Final Project Report

Document information	
Project Title	Flexible and Dynamic Use of Wake Vortex Separations
Project Number	06.08.01
Project Manager	EUROCONTROL
Deliverable Name	Final Project Report
Deliverable ID	D27
Edition	00.01.01
Template Version	03.00.04
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Abstract

The project aimed at increasing runway throughput through several concept areas: optimisation of wake separations, development of enhanced braking system and the revision of minimum radar separations. Validation activities were performed on the different concepts with TBS (Time Based Separation) achieving the pre-operational maturity level and is now deployed at London Heathrow. The other concepts have not yet achieved the pre-operational maturity level and additional work is necessary.

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Rational for rejection
None.

Document History

Edition	Date	Status	Author	Justification
00.00.01	24/08/2015	Draft	[redacted]	First draft for gate 2015

00.00.02	11/12/2015	Draft	[redacted]	Added exercise 835
00.00.03	29/1/2016	Draft		New template
00.00.04	17/2/2016	Draft		New template + taken into account comment from Olivier Mongenie
00.00.05	31/3/2016	Draft		Consolidated version
00.00.06	25/05/2016	Draft		Taken into account comments
00.01.00	31/05/2016	Final		For delivery
00.01.01	07/07/2016	Final		New version after SJU comments

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This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ANSP	Air Navigation Service Provider
AROT	Arrival Runway Occupancy Time
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
BD	Big Data
CAA	Civil Aviation Authority
CDM	Collaborative Decision making
D-PWS	Dynamic Pair Wise Separation
DSNA	Direction des Services de la Navigation Aérienne (France)
EASA	European Aviation Safety Agency
EBS	Enhanced Braking System
ENAIRE	Air Navigation Manager, Spain
ENPRM	EUROCONTROL Notice of Proposed Rule-Making
FAA	Federal Aviation Authority
GBAS	Ground Based Augmentation System
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
HP	Human Performance
ICAO	International Civil Aviation Organization
LVC	Low-Visibility Conditions
LVP	Low-Visibility Procedures
ML	Machine Learning
MRS	Minimum Radar Separation
NATS	National Air Traffic Services (UK)

NM	Nautical Mile
OFA	Operational Focus Area
OI	Operational Improvement
ORD	Optimise Runway Delivery
OSED	Operational Services and Environment Description
PCP	Pilot Common Project
PWS	Pair-Wise Separation
RECAT	Re-categorisation (of wake categories)
ROT	Runway Occupancy Time
RSP	Required Surveillance Performance
RTS	Real Time Simulation
SAR	Safety Assessment Report
SJU	SESAR Joint Undertaking
SPR	Safety and Performance Requirements
S-PWS	Static Pair-Wise Separation
TBS	Time Based Separation
VALP	Validation Plan
VALR	Validation Report
WDS	Weather Dependent Separation
WT	Wake Turbulence
WTS	Wake Turbulence Separation

1 Project Overview

The project addressed concepts allowing enhancement of runway operations through the optimisation of wake separations (WAKE), development of Enhanced Braking system (EBS) and revision of Minimum Radar Separations (MRS).

1.1 Project progress and contribution to the Master Plan

WAKE

The project addressed wake turbulence separations for arrivals and departures in segregated mode operations. Single runway was the main focus of the project since this is the most frequent configuration in major and medium-sized European airports.

The spacing delivery aspects were considered so as to enable the wake turbulence separation concepts to be deployed efficiently within the operationally observed diversity of aircraft speeds employed for both arrivals on final approach and for departures on the take-off and initial climb phase of flight.

The user and system requirements for controller tool provision were defined taking into account the arrival separation of arrival pairs on final approach and departure pairs on the take-off and initial climb phase.

The validations were based on LiDAR / Radar data analysis for the safety assessment of the optimised wake separations and on real-time simulations for the validation of the system allowing ATCO (Air Traffic Controller) to deliver such separations. The real time simulations were conducted using platforms emulating approach and tower environments. Additional LiDAR wake measurement campaigns were also conducted for filling the gaps in the existing European databases.

The HP (Human Performance) aspects of the solutions were also analysed for arrivals on the basis of the ATCO feed-back recorded during the simulation and through workshops.

In addition, the effect of wake encounter on flight safety was evaluated during flight simulation campaign.

Surveys were conducted in several European airports to understand current practices in separation delivery and they identified best practices to be recommended.

Analyses of the weather forecast / nowcast capabilities supporting weather dependant definition of wake separation were also conducted to support the definition of INTEROP requirements defining the weather inputs required and identifying the available technical options.

The "Optimised Runway Delivery" study analysed 6 major airport radar tracks and interviewed controllers for improving understanding of aircraft behaviour on the glide in order to improve predictability of the speed profile. This was based on radar track databases collected in several European airports.

Finally, Machine Learning (ML) and Big Data (BD) techniques were investigated to identify future further improvements of the aircraft speed profile predictably that will feed the concept of Fully Dynamic Pairwise separation for which the validation will be completed in S2020.The purpose of the analysis is to investigate how ML and BD techniques can improve predictability of separation delivery and progressively replace current model based approaches.

MRS

The project addressed reductions of the minimal-pair separations linking the reductions to the use of Required Surveillance Performance (RSP) criteria. Reductions were investigated down to 2 NM and the airport configuration applicability was determined.

The interaction and interdependence between minimal-pair separation and Runway occupancy times was noted and the performance borderline was determined for various mixes of aircraft. It was also determined that the reduction to 2NM is not useful in dependent parallel arrivals since the diagonal separation requirement between aircraft landing on the parallel runway obliges the separation between aircraft landing on the same runway to be more than 2NM. The 2NM in trail was considered as achievable reduction, while on parallel approaches1.5 will be considered in future studies.

The RSP criteria were initially proposed using the 3 and 5 NM RSP for en-route, and then further developed and refined for approach.

The validations were based on fast time simulations for the quantitative analysis and workshops with controllers and pilots for the HP and safety aspects.

Further work will be needed for identifying subsequent bottle neck in the definition of serration: Once reduced MRS allowed, it is likely that ROT or other operational criteria may become the constraining factor to be improved for increasing capacity.

The HP aspects dealt with how the controllers, pilots, and airport operators could put in place methods and procedures to help reduce the runway occupancy time, thus allowing a reduction in the minimal pair separation.

EBS

The aim of EBS was to contribute to an increase in runway throughput at congested airports by reducing the Arrival Runway Occupancy Time (AROT) of individual flights equipped with Enhanced Braking Systems (EBS) technology. Coupled with an accurate prediction of the runway exit and confidence that the exit will be achieved, it was expected that the ground system will be in a better position to develop accurate time based trajectories and better manage runway and surface movements.

Aircraft Enhanced Braking System decelerates an aircraft, once on the runway, to a speed which is in line with the exit speed given in the airlines Standard Operating Procedures. The consistency with which the deceleration profile is achieved and that it can be predicted in advance of the landing, are the key elements exploited within the concept.

The airborne system downlinks the expected AROT for each landing together with the intended runway exit. The runway exit and time at that exit allows the ground Air Traffic Management (ATM) system to compute accurate time-based ground trajectories from runway exit to parking stand (taxi in route) and to share this information with the airport Collaborative Decision making (CDM) processes.

The downlink by the aircraft of the runway exit point and its use by the controllers were evaluated through a real-time simulation.

The following table lists the OI (Operational Improvement) steps covered by project 6.8.1 and gives the level of maturity met at the end of the project.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
AO-0303	Time Based Separation for Final Approach - full concept	Two validation exercises were run to validate the use of Time Based Separation minima by Tower Air Operations Controllers and Approach Controllers according to the concept of operations. In particular the use of new controller practices and procedures in combination with controller support tools enabled the use of refined time based separation minima in an effective way in typical operational circumstances, challenging wind conditions and some off-nominal cases.	V1	V3
AO-0304	Weather-dependent reductions of Wake Turbulence	A real time simulation was planned to validate at a V2 level the suitability of the Weather Dependent Departure Separation concept, practices and	V1	V1

	separations for departure	procedures and associated tools support but no platform was available to accommodate the require specifications, so the simulation had to be cancelled, thus the OI did not reach V2.		
AO-0306	Wake Turbulence Separations based on Static Aircraft Characteristics	Two real-time simulations were run to validate at V2 level the suitability of the concept, practices and procedures and associated tools support for TBS on Approach for Tower Air Operations and potentially also the application of the RECAT1 (Re-categorisation of wake categories) and RECAT2, using the Thales system prototype tool for controllers One real-time simulation was run at V2 level to validate the suitability of the concept, practices and procedures and associated tools support for TBS on Approach, RECAT 2 and initial testing of ORD (Optimised Runway Delivery - Compression effect). A last real-time Approach/Tower simulation was run covering Time Based Static Pairwise (full RECAT 2 matrix) with Optimised Runway Delivery and 2NM MRS at London Heathrow.	V1	V2
AO-0307	Wake Turbulence separations (for arrivals) based on Dynamic Aircraft Characteristics	Only an initial version of the OSED was developed.	V0	V1
AO-0309	Minimum-Pair separations based on RSP	A fast-time simulation validated the reduction of minimal pair longitudinal arrival separation to 2NM at V1 level. Then a fast time simulation validated at V2 level the combined performance of the reduced minimal pair arrival separations with the inclusion of ROT (Runway Occupancy Time) reductions. Finally a real time simulation validated the level of the suitability of the concept, practices and procedures and associated tools support for the application of the 2NM separation.	V0	V2
AO-0310	Weather-dependent reductions of Wake Turbulence separations for final approach	One real time simulation was run to validate the suitability of the concept, practices and procedures and associated tools support for Weather Dependent Separations for arrivals.	V1	V2
AO-0324	Wake Turbulence separations (for departures) based on Dynamic Aircraft Characteristics	Only an initial version of the OSED was developed.	V0	V1
AO-0328	Optimised Runway Delivery on Final Approach	One real time simulation was run to validate separation delivery tool derived from the TBS tool. That tool allows applying complex set of constraints giving the controller the indication of	V0	V2

		the minimum distance to apply taking into account: Time Based, ROT, MRS, Mix mode…		
AUO-0703	Optimised enhanced braking information at a pre-selected runway exit coordinated with Ground ATC (Air Traffic Control) by Datalink	One exercise was conducted to validate surface routing in a data link environment (D-TAXI), focusing on ground-board interoperability.	V1	V2
AO-0311	Reduced low visibility CAT II & III arrival separations	A validation activity was performed whose purpose was to validate the viability of reducing the separations in CAT II and CAT III for arrivals (on final approach, at the point that the leading aircraft in the pair crosses the runway threshold), between successive aircraft when LVC (Low-Visibility Conditions) existed and a LVP (Low-Visibility Procedures) had been declared.	V1	V2

Project 06.08.01 contributed to:

- SESAR 1 solution #64 - Time Based Separation (for AO-0303) reached full V3 in SESAR 1 and is implemented at Heathrow.

Work will continue is SESAR 2020 on the following topics, with the objective to reach V3 in 2019:

- Wake turbulence separation optimization (for AO-0304, AO-0306 and AO-0310).
- Minimum-Pair separations based on RSP (for AO-0309).

1.2 Project achievements

WAKE

The project has delivered validation of several concepts, two of them have reached V3 or close to V3 maturity level: Time based separation (TBS) that is part of the PCP (Pilot Common Project) regulation and for which a local solution has been implemented in London Heathrow, and RECAT-2, also called Static Pair Wise Separations (S-PWS), that is now considered for implementation (at 3-5 years' time horizon, once V3 completed in SESAR-20202) by ANSPs (Air Navigation Service Provider) as it easily improves TBS concept by providing additional capacity, on the top of runway throughput resilience in case of headwind. Moreover, with minor modification, the ATCO support tool developed for the TBS concept is perfectly able to also support the implementation of S-PWS. The safety requirement and safe tool settings have been proposed as starting point for local customisation.

It is important to mention that, a sub-product of the RECAT-2 work is the definition of methodology for defining separation for new or future Heavy aircraft that was cascaded to the bi-lateral agreement jointly prepared by EUROCONTROL, EASA (European Aviation Safety Agency) and the FAA (Federal Aviation Authority).

Weather dependant separations (reduction of separation in case of minimum total wind or crosswind) have also been validated in principle. This means that the separation reduction as a function of wind has been shown to be acceptably safe. However, even if the weather input requirements have been defined, some aspects of the concept related to the strategic and tactical use of the concept have not been assessed in real-time simulation and may require further work (as planned in S2020 PJ-02 Dow 1.0).

MRS

The project developed the concept of new minimal-pair separation minima reducing the longitudinal arrival separation to 2,0 NM. This new, reduced separation is enabled through the definition of Required Surveillance Performance specifications. The individual criteria in these specifications describe the factors to be considered when implementing the minima in order to have sufficiently safe surveillance.

The project provided a table showing separation minima in which previous separation minima (3/2.5 NM), has been reduced to 2 NM in the cases where 2.5NM was not the Wake Vortex separation. It also provided the potential benefits that an airport could achieve, depending upon the runway occupancy time and the traffic mix.

EBS

Some work and experiments were performed on EBS through voice with the conclusion that the controller workload was too heavy to give any benefit in big airports where the benefits were looked for. The associated OI AUO-0702 was then deleted).

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
06.08.03 D24	S2 V1 Interoperability Requirements	MRS step 2 V1 INTEROP for the secondary separation reduction, following D23 Operational Service and Environment Definition (OSED). This document describes what other ATM systems are required, in order for an airport to implement these reduced separations for a given pair of aircraft.
06.08.03 D22	S2 Separation Minima Reduction Selection Methodology	This document presents the methodology to select the Step 2 airport related separation minima to be investigated as to how it can help achieve the required increase in European Air Traffic Capacity. It presents the reductions that can safely be implemented and under which constraints.
D26	D26 - 06.08.02 VALR for V2 and V3 exercises report	This document is the Validation Report for the Step 1 V2 validation activities on EBS. It describes the validation exercises that took place between April 2013 and December 2013, as well as the analysis of those exercises and recommendations for next steps of the project. These validation activities consisted of a live trial incorporating an EBS voice procedure at London Heathrow. This trial was a V3 activity focused on voice transmission of the runway exit from the aircraft. Two independent fast-time simulations incorporating differing EBS equipage levels investigated various runway airport operations.
D30	OFA 01.03.01 Enhanced Runway Throughput Consolidated Final Step 1 OSED	The document presents the Step 1 final OSED of OFA 01.03.01 - Enhanced Runway Throughput.
D32	OFA 01.03.01 Enhanced Runway Throughput Consolidated Final	The document presents the Step 1 final SPR of OFA 01.03.01 - Enhanced Runway Throughput.

	Step 1 SPR	
D34	OFA 01.03.01 Enhanced Runway Throughput Consolidated Final Step 1 Interop	The document presents the Step 1 final Interop of OFA 01.03.01 - Enhanced Runway Throughput.
D52	EXE 689 Exercise report - VALR	This document presents and gives the results of the V2 Real Time Simulation conducted by EUROCONTROL, THALES and DSNA in early 2016 with the purpose of advancing the maturity of a generic Separation Delivery tool at V2 (feasibility) which can operate with a range of Wake Turbulence (WT) schemes. The main focus of the RTS (Real Time Simulation) was on Time Based Static Pair Wise Separation with Optimised Runway Delivery (ORD), with an initial assessment of a Weather Dependent Separation (WDS) concept with ORD.
D57	S2 V1 SPR - Report	This document identifies the Safety and Performance Requirements needed for the use of reduced arrival separations in CAT II and CAT III conditions using GLS/GBAS (GNSS Landing System/Ground Based Augmentation System).
D59	EXE 753 S2 V1 Validation Report	This document presents the V1 Fast Time validation activities performed by ENAIRE Reduced low visibility CAT II & III arrival separations and gives the results of the simulation.
D44	EXE 688 Exercise report - VALR	This document presents the V2 Real Time Simulation that was performed by EUROCONTROL as part of Time Based PWS (Pair-Wise Separation) Validation and gives the results of the simulation.
D38	RECAT 2 - Final ICAO Formatted Deliverable	This document presents the safety risk assessment of static pair-wise wake turbulence distance-based separation (S-PWS) / 'RECAT2-EU' minima on Approach and Departure. This report describes the safety specification, risk metrics, design methodology and data, with associated arguments and evidence which provide assurance that the resulting separation minima are acceptably safe and can be used as a basis to update current wake turbulence separation schemes.
D41	EXE 690 Exercise results - VALR	This document presents the V2 validation activities that were performed by NATS using a combined Tower and Approach Real Time Simulation based on combined approach and tower functions at Heathrow airport and describes the results of the validation that considered: • Static Pair-Wise Separation (S-PWS) • Optimised Runway Delivery (ORD)
D64	EXE 835 Exercise results - VALR	This document presents the second phase of the Real Time validation activities performed by NATS for the Flexible and Dynamic Use of Wake Vortex

		Separations, and the results of the simulations. It describes multiple new wake separation and supporting concepts/enablers that are to be developed and validated on top of the TBS baseline from Phase 1 within NATS. These include: • Static Pair-Wise Separation (S-PWS); • Optimised Runway Delivery (ORD). • 2Nm Minimum Radar Separation (2Nm MRS).
D60	S2 V1 Safety Report	This document specifies, inter alia, the safety assurance activities that are to be carried out in relation to the Operational Improvement Step AO-0311 which will be used for the production of the Safety Assessment Report (SAR) and SPR.
D61	S2 V1 OSED update	This document provides the OSED for Operational Improvement AO-0311 (Reduced low visibility CAT II & III arrival separations). It is an updated V1 OSED after the V1 validation activity.
D56	EXE 754 Exercise report - VALR	This document presents the V2 Fast Time Validation activities performed by ENAIRE on Minimum-Pair separations based on RSP and gives the results of the simulations.
D10	Validation Report (VALR) for Time Based Separation (TBS)	This document presents the two V3 Real Time Simulations performed by NATS on Time Based Separation tool and procedures and gives the results of the simulations.
D11	Internal exercise results: Human performance, LIDAR, Benefit and Safety assessment reports	This document is made of four annexes complementing the results presented in deliverable D10.
D05	Operational Service and Environment Definition (OSED) for Time Based Separation for Arrivals (TBS)	This document is the OSED related to the application of Time Based Separation for Arrivals (TBS) to provide for improved achieved arrival capacity resilience to headwind conditions on final approach.
D65	D-PWS OSED	This document presents an initial view of the Dynamic Pair Wise Separation concept for arrivals and departures covering OIs AO-0307 and AO-0324.

1.4 Contribution to Standardisation

WAKE

In accordance with the ‘’Indicative roadmap with respect to standardisation and regulatory needs’’ EUROCONTROL has been mandated to undertake a standardisation activity to produce a ‘’Standard on TBS tools Performance Specification’’. The development of the Specification on TBS has been done in support of the deployment of AF2: AO-0303 ‘’TBS for Final Approach’’ of the PCP

Regulation1. This Specification is now going for all stakeholders review (EUROCONTROL Notice of Proposed Rule-Making - ENPRM).
A High-level Group composed of both US and EU Aviation Authorities (EASA and EUROCONTROL) representatives was established in March 2014 to address the issues linked to the determination of wake turbulence separation (WTS) minima for new Heavy and larger aircraft (e.g. ICAO (International Civil Aviation Organisation) Heavy and Super Heavy categories) by safety regulators. As the result of the series of discussions held between March and September 2014, the report contains the proposal for a US / EU bilateral working arrangement that recognizes the mutual authority, trust, and expertise in this field. The technical support provided by EUROCONTROL with this respect is largely extracted from the work conducted in the context of RECAT-EU (EUROCONTROL Network manager Directorate project) and RECAT-2 development AO-0306. The Project 6.8.1 prepared the documentation and safety case now introduced for review and regulatory decision to EASA.

MRS

The Minimal-pair Separation activity was dependent upon using a Required Surveillance Performance (RSP) specification. This specification was begun using the EUROCONTROL RSP specification for 3NM and 5NM separations as a template. Studies were performed to bring the maturity of this specification to the V2 level. This separation reduction still requires significant regulatory work.

EBS

The project had no standardisation activity on EBS because the concept did not reach full maturity.

1.5 Project Conclusion and Recommendations

WAKE

The Wake Turbulence Separations based on Static Aircraft Characteristics have been validated up to V2 in SESAR 1. The proposed Pair Wise Separations for the top 96 most frequent aircraft type, the generalisation of methodology to all types and the associated Safety Case was reviewed by a task force including ANSPs, CAA (Civil Aviation Authority) and Manufacturers.
EASA will eventually conduct the technical review prior to endorsement.
As such these separations can be used for creating an optimised 6 category scheme but need an ATCO supporting tool allowing pairwise separation delivery. The finalisation of this tool is a gap to be fulfilled for reaching V3. The remaining work is on the tool and associated procedures, the minima are validated.

The finalisation of a totally generic tool requires (for being used in all airports and for all concepts including PWS) characterisation of aircraft types performance and behaviour on the glide (mainly in deceleration phase), specification of required wind monitoring and nowcasting capabilities, definition of local parameterisation procedures of the tool for deployment in specific operational environments and development of additional functionalities (alerting, sequence definition) identified during real-time simulation.

Most of these issues have however been resolved for the local implementation of TBS at London Heathrow. For Time Based Static Pairwise Separation with Optimised Runway Delivery there is still outstanding work to be conducted in these areas although the tool has been widely accepted by the controllers. Significant increases in landing rates were achieved using the concept but these came at the expense of fatigue to the controllers. Further work is required to investigate how to address the human factors issues that have been identified.

The weather criteria (mainly wind) to be met for allowing separation reduction will be fully validated based on wake, wind and traffic data analysis. A first real-time simulation tested the use of an ATCO separation delivery tool.

1 Commission Implementing Regulation (EU) No 716/2014 of 27 June 2014 (The Pilot Common Project Regulation)

For weather dependent separation, the gaps for reaching V3 are, firstly, the refinement of the tool for efficient use of weather based separation and, secondly, the definition of stable and detailed strategic decision process for actually turning in capacity the tactical reduction as a function of wind. This process shall trade-off frequency of separation reduction, rate of inaccurate wind prediction, buffer to be applied for dealing with met forecasting deviation and capacity benefit. Also the impact of the performance of the meteorological prediction and measurement technologies will need to be considered in the definition of V3 procedures.

Now, incentive works need to be conducted in order to support the ANSP in the selection of the relevant concept to apply as a function of local traffic mix, traffic pressure and weather conditions.

In the next SESAR program, the simultaneous deployment of different solutions developed here and their interaction should be investigated. Especially, the use of enhanced approach procedures will be the ultimate refinement of the approach that should lead to applying wake separation minima only when strictly needed meaning rarely.

MRS

Further study is required on the reduction of arrival minimal-pair separation below 2.5 NM. More procedure development needs to be performed to determine the constraints on the benefits due to differing operational conditions such as headwind/tailwind. The main recommendations to consider in further validations are listed below:

- ATC control spacing must be included somehow in order to adapt on the go the minimal-pair arrivals between 2.0NM and 2.5NM, depending upon the standard AROT of the leader. The clearance to land spacing will need to take into account:
    - The runway occupancy time of the lead aircraft
    - The time/distance from the runway landing threshold that the clearance to land should be issued
    - The distance the follower aircraft will fly to the clearance to position in the runway occupancy time of the lead aircraft, taking into account the associated ground speed profile of the follower aircraft, through taking into account:
- The transition from the intermediate approach 3NM MRS to the reduced 2NM MRS needs to be considered with respect to the benefits validation; particularly with respect to transition to the same glideslope such that 1,000ft vertical separation cannot be utilised during the transition.
- Go-around reasons should be consolidated, since they may be ordered by ATC or decided by the Flight Crew in command. As a go-around does not itself constitute any sort of emergency (although it can be in response to an emergency) it will be also subject to local procedures which can make the ATC decide there is an unsafe condition, aircraft, vehicle or object on the runway, but the location and the distance from the arriving aircraft may be very different from one airport to another.
- Future theoretical studies should include the different considerations for the stabilisation of the approach speeds. The landing approach speed should be stabilised by 1000ft above ground level and thus any continuous airspeed deceleration modelling should end at approximately 3NM from the runway threshold rather than at the runway threshold.

EBS

As only one Real Time Simulation mainly focused on the controller side assessed the benefits of EBS, it is recommended that further investigation is made into quantifying the impact on runway throughput considering different or variable separation minima and associated technologies in a future based operating environment. Additionally, further investigation into establishing optimum mixed mode operations where the benefit of EBS can be maximized in terms of runway throughput as well as delay reductions..

2 References

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[5] 06.08.03, S1 V1 Interoperability Requirements, D03, 01.00.00, 30 October 2012

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