

E.2. Deriving Safety Requirements at Design level for Normal conditions of operation

E.2.1 Safety Requirements at Design level (SRD) – Normal Conditions of Operation

This section provides a consolidated list of the Safety Requirements at Design Level (functionality and performance) for normal operations. These are derived by mapping the SRS onto the related elements of the Design Model.

E.2.2 Safety Requirements at Design level (SRD) – Normal conditions of operation

Safety Requirement ID [Design Model Element]	Safety Requirement (functionality & performance)	Derived from SRS (ID)
SRD 201	The SID Route timer shall be subject to internal data integrity checks.	SRS 01
SRD 202	The data presented by the SID /Route timer to the ATCO shall be reviewed and monitored on a regular basis.	SRS 01

SRD 203	The TMA data feed shall be subject to internal data integrity checks.	SRS 02
SRD 204	The data presented by the TMA data feed to the ATCO shall be reviewed and monitored on a regular basis.	SRS 02
SRD 109	All procedures shall be assured in accordance with existing ANSP standard practices. This includes procedure design, training needs analysis, sim assessments and APSAs.	SRS 01
SRD 110	The SID / Route timer on the HMI shall differentiate between route times and flow restriction time (given by TMA data feed).	SRS 01
SRD 111	The SID Route timer shall indicate which SID pairing the separation time applies to.	SRS 01
SRD 112	The wind / meteorological data utilised by the extended OSD tool shall be suitably assessed and assured as accurate and current.	SRS 01

Table 34: Safety Requirements at design level (functionality and performance) satisfying SRS for Normal conditions of operations.

E.2.3 Static & Dynamic Analysis of the Functional System Behaviour – Normal Conditions of Operations.

Static Analysis: A thread analysis normally assesses a system in an end-to-end context, from initiation to completion. This may include functional steps, equipment elements and external dependencies for the whole system. In this solution, the two new elements discussed in this bespoke safety assessment are only a small part of the whole system and these proposed enhancements do not change the algorithm or the solution, instead, it provides the ATCO with more accurate information. The relevant new functional steps have been assessed through the EATMA diagrams and relevant workshops and recorded in this bespoke safety assessment, therefore, a full static analysis considering all system elements should be conducted in future projects when the solution design has matured further.

Dynamic Analysis: The assurance requirements in this bespoke safety assessment were established in an expert workshop and in a HAZID post simulation validation session. A dynamic analysis is not available at this stage of the solution, but it is recommended to be conducted in future projects when the maturity has been developed further.

E.2.4 Effects on Safety Nets – Normal Conditions of Operations.

There are no additional safety nets proposed for the two elements.

E.3. Deriving Safety Requirements at Design level for Abnormal Conditions

The purpose of this section is to present the Safety Requirements and Design level for abnormal conditions of operation. These are derived from the SRS (functional and performance) which have been identified when mitigating risks inherent to aviation during abnormal conditions.

No abnormal conditions have been identified, therefore there are no SRDs to be derived.

E.4. Safety Requirements at Design Level addressing Internal Functional System Failures

The purpose of this section is to present the Safety Requirements at Design Level associated with internal failures (i.e., the failure case). These SRDs are derived from the SRS (functionality, performance, integrity and reliability) that have been identified during the HAZIDs, detailed in Appendix I.

E.4.1 Design Analysis Addressing Internal Functional System Failures

The analysis has been performed following the process detailed in the SAM PSSA and related GUI in STELLAR.

E.4.2 Safety Requirements at Design level Associated to Internal Functional System Failure

Safety Requirement ID	Safety Requirement at Design level (SRD) (integrity / reliability)	Derived from SRS integrity & reliability (ID)
SRD 101	The SID / Route timer shall be assessed and assured in accordance with ED153.	SRS 01
SRD 102	The HMI shall display any failure of the SID route timer.	SRS 01
SRD 103	Input data for the SID / Route timer shall be subjected to integrity checks to assure timeliness and accuracy.	SRS 01
SRD 104	The Tower Supervisor shall have the ability to turn the SID / Route timer off if corrupt data is believed to be present.	SRS 01
SRD 105	The TMA data feed shall be assessed and assured in accordance with ED153.	SRS 02
SRD 106	The HMI shall display any failure of the TMA data feed.	SRS 02
SRD 107	Input data for the TMA data feed shall be subjected to integrity checks to assure timeliness and accuracy.	SRS 02

SRD 108	The Tower Supervisor shall have the ability to turn the TMA data feed off if corrupt data is believed to be present.	SRS 02
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Table 35: SRD (Integrity / reliability) to mitigate the operational hazards.

E.4.3 Process Assurance of the Safety Specifications at ATS Service Level

In order to obtain the evidence required for the Safety Specifications at ATS Service level the following activities were undertaken. Each of these complied with the SRM processes laid down in the reference material [2][3][4] in order to define the relevant SACs and derive the SRSs

- A Scoping and Change assessment with Solution members to identify main safety issues and possible hazards to aviation.
- Initial Hazard identification workshop with solution members to derive safety and validation simulation objectives.
- Safety Criteria & Safety Requirement Workshop prior to validation simulations.
- Safety workshop – post validation simulations to derive any safety issues and suggested mitigations.

E.4.4 Safety Criteria Achievability

This partial safety assessment for the two new elements of this solution has been conducted as per the SESAR Safety Reference Material [2] and the supporting Guidance Material [3] SRSs and SRDs have been derived accordingly.

A twofold approach has been utilised:

- A success approach which is concerned with the safety of the Solution operations in the absence of failure within the end-to-end Solution functional system, encompassing both Normal operation and Abnormal conditions.
- A conventional failure approach which is concerned with the safety of the Solution operations in the event of failures within the end-to-end Solution functional system.

These two approaches have applied to the derivation of safety properties at each of the successive lifecycle stages of the Solution development (Safety Requirements at service level and at design level).

Hazards and mitigations have generally been identified through systems analysis and consultation with air traffic controllers and the solution team.

The supporting workshop was run in accordance with Guidance G in the SESAR Safety Reference Material [2] and was attended by Suitably Qualified and Experienced Personnel (SQEP).

This partial assessment has resulted in the following output:

- SRS Normal Operations.
- SRS Failure Conditions.
- SRD Normal Conditions.
- SRD Failure Conditions

Due to this bespoke Safety Assessment Report only covering the two new elements introduced into this solution, only a partial assessment has been completed to understand any safety delta, therefore, demonstrating the full achievability of the safety criteria has not been undertaken.

Appendix F. Preliminary Safety Impact Assessment

F.1. Relevant Hazards Inherent to Aviation

The Safety Reference Material (SRM) Guidance D and E [2][3] provide a set of Accident Incident Models (AIM - one per each type of accident) which represent an integrated risk picture with respect to ATM contribution to aviation accidents.

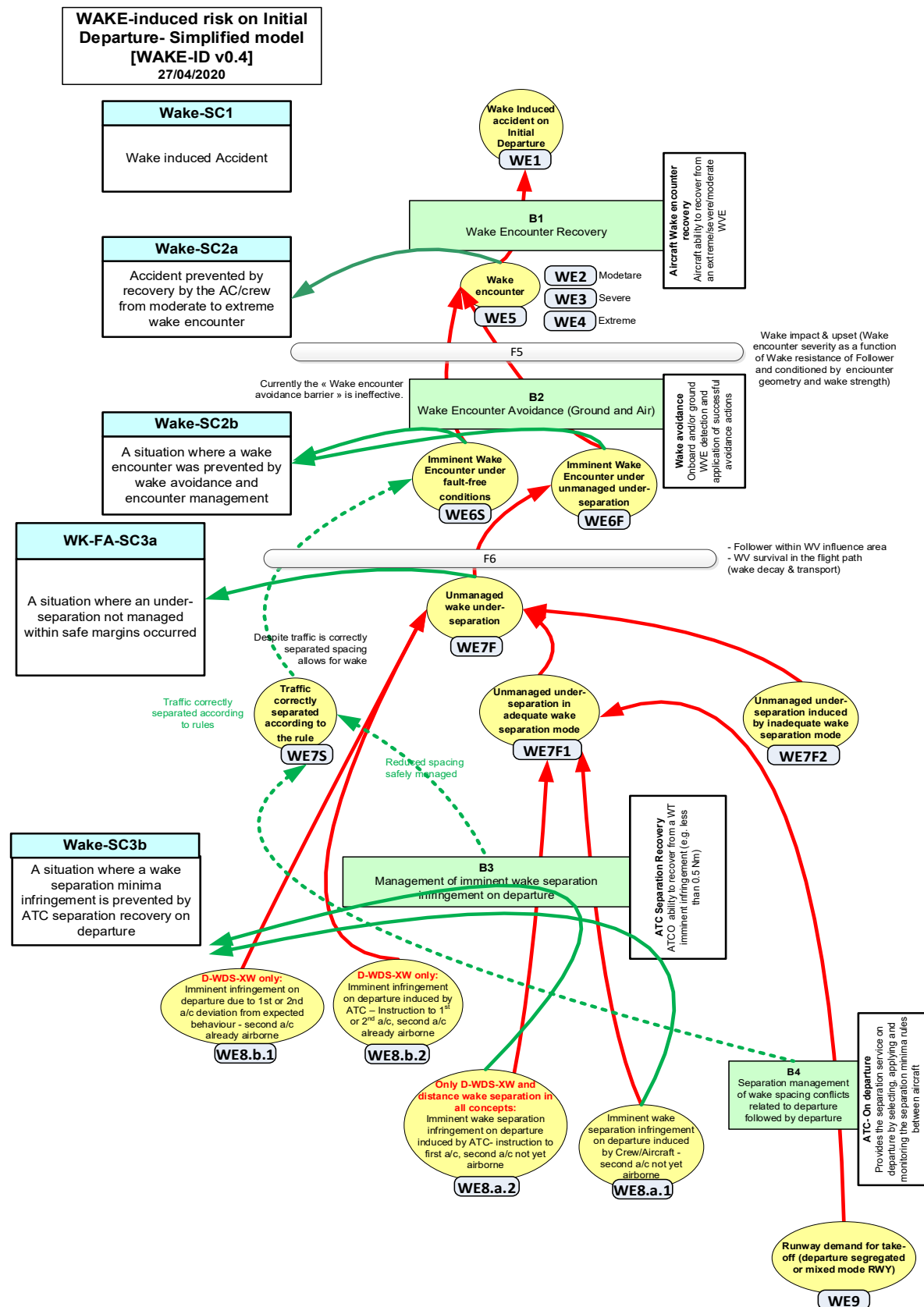
In order to determine which AIMs are relevant for the PJ37-W3-ITARO (01B) solution, this sub-section presents the relevant aviation hazards (i.e., the hazards that pre-exist in the operational environment before any form of de-confliction has taken place).

The following inherent hazards have been extracted from the DEMOP Part II [1] and formed an input into the HAZID in Appendix I:

Pre-existing hazards (Hp)	ATM-related accident type & AIM model
Hp#D1 Adverse Wake Encounter on Initial Common Departure Path	Wake Turbulence-induced Accident (WTA) on initial common Departure Path – associated AIM model
Hp#D2 Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict – Initial Common departure Path	Mid-Air Collision (MAC) on the initial Common Departure path – associated AIM model
Hp#D3 Situation in which the intended 4-dimensional (4D) trajectories of two or more airborne aircraft are in conflict in the TMA	Mid-Air Collision (MAC) in the TMA – associated AIM model

Table 36: Hazards inherent to aviation relevant for the Solution.

The relevant AIM models are shown in Figure 35 and Figure 36:



MAC-SC1
A situation where an aircraft comes into physical contact with another aircraft in the air.

MAC-SC2a
A situation where an imminent collision was not mitigated by an airborne collision avoidance but for which geometry has prevented physical contact.

MAC-SC2b
A situation where airborne collision avoidance prevents near collision

MAC-SC3
A situation where an imminent collision was prevented by ATC Collision prevention

MAC-SC4a
A situation where an imminent infringement coming from a crew/aircraft induced conflict was prevented by tactical conflict management

MAC-SC4b
A situation where an imminent infringement coming from a planned conflict that should have been resolved by Traffic planning&Coordination was prevented by tactical conflict management

MAC Accident (MF3)
Conflict Geometry Non-intersecting Trajectories. Collision avoided by chance without any intervention

Near MAC Accident (MF3a)
Detects visually or by ACAS (RA) an imminent collision and asks for evasive action

Imminent Collision (MF4)
Detects with or without STCA imminent or potential collision and asks for evasive action

Imminent Infringement (MF5-9)
Detects with or without STCA imminent or potential collision and asks for evasive action

Planned Tactical Conflict (MF5.1)
Detects with or without STCA imminent or potential collision and asks for evasive action

VFR IFR conflict (MF9.1)
Detects with or without STCA imminent or potential collision and asks for evasive action

ATC Induced Tactical Conflict (MF7.1)
Detects with or without STCA imminent or potential collision and asks for evasive action

ASAS Induced Conflict (MF8.1)
Detects with or without STCA imminent or potential collision and asks for evasive action

Crew/aircraft Induced Tactical Conflict (MF6.1)
Detects with or without STCA imminent or potential collision and asks for evasive action

Tactical Conflict Management (B6-8)
Mitigates tactical conflict. Detects and resolves them before they result in loss of separation

Traffic Planning & Coordination (B10)
Prevents potential conflicts from becoming tactical conflict by early tactical planning and intervention

Pre-Tactical Conflict (MF10)
Detects with or without STCA imminent or potential collision and asks for evasive action

OVERLOADS
Detects with or without STCA imminent or potential collision and asks for evasive action

ENR OVERDELIVERIES
Detects with or without STCA imminent or potential collision and asks for evasive action

Short Term DCB
Detects with or without STCA imminent or potential collision and asks for evasive action

POST MID-LONG TERM DCB TRAFFIC IMBALANCES & COMPLEXITY
Detects with or without STCA imminent or potential collision and asks for evasive action

Impact on Barrier Performance
Detects with or without STCA imminent or potential collision and asks for evasive action

Network Management
Removes short term overloads and high complexity situations reducing the potential for tactical conflict

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F.2. Functional System-Generated Hazards (Preliminary)

Functional system-generated hazards (preliminary)	Impact (new/modified) and justification
Aircraft depart under-separated	Example of cause impacted by the change: Extended OSD Tool gives corrupt but believable data / time. Extended OSD Tool doesn't indicate which aircraft pair the spacing applies to. Incorrect SID is inputted into the tool. Differing take off profile / SID flown by crew. Unexpected actual wind conditions.
Inadequate separation between aircraft in TMA	Example of cause impacted by the change: Extended OSD Tool gives corrupt but believable data / time. TMA data feed gives corrupt data / information. Extended OSD Tool doesn't indicate which pair the spacing applies to. Incorrect SID is inputted into the tool. Differing take off profile / SID flown by crew. Misinterpretation of TMA data feed information versus v extended OSD data / times. Technical issue onboard aircraft that has not been communicated.

Table 37: Functional system-generated hazards applicable to the Solution (preliminary list).

Appendix G. Derivation of SRS (Functionality & Performance) for Normal conditions of Operation

G.1. EATMA Process Models or Alternative Description

The European ATM Architecture (EATMA) Operational activity models are process models used to describe operational scenarios/use cases (could be produced per phase of flight if practical). They are hosted by the EATMA Operational layer, which contains the elements needed to describe the operational concepts. This includes process models and descriptions of how ATM actors collaborate.

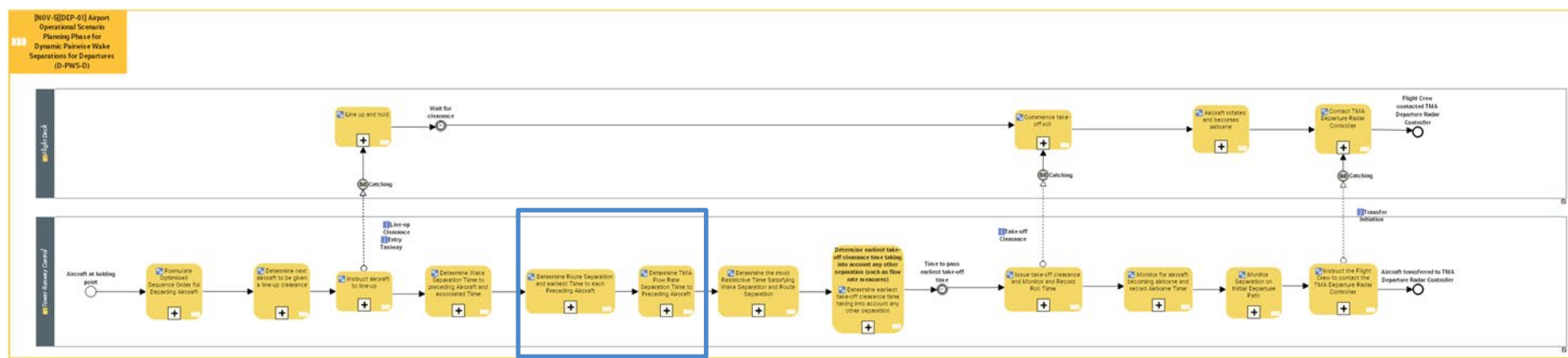


Figure 37: Full EATMA Diagram for PJ37-W3-ITARO (01B).

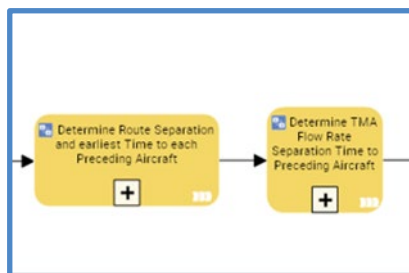


Figure 38: Cropped EATMA Diagram relevant for the 2 new elements.

G.2. Derivation of SRS for Normal Operations

ATS Operational Service	EATMA Use Case- Activity or Flow	Derived SRS	Related SAC# (AIM Barrier or Precursor)
Tower Runway Control	Determine Route Separation and earliest time to each preceding aircraft	SRS-01 - The SID/route timer shall ensure that the data presented to the ATCO is in accordance with the relevant SID target spacings and ATC regulations.	SAC#D1a, SAC#D2a, SAC#D3, SAC#D5a, SAC#D5b, SAC#D6 in relation to incorrect data may cause the aircraft to be under separated / infringe MRS
Tower Runway Control	Determine TMA flow rate Separation time to each preceding aircraft	SRS02 - TMA data feed to the ATCO shall be in accordance with ATC regulations.	SAC#D5a, SAC#D5b in relation to corrupt data may cause the aircraft to be under separated or infringe MRS.

Table 38: Derivation of SRS for Normal Operations driven by EATMA Process models.



Appendix H. Risk Analysis of Abnormal Conditions and Derivation of SRS (Functionality & Performance)

No abnormal conditions were identified.



Appendix I. Risk Analysis Addressing Internal Functional System Failures and Derivation of SRS

I.1. HAZID Workshop

Use Case / Operational failure mode	Example of causes & preventive mitigations	Operational effect	Mitigations protecting against propagation of effects	Operational hazard & Severity
Erroneous SID Route timer output	This refers to the SID route timer providing erroneous or corrupt output that would not be detected by the tower controller.	Potentially insufficient SID / Route separation if timer provides incorrect time.	SRD 101: The SID / Route timer shall be assessed and assured in accordance with ED153. SRD 102: The HMI shall display any failure of the SID route timer. SRD 103: Input data for the SID / Route timer shall be subjected to integrity checks to assure timeliness and accuracy. SRD 104: The Tower Supervisor shall have the ability to turn the SID / Route timer off if corrupt data is believed to be present.	OH-01: Inadequate separation management of a pair of aircraft on departure due to ATC tool internal failure. Severity Class – WK-ID-SC3b MTFoO¹⁴ (per Departure) – 1E-02

¹⁴ • MTFoO stands for the Maximum Tolerable Frequency of Occurrence being the maximum probability of the hazard's effect.

Use Case / Operational failure mode	Example of causes & preventive mitigations	Operational effect	Mitigations protecting against propagation of effects	Operational hazard & Severity
Erroneous TMA data feed output	This refers to the TMA data feed providing erroneous or corrupt output, that would not be detected by the tower controller.	Potentially aircraft being insufficiently separated into the TMA causing the TMA ATCO an increase in workload and potentially an increase of tactical conflicts.	SRD 105: The TMA data feed shall be assessed and assured in accordance with ED153. SRD 106: The HMI shall display any failure of the TMA data feed. SRD 107: Input data for the TMA data feed shall be subjected to integrity checks to assure timeliness and accuracy. SRD 108: The Tower Supervisor shall have the ability to turn the TMA data feed off if corrupt data is believed to be present.	OH-02: Inadequate separation management of a pair of aircraft departing into the TMA due to ATC tool internal failure. Severity Class – MAC-SC4b MTFoO (per fh) – 1E-02
Controller error	The only controller human error that was deemed if the controller misinterpreted the SID / route times and or the TMA data feed times (Flow restrictions) thus clearing an aircraft to take off with less separation than required. These can be mitigated through	Potentially insufficient SID / Route separation	SRD 109: All procedures shall be assured in accordance with existing ANSP standard practices. This includes procedure design, training needs analysis, sim assessments and APSAs. SRD 110: The SID / Route timer on the HMI shall differentiate between route times and flow	No new hazards. Assurance addressed by HF.

Use Case / Operational failure mode	Example of causes & preventive mitigations	Operational effect	Mitigations protecting against propagation of effects	Operational hazard & Severity
	procedures and HMI design (to be assessed by Human Factors team)		restriction time (given by TMA data feed). SRD 111: The SID Route timer shall indicate which SID pairing the separation time applies to.	
Unexpected Wind Conditions	This refers to unexpected wind conditions occurring in the vicinity of the aerodrome. These could include gust fronts, microbursts and windshear, none of which can be forecasted or visually seen. This would be no different to that in today's operations	Potentially insufficient SID / Route separation on departure and into the TMA	SRD 112: The wind / meteorological data utilised by the extended OSD tool shall be suitably assessed and assured as accurate and current.	No new hazards.
Pilot Error	This refers to the pilot mistakenly flew a different SID than what was recorded on the EFPS.	Potentially insufficient SID / Route separation on departure and into the TMA	ATC would intervene as soon as this scenario became apparent (utilising radar screen)	No new Hazard

Use Case / Operational failure mode	Example of causes & preventive mitigations	Operational effect	Mitigations protecting against propagation of effects	Operational hazard & Severity
	Mitigated as this scenario occurs in today's operation. This is discounted in this assessment as this isn't part of the tool / new element instead part of the whole solution PJ.37-W3-01B.			
Abnormal Aircraft behaviour	Technical issue onboard aircraft that has not been communicated to ATC. Mitigated as this scenario occurs in today's operation. This is discounted in this assessment as this isn't part of the tool / new element instead part of the whole solution PJ.37-W3-01B.	Potentially insufficient SID / Route separation on departure and into the TMA	ATC would intervene as soon as this scenario became apparent (utilising radar screen and or visual references)	No New Hazard

Table 39: Post Validation Simulation HAZID Working Table.

I.2. Post Validation Simulation HAZID Participation List

	Name	Role / Responsibility
1	On request	NATS PJ.37-W3-01B Technical Lead
2	On request	NATS R&D
3	On request	NATS R&D
4	On request	NATS R&D
5	On request	Human Factors
6	On request	Validation
7	On request	Validation
8	On request	LHR Tower ATCO
9	On request	LHR Tower ATCO
10	On request	Human Factors
11	On request	NATS PJ.37-W3-01B Solution Lead
12	On request	Safety Expert
13	On request	LHR Tower ATCO
14	On request	NATS R&D

Table 40: Post Validation Simulation HAZID Participation List.

I.3. Derivation of SRS

The method to calculate SO for a given operational hazard is as follows:

$$SO = \frac{MTFoO_{relevant_severity_class}}{N \times IM}$$

- **MTFoO** stands for the Maximum Tolerable Frequency of Occurrence being the maximum probability of the hazard's effect.
- **N** is the overall number of operational hazards for a given severity class at a given barrier.
- **IM** is the Impact Modification factor to take account of additional information regarding the operational effect of the hazard, in particular related to the number of aircraft exposed to the operational hazard.

SRS ID	Safety Requirements at ATS Service Level (integrity/reliability)	Operational Hazard	Severity and IM
SRS 101	The frequency of occurrence of “A situation where an unmanaged under separation is prevented by ATC separation recovery on departure” shall not be greater than 1x10⁻² /departure Explanation:	OH 01	WK-ID-SC3b = 5 = N* IM:10

	Computation of the Safety Requirement at Service level: $SRS = MTFoO / (N \times IM) = (1E-02) / (5 \times 10) = 2E-04$ occurrences per departure Computation of the number of occurrences per day: $2E-04 \times 135000 / 365 = 0.07$ Which equates to 27 occurrences every year MTFoO = $1E-02$ IM = 10 N = 5	
SRS 102	The frequency of occurrence of “A situation where an imminent infringement coming from a planned conflict was prevented by tactical conflict management” shall not be greater than 1×10^{-2} /flight hour Explanation: Computation of the Safety Requirement at Service level: $SRS = MTFoO / (N \times IM) = (1E-02) / (100 \times 10) = 1E-05$ occurrences per flight hour	OH 02 MAC-SC4b=100 = N IM:10

Computation of the number of occurrences per day: $1E-05 \times 24 \text{hr}$ Which equates to $2.4E-04$ occurrence every day. $\text{MTFoO(per fh)} = 1E-2$ $N = 100$ $IM = 10$		
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Table 41: Calculations of Derivation of SRS.

Appendix J. Designing the Solution Functional System for Normal Conditions

J.1. Deriving SRD from SRS

SRS for Normal Operation (ID & content)	Safety Requirement at Design level ¹⁵ (SRD) or Assumption	Maps onto
SRS 01: The SID/route timer shall ensure that the data presented to the ATCO is in accordance with the relevant SID target spacings and ATC Regulations	SRD 201: The SID Route timer shall be subject to internal data integrity checks.	Tower Runway Control
SRS 01: The SID/route timer shall ensure that the data presented to the ATCO is in accordance with the relevant SID target spacings and ATC Regulations.	SRD 202: The data presented by the SID /Route timer to the ATCO shall be reviewed and monitored on a regular basis to ensure recency.	Tower Runway Control
SRS 02: The TMA data feed shall ensure that the data presented to the ATCO is in accordance with ATC regulations	SRD 203: The TMA data feed shall be subject to internal data integrity checks.	Tower Runway Control
SRS 02: The TMA data feed shall ensure that the data presented to the ATCO is in accordance with ATC regulations.	SRD 204: The data presented by the TMA data feed to the ATCO shall be reviewed and monitored on a regular basis.	Tower Runway Control

Table 42: SRD derived by mapping SRS for normal conditions of operation to Design Model Elements.

J.2. Static Analysis of the Solution Functional System Behaviour

A static analysis is a thread analysis of each Use Case to derive additional requirements. It informs us about the intended operation of the whole functional system. Due to this bespoke safety assessment only covering the two new elements and assessing any safety delta, a static analysis has not been conducted for the two new elements of this solution.

¹⁵ iSRD for the initial design or rSRD for the refined design.

J.3. Dynamic Analysis of the Solution Functional System Behaviour

A dynamic analysis is normally a simulation assessment of each Use Case scenario. As described above this has not been conducted for the 2 new elements of this solution.

Appendix K. Designing the Solution Functional System for Abnormal Conditions of Operation.

No abnormal conditions have been identified.

Appendix L. Designing the Solution Functional System Addressing Internal Functional System Failures

L.1. Deriving SRD from the SRS (integrity / reliability)

The purpose of this section is to derive the following from the SRSs:

- SRD (functional and performance) in order to provide adequate mitigation to reduce the likelihood that specific failure would propagate up to the operational hazard.
- SRD (integrity and reliability) to limit the failure rates of system elements, such that the top-level target can be met. Note that certain failure rates are not known at this stage, such as those relating to aircraft behaviour. Therefore, certain assumptions have been made.

L.1.1 Top- Down Causal Analysis

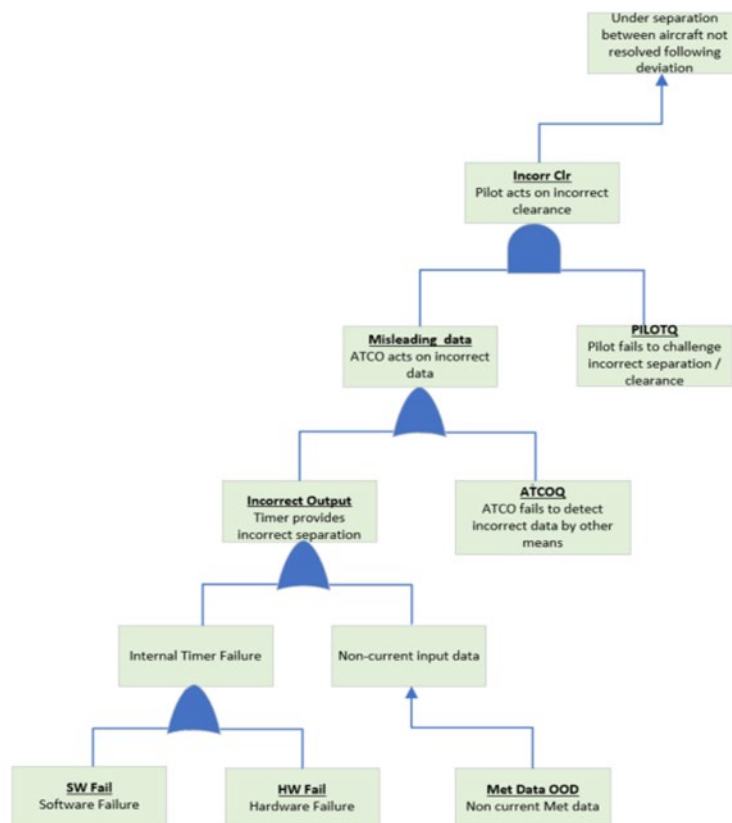


Figure 39: Fault Tree for SID / Route Timer.

Cause ID (in fault tree)	Cause	Detailed description	Mitigation/Safety Requirement
SW Fail	Software Failure	This refers to software creating erroneous or corrupt data, that would not be detected by the tower controller. During the HAZID workshop it was agreed that a known/obvious failure of the tool (e.g., loss of indication) would not have safety implications, as the operation would simply revert to procedures providing safe separation using a ready-to-go matrix.	SRD 101: The SID / Route timer shall be assessed and assured in accordance with ED153. SRD 103: Input data for the SID / Route timer shall be subjected to integrity checks to assure timeliness and accuracy.
HW Fail	Hardware Failure	This refers to hardware creating erroneous or corrupt output, that would not be detected by the tower controller. This could be caused by an internal failure of the tool or a network failure.	SRD 102: The HMI shall display any failure of the SID route timer. SRD 104: The Tower Supervisor shall have the ability to turn the SID / Route timer off if corrupt data is believed to be present.
Met Data OOD	Meteorological data is out of date / not current	This refers to the meteorological data that the system receives being out of date and thus the algorithm calculates the spacing between aircraft pairs incorrectly.	SRD 112: The wind / meteorological data utilised by the extended OSD tool shall be suitably assessed and assured as accurate and current.

ATCOQ	ATCO fails to detect incorrect data by other means	It was discussed that the controllers will be fully basing their decision on the SID Route timer output and will not have any way of knowing if the tool is providing incorrect data. The controllers will have no redundant (secondary) method of determining the applicable separation standards other than their own knowledge which over time and with an increased reliance on the tool will reduce. (Assumption ASM01).	Solution dependant on tool providing correct output. Assurance provided by SRDs 102 and 103.
PILOTQ	Pilot fails to challenge incorrect separation / clearance	Considering the number of separations / spacing permutations available, it is unlikely that pilots would query anything but the most prominent separation/spacing errors (Assumption ASM02). Therefore, a probability of 1 has been assumed.	Solution dependant on tool providing correct output. Assurance provided by SRDs 102 and 103.

Table 43: Table detailing the fault tree causes and associated mitigations (SRD, preventing operational hazard occurrence) for the SID/ Route Timer.

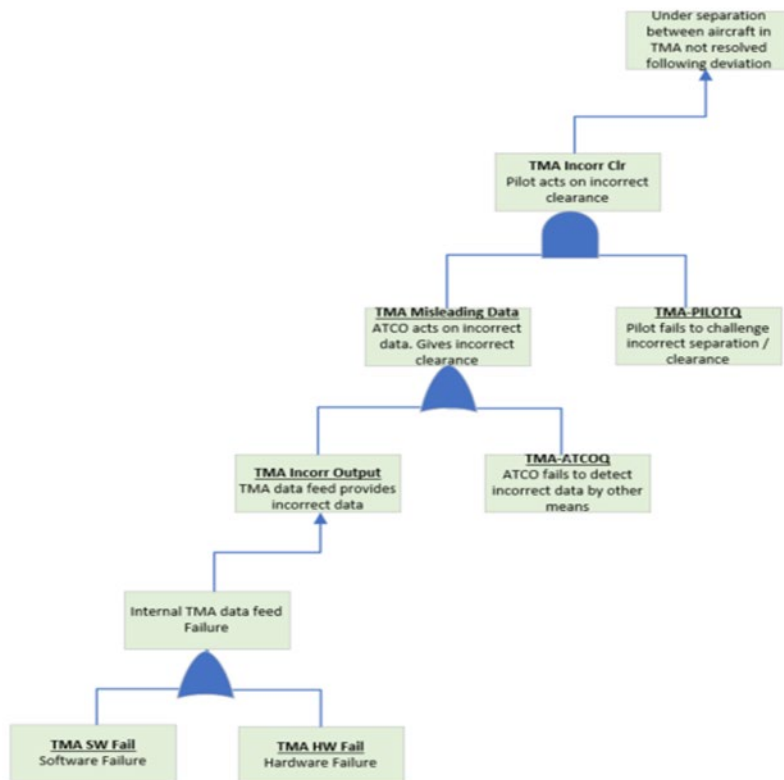


Figure 40: Fault tree for TMA data feed.

Cause ID (in fault tree)	Cause	Detailed description	Mitigation/Safety Requirement
TMA SW Fail	Software Failure	This refers to software creating erroneous or corrupt data, that would not be detected by the tower controller. During the HAZID it was agreed that a known/obvious failure of the TMA data feed (e.g., loss of indication) would not have safety implications, as the operation would simply revert to procedures to contact TMA ATCO direct and	SRD 105: The TMA data feed shall be assessed and assured in accordance with ED153. SRD 107: Input data for the TMA data feed shall be subjected to integrity checks to assure timeliness and accuracy.

		revert to a manual application of integer minute flow restrictions.	
TMA HW Fail	Hardware Failure	This refers to hardware creating erroneous or corrupt output, that would not be detected by the tower controller. This could be caused by an internal failure of the tool or a network failure.	SRD 106: The HMI shall display any failure of the TMA data feed. SRD 108: The Tower Supervisor shall have the ability to turn the TMA data feed off if corrupt data is believed to be present.
TMA Incorrect Output	ATCO fails to detect incorrect data by other means	It was discussed that the controllers will be basing their decision on the TMA data feed output and / or a flow restriction information bar located on EFPS. If this information provides incorrect data, the controllers will have no alternate method of determining the applicable separation standards (Assumption ASM01).	Solution dependant on tool providing correct output. Assurance provided by SRDs 106 and 107.
TMA-PILOTQ	Pilot fails to challenge incorrect separation / clearance	Considering the number of separation and spacings permutations available, it is unlikely that pilots would query anything but the most prominent separation / spacing errors (Assumption ASM02).	Solution dependant on tool providing correct output. Assurance provided by SRDs 106 and 107.

Table 44: Table detailing the fault tree causes and associated mitigations (SRD, preventing operational hazard occurrence) for the TMA data feed.

L.1.2 Bottom-up Failure Modes and Effects Analysis.

Functional system element	Failure mode	Effects	Mitigation/Safety Requirement	Operational hazard
ATC Tools SW Fail	Erroneous Output	As output is binary the output is unlikely to be detected. Failure can propagate to top event.	SRD 101 SRD 103	OH-01
ATC Tools HW Fail	Erroneous Output	As above	SRD 102 SRD 104	OH-01
Met Data input	Met data not current	ATC tools algorithms based on incorrect (non current) data	SRD 112	OH-01

Table 45: Failure Modes and Effect Analysis for SID/Route Timer.

Functional system element	Failure mode	Effects	Mitigation/Safety Requirement	Operational hazard
ATC Tools TMA SW Fail	Erroneous Output	As output is binary the output is unlikely to be detected. Failure can propagate to top event.	SRD 105 SRD 107	OH-02
ATC Tools TMA HW Fail	Erroneous Output	As above	SRD 106 SRD 108	OH-02

Table 46: Failure modes and Effects Analysis for TMA data feed.

L.2. Deriving SRD from SRS (Functionality & Performance for Protective Mitigation.

The purpose of this section is to derive additional SRDs to provide further mitigation considering potential common cause failures in the system by mapping each SRS to related elements of the design model. Considering the fault modelling of this system in Sections G1.1 and G1.2 for the two new elements only, no further SRDs are considered necessary to stop fault propagation at this stage. Once the completed system is more mature, a full fault tree together with associated probabilities should be produced.

As can be seen in Section G1.2, it is ATC tools that are dominant and have the ability to realise the hazards associated with this design. Therefore, assurance for this design is primarily based on hardware and software assurance.

Appendix M. Demonstration of Safety Criteria achievability

Due to the nature of this bespoke safety assessment on only two new elements of the solution, SAC achievability has not been undertaken. Instead, the DEMOR PART II report defines three safety objectives with associated success criterion, which have been derived from the SACs listed within this document at Appendix C.7.

Appendix N. Assumptions, Safety Issues, Limitations

N.1. Assumptions Log

Ref	Assumption	Validation
PJ37-W3-SAF-ASSUMP-01	ATCO is unable to detect tool incorrect output by reference to other means.	Validated
PJ37-W3-SAF-ASSUMP-02	Considering the number of permutations available it is likely that pilots would be query anything but the most significant errors.	Not Validated

Table 47: Assumptions Log.