



The CREDOS Project

“WP4 Final Report”

Abstract: The CREDOS project aims to demonstrate the feasibility of a departure operation whereby the wake turbulence separations between successive aircraft are temporarily suspended under specific (favourable) crosswind conditions. The present report constitutes the Final Report of Work Package 4 "Operational Concept and Validation" of the CREDOS project. This Work Package has three objectives:

- To define a new concept of operations for crosswind departures and to support its safe implementation.
- To prepare the Validation Case for the safe introduction of the CREDOS concept at European airports. This concerns the Safety Case, Human Factors Case, Environmental Case and Business Case, as well as additional activities necessary to show conformance with the EUROCONTROL Safety Regulatory Requirements (ESARRs) (such as the development of a Wake Vortex safety management system).
- To define and validate the concept of operations and system requirements, including interoperability with existing ATC systems and usability and acceptability for air traffic controllers and pilots. Following the definition of operational concept and procedures, this aim is realised through ATC real-time simulations.

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Acronyms

ACRONYM	DEFINITION
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
CBA	Cost Benefit Analysis
CND	Clearance Delivery
CREDOS	Crosswind Reduced Separations for Departure Operations
DEP	Departure Controller
DMAN	Departure Manager
EATMP	European Air Traffic Management Programme
ECAC	European Civil Aviation Conference
EMOSIA	The European Model for Strategic ATM Investment Analysis
E-OCVM	European Operational Concept Validation Methodology
ESARR	EUROCONTROL Safety Regulatory Requirements
EUROCONTROL	European Organisation for the Safety of Air Navigation
FHA	Functional Hazard Assessment
GND	Ground Controller
GSN	Goal Structured Notation
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
LIDAR	Light Detection and Ranging
METAR	Meteorological Terminal Aviation Routine Weather Report
NLR	Netherlands National Aerospace Laboratory
NM	Nautical Mile
NPV	Net Present Value
PANS-ATM	Procedures for Air Navigation Services - Air Traffic Management
PSSA	Preliminary System Safety Assessment
PSC	Preliminary Safety Case
R&D	Research and Development
SAM	Safety Assessment Methodology
SID	Standard Instrument Departure
SO	Safety Objective
ST	Safety Target



SUP	ATC supervisor
TAF	Terminal Aerodrome Forecast
TMA	Terminal Maneuvring Area
TWR	Tower Controller
VESA	Vortex Encounter Severity Assessment
WVE	Wake Vortex Encounter
WT	Wake Turbulence
WTA	Wake Turbulence Advisory
WTTSSAV	Wake Turbulence Separations Suspension Airspace Volume

Executive Summary

The CREDOS project aims to demonstrate the feasibility of a departure operation whereby the wake turbulence separations between successive aircraft are temporarily suspended under specific (favourable) crosswind conditions. The present report constitutes the Final Report of Work Package 4 "Operational Concept and Validation", which has three tasks:

- WP4.1 concerns the definition of the concept of operations, the refinement of this concept based on the CREDOS modelling and validation results, and requirements for the system (the procedures, user requirements, and system requirements);
- WP4.2 concerns the development of the validation strategy and plan, the execution of the different validation cases (business case, environmental case, safety case, and human factors case and other activities necessary for safe introduction of CREDOS);
- WP4.3 concerns the validation of the concept of operations and Human Machine Interface requirements through the use of real-time simulation (with support of intermediate recommendations resulting from the human factors and safety activities).

The basic idea behind CREDOS is that, for departures, the wake turbulence separation criterion may be relaxed on the runway and for the first part of the climb path when the crosswind is such that the wake turbulence generated by the preceding aircraft will have been blown out of the departure track of the succeeding aircraft. The benefits of the proposed concept would be a temporarily increase of the departure runway throughput in such a way that it absorbs capacity peaks or reduces departure delays. This increase occurs only when an aircraft of lighter wake category directly follows a heavier one and the CREDOS criteria are met. Only in such cases is there a potential for reducing the spacing between that aircraft pair compared to the wake turbulence separation that would otherwise have to be applied. The actual benefits would then also be dependent on traffic composition, usage of the runway and the SID structure. The safe application of CREDOS separation suspension would require new information to be considered by controllers. CREDOS is a wind-dependent concept. Consequently, the safe application of the concept requires the wind conditions to be monitored in the area surrounding the aircraft departure path. The range of the concept applicability is thus dependent on the wind monitoring capabilities of the airport (wind measurements, wind nowcast and/or forecast). At this stage, the CREDOS concept has been kept as generic and as simple as possible. The concept is thus to be considered rather as guidance material than as a description of one particular endorsed solution. A number of improvements are also envisaged for the future. The different validation cases have shown that, although there is clear potential from a Business Case, Environmental Case and Human Factors point of view, further work in the area of safety is needed. It is also concluded that the next step for crosswind concept validation should be aimed at performing one or more local implementation cases.

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1 Introduction

1.1 Background and scope

Increases in air traffic over recent years have resulted in congestion at many airports. The need to increase airport capacity is one of the major challenges facing ATM research today. Such an increase could be achieved by reducing the current separation minima while maintaining levels of safety. ICAO wake turbulence separation standards for landing and take-off were implemented in the 1970's to protect an aircraft from the wake turbulence of a preceding aircraft. However research has shown that the transport and persistence of wake vortices are highly dependent on meteorological conditions, so that in many cases the ICAO standards are over-conservative. By developing a full understanding of wake vortex behaviour in all weather categories separations could be reduced under certain suitable conditions. The CREDOS project studies the operational feasibility of this approach by focussing on crosswind conditions for departures. The CREDOS project only considers the single runway case. Some important differences should be noted when considering the potential for reduced separations for departures as compared to arrivals. The departure configuration has significant advantages for weather-dependent reduced separations:

- The follower aircraft is on the ground so the controller always has the possibility to extend the separation without requiring the pilot to make a manoeuvre.
- The leader aircraft is generally faster so that the actual separations tend to increase over time. This is in contrast to the arrivals situation where the slower speed of the leader generally leads to catch up by the follower (compression effect).
- A follower aircraft can climb or turn out of an encounter more easily in a climb phase than in a descent phase.

However the departure configuration also presents a problem, not found for arrivals:

- There is not an equivalent of the standard glide-slope associated with arrivals on a particular runway. Depending on aircraft type, the piloting preferences and the choice of entry taxiway, the take off rotation point can vary considerably. Once airborne different aircraft will follow a range of climb angles and departure routes making it more difficult to predict the likely position of the wake vortex.
- Thus although the departure configuration may initially appear simpler, the reduced predictability of the leader and follower aircraft positions means that it will be more complex to define the operational concept. Any attempt to reduce separations based on predicted wake vortex behaviour must take into account the probabilistic nature of

predictions. Whenever aircraft are flying they generate wake vortices, so there is never a zero probability of wake vortex encounter, even with the current ICAO separations.

1.2 Objectives

The main objectives of the CREDOS Operational concept and validation activities are:

- To define the new concept of operations for crosswind departures based on work of the ConOps Evaluation Team and to support its safe implementation at airports.
- To prepare the Validation Case for the safe introduction of the CREDOS concept at European airports. This concerns the Safety Case, Human Factors Case, Environmental Case and Business Case, as well as additional activities necessary to show conformance with the EUROCONTROL Safety Regulatory Requirements (ESARRs) such as the development of a Wake Vortex safety management system.
- To define and validate the concept of operations and system requirements, including interoperability with existing ATC systems and usability and acceptability for air traffic controllers and pilots. Following the definition of the operational concept and procedures, this aim is realised through ATC real-time simulations (with support of intermediate recommendations resulting from the human factors and safety activities).

1.3 Approach and methodology

The approach covers both the design and validation of the operational concept proposed for crosswind departures. This concept will be developed from work already performed in the USA so that the larger part of the effort will be spent on the validation activity. The ConOps Evaluation Team (CET) studied the possibilities for wake vortex mitigation concepts in the context of the USA WakeVAS project. This work will serve as an input to the work, which will consider the European potential of these concepts. At the start, a validation strategy and plan that states what will be addressed in terms of Benefits, Human Factors, Safety, Technology and Environment will be established. This work package comprises three tasks, with as main objectives and activities:

- WP4.1 concerns the definition of the concept of operations, the refinement of this concept based on the CREDOS modelling and validation results, and requirements for the system (the procedures, user requirements, and system requirements);
- WP4.2 concerns the development of the validation strategy and plan, the execution of the different validation cases (business case, environmental case, safety case, and human factors case and other activities necessary for safe introduction of CREDOS);
- WP4.3 concerns the validation of the concept of operations and Human Machine Interface requirements through the use of real-time simulation (with support of intermediate recommendations resulting from the human factors and safety activities).



1.4 Document structure

Section 2 contains a description of the operational concept and system design. The sections 3, 4, 5, and 6 comprise the main observations and findings from the four validation cases, namely Business Case, Environmental Case, Safety Case, and Human Factors Case respectively. Section 7 contains the main conclusions and recommendations from work undertaken in Work Package 4 of the CREDOS project.

2 Operational concept and system design

2.1 Background

It has been highlighted, in the EUROCONTROL “Performance Review Commission Report” (published in mid-2004) [16] and in the EUROCONTROL “Constraints to Growth” study [17], that the cost and impact of airport related delays had reached parity with those for en-route and noted that airports were now a major constraint to growth, leading to the conclusion that airport throughput capacity has to be increased. In addition, it is commonly recognised that, in today’s operations, airport capacity is constrained, amongst others, by the application of wake turbulence separation minima. Consequently, years of effort have been put into the investigation of potential solutions to reduce the wake turbulence separation minima.

2.2 Scope

The CREDOS project is investigating the possibilities of safe conditional reduction of separation minima for departure, by suspending the wake turbulence separation under specific crosswind conditions. Today’s wake turbulence time-based or distance-based separation minima are defined in the ICAO PANS-ATM document [18], see Table 1.

Table 1: Current ICAO wake turbulence separation minima for departures.

Leading Aircraft	Following Aircraft	Distance-based wake turbulence separation minima	Time-based wake turbulence separation minima
HEAVY	HEAVY	4.0 NM	-
HEAVY	MEDIUM	5.0 NM	2 min*
HEAVY	LIGHT	6.0 NM	2 min*
MEDIUM	LIGHT	5.0 NM	2 min*

* 3 minutes if taking off from an intermediate position

In addition to the wake turbulence separation minima, the ICAO PANS-ATM recommends that the horizontal separation minimum based on radar and/or ADS-B shall be 5.0 NM. It also states that this radar separation minimum may be reduced (if allowed by the appropriate ATS authority) to 3.0 NM (or even 2.5 NM), where surveillance system capabilities permit.

The ICAO wake turbulence separation minima have been set out to be applied regardless of the meteorological conditions. Of course applying such minima is effective in avoiding potentially dangerous wake turbulence encounters but it also reduces runway throughput due to the additional distance/time to be maintained between certain aircraft pairs. Moreover, it is recognized that these separation minima are over-conservative in certain weather conditions and therefore unnecessarily reduce the airport capacity. The basic idea behind CREDOS is that, for departure, the wake turbulence separation may be relaxed on the runway and for the first part of the climb path when the crosswind is such that the wake turbulence generated by the preceding aircraft should have been blown out of the departure track of the succeeding aircraft. The benefit of such a suspension of the wake turbulence separation would be a reduction of the aircraft take-off interval. This would enable a temporarily increase of the departure runway throughput in such a way that it absorbs capacity peaks and/or reduces departure delays. The CREDOS concept only aims to relax the wake turbulence separation for departure when wind conditions are favourable. In no circumstances, does it intend to reduce the minimum standard radar separation of 3.0 NM (when radar capabilities permit). The CREDOS concept is based on today's technical environment. It does not rely on any advanced tools such as DMAN or electronic flight strips. The concept is based on the assumptions that:

- departures are controlled in an ATS surveillance system environment;
- ATS surveillance system based separation minima are applied between aircraft after departure;
- the runway controller is responsible for establishing ATS surveillance system based separation minima for departing aircraft;
- a single independent runway is used in a segregated mode for departures only.

The suspension of the 3 minutes wake turbulence separation rule when departing from an intersection (see Table 1) is not considered in the concept. In the same way, "SUPER HEAVY" aircraft, such as the Airbus 380, are not included in the CREDOS concept. Although limited in its scope, the CREDOS concept of operations offers a possible solution for temporarily increasing runway throughput.

2.3 CREDOS concept of operation

The concept is built on the assumption that, when suitable, the crosswind should blow the wake turbulence generated by a preceding aircraft out of the path of the succeeding aircraft and consequently that the wake turbulence separation may be suspended when a pre-defined crosswind component threshold is reached.

This crosswind component threshold has to be determined by a local validation on the basis of a measurement data collection with LIDAR and wind meters. Because it is wind

dependent, the application of the concept requires that wind conditions have to be monitored in the aircraft departure area. The extent of the concept is thus dependent on the wind monitoring capabilities of the airport, since the concept obviously does not apply where the wind cannot be accurately evaluated. Wind monitoring is based on wind measurements but could also include wind nowcast and/or wind forecast. These wind determination capabilities define a volume surrounding the aircraft departure path within which the wind can be monitored and therefore within which the wake turbulence separation may be suspended. In the context of the CREDOS concept, this volume is named 'Wake Turbulence Separations Suspension Airspace Volume' (WTSSAV), see Figure 1. The determination of the size of this volume is described in reference 11.

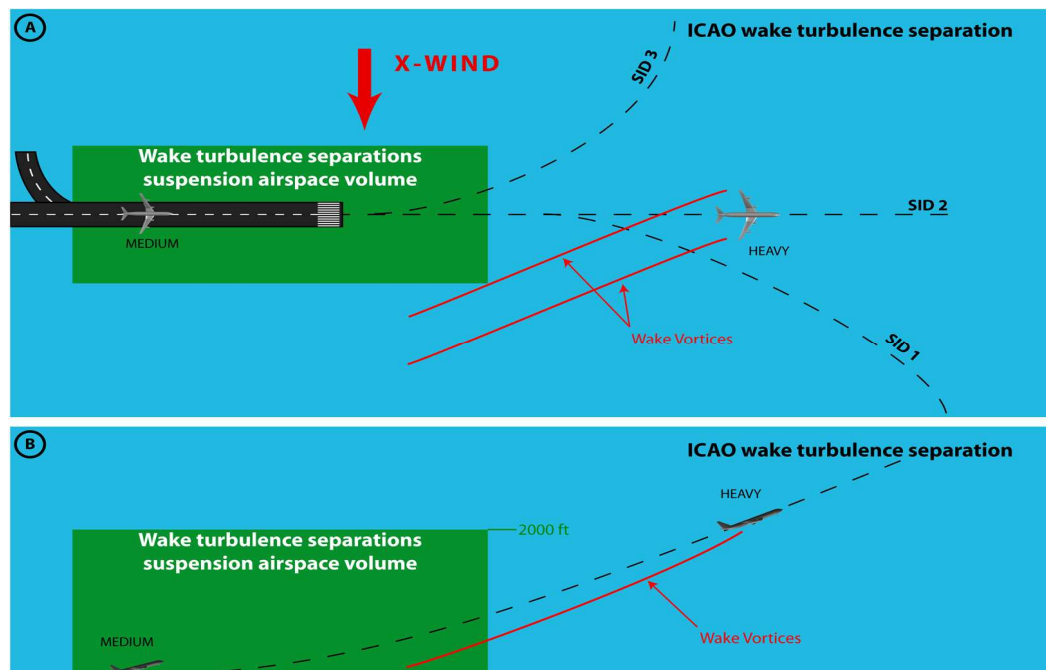


Figure 1: Illustration of the CREDOS WTSSAV determined by the wind monitoring capabilities

Inside the WTSSAV, when the CREDOS wind level is reached, the wake turbulence separation may be suspended. Outside, since the wind conditions cannot be monitored, the ICAO standard wake turbulence separation minima apply. Consequently, the spacing between two consecutive departures, when CREDOS operations apply (i.e. when the wake turbulence separation may be suspended inside the WTSSAV) has to be set so that a transition:

- from no wake turbulence separations, when inside the WTSSAV,
 - to ICAO wake turbulence radar separation minima, when outside,
- is properly achieved.

This transition constraint leads to the conclusion that CREDOS suspension of wake turbulence separation minima does not directly imply that applicable spacing between consecutive departures are equal to the minimum radar separation (i.e. 3.0 NM) but rather a value between 5.0 NM and 3.0 NM. The methodology used to determine the suitable reduced spacing is further described in reference 11. It is worth noting that the suitable reduced spacing is defined on the basis of the pre-defined crosswind threshold and the pre-defined size of the WTSSAV. It will not therefore fluctuate with variation of the crosswind component. When the crosswind component meets the pre-defined requirement, CREDOS reduced spacing may be applied. When below the defined crosswind component threshold, CREDOS may not be applied. Finally, it is also to be taken into account the respective SIDs of the aircraft. CREDOS is based on the lateral transport of the wake turbulence due to the crosswind, therefore, the suspension of the wake turbulence separation minima may only be applied if the departing route of the second aircraft does not go in the direction where the wake turbulence generated by the first one is blown (i.e. the SID of the second aircraft is not downwind from that of the leader). In other words, CREDOS may be applied only for an aircraft departing on the same or an upwind SID compared to the departure of a preceding heavier aircraft. In order to support the runway controller in determining whether or not the SID of the follower aircraft is upwind, advisory tools and procedures should be developed. The conclusion from above is that any actual application of CREDOS suspension of the wake turbulence separation minima has to be determined per airport, per runway, and even per departing aircraft pair (i.e. taking into account the respective aircraft's SID).

2.4 Minimum reduced spacing

The suitable spacing between two consecutive departures in CREDOS operations may be expressed in terms of a time-based minimum (as it is mainly applied today) or in terms of a distance-based minimum. At this stage, it is considered to be a local responsibility to determine the best spacing means, according to specific local infrastructure, procedures, constraints, requirements and expectations.

2.5 Determination of the WTSS box size

It has been concluded that CREDOS application requires monitoring of the wind to determine whether the crosswind component reaches the pre-defined threshold. The range of the Wake Turbulence Separations Suspension Airspace Volume is limited by the technical capability to evaluate, with sufficient accuracy for CREDOS application, the wind condition prevailing in the area surrounding the departure path. Most of the time, such technical issues will limit the height of the WTSSAV, which then also defines the altitude at which the transition from CREDOS reduced spacing to ICAO standard wake turbulence

separations has to be obtained. Of course, the higher the vertical size of the WTSSAV, the more time will be available to perform the transition (including for instance the pull-away effect where aircraft spacing increases over time). Consequently, the higher the vertical size of the WTSSAV, the shorter the CREDOS reduced spacing can be thus increasing the benefits of CREDOS application. Laterally, besides the limitation due to the range of the wind assessment equipment, the size of the WTSSAV is mainly determined by the required width of the wake turbulence safety corridor around the path of the departing aircraft. The width of the corridor is established on the basis of safety arguments, taking into account the range of the wind assessment equipment (which should not constitute a limitation) and the capability of the aircraft to accurately navigate their departure paths. In conclusion, the size of the WTSSAV has to be defined locally on the basis of local wind monitoring means (height of the airspace volume), of the aircraft's accuracy to fly the local departure paths (width of the airspace volume) and of the structure of the SIDs.

2.6 Determination of CREDOS spacing

As indicated, a local evaluation of both time-based and distance-based separation is required to select the more appropriate. Hence, what is described in this section is the methodology that guides the determination of the suitable spacing minimum regardless of the spacing method (time or distance). This methodology is applied during a determining phase of implementation before the concept is taken into operational use. When applicable, the suspension of wake turbulence separation would ultimately lead to a reduction of the aircraft separation down to the minimum radar separation, in general 3.0 NM (corresponding approximately to a 1 minute time separation). But, as described above, the time needed for the crosswind to blow the vortices clear of the succeeding aircraft's departure path, and the requirement to obtain the ICAO wake turbulence separation when this follower aircraft exits the WTSSAV have to be taken into account. So the CREDOS aircraft wake turbulence separation reduction, when enabled by the crosswind component, is determined by all of the following conditions:

- the time between two departures, when the wake turbulence separation minima are suspended, has to be sufficient to ensure that the wake turbulence is transported out of the departure path of the follower;
- consecutive departing aircraft always have to be separated by at least the applicable ATS surveillance system based separation minimum (usually 3.0 NM);
- transition from CREDOS spacing to ICAO standard wake turbulence separation has to be obtained prior to the point at which the succeeding aircraft reaches the upper boundary of the WTSSAV.

Of course, to be considered suitable, the CREDOS reduced spacing has to satisfy each of these constraints. This can be ensured by the use of a general iterative decision-making process illustrated by the decision tree in Figure 2.

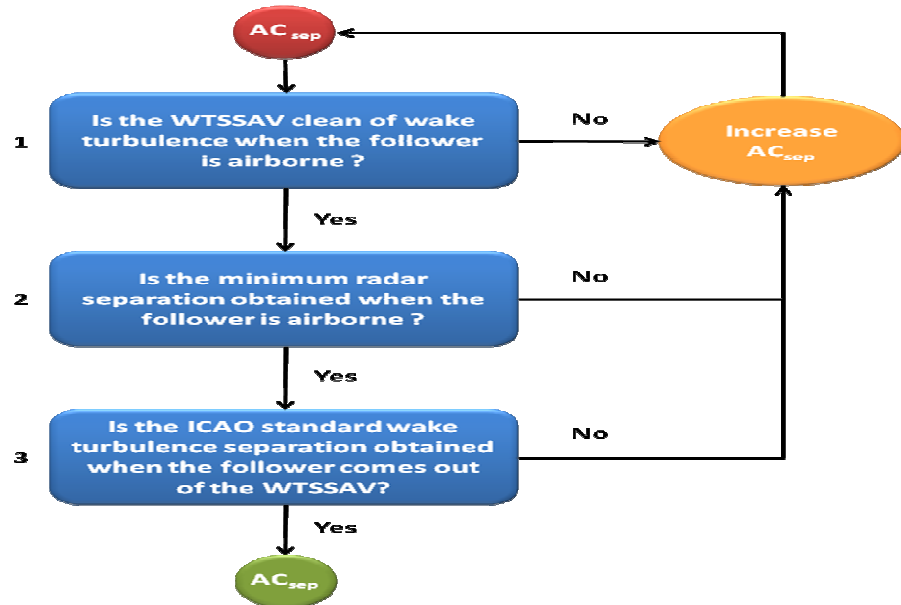


Figure 2: Decision-making process for determining the suitable CREDOS reduced spacing.

During this iterative process, any CREDOS reduced spacing candidate is checked against each of the three constraining factors to assess whether each constraint is satisfied or not. If a criterion is not met, the spacing has to be increased. The input to this process is collected radar tracks of known identity (aircraft type, airline etc) of local traffic at the candidate airport. The output of the process is a spacing that accommodates all three constraining factors.

2.7 Human Machine Interface

A separation support tool has to be developed to support controllers when applying CREDOS operations. It shall also give clear advice on whether wake turbulence separations can be suspended or not (i.e. the system is available and the wind criteria are satisfied). HMI or procedures for determining upwind/downwind SID's per aircraft are also needed. The Human Machine Interface shall be easy to understand and use. See Section 6 "Human Factors case" for more details and recommendations on this issue.

2.8 CREDOS roles and procedures

The details of the proposed roles and procedures for CREDOS concept are described in the CREDOS final concept of operations [11]. The main change in the roles and



procedures of controllers introduced by the CREDOS concept is that when it applies, it is presumed that it is the Runway Controller who is responsible for obtaining aircraft separation after departure. This includes the monitoring of the transition from CREDOS reduced separation to the ICAO standard wake turbulence separations.

3 Business case

3.1 Introduction

The CREDOS Business Case [13] provides an initial generic Cost Benefit Analysis of the CREDOS Concept. As defined in the CREDOS Validation Strategy and Plan [3], this exercise aims at the validation objective *'The cost of implementation of the crosswind departure concept will be lower than the economical benefits derived from it'*.

Taking into account this goal, the work is conducted in several stages: first, the analysis of the airports chosen by EUROBEN project [19] and the benefits obtained in the CREDOS Operational Benefits Assessment [8], then the selection of the airports which expect to reach benefits with CREDOS technology. Lastly, the exercise develops the economical model for each airport chosen which yields economical indicators, e.g. the Net Present Value (NPV), the Sensitivity Analysis, etc...

3.2 Generic approach

In economic terms, the aim of the CREDOS project is related to obtaining the potential benefits related to efficiency of the considered airport as well as the potential costs savings for the airlines. These benefits could be represented by the following indicators:

- **Efficiency:** CREDOS reduces wake vortex separation, since as it has the potential to significantly increase the efficiency of departure movements by the reduction of delays.
- **Cost savings for Airlines:** savings resulting from aircraft delay absorption. This delay reduction will impact significantly on airline costs

For economical analysis, we have considered that benefits come from reducing delay, as calculated in the Operational Benefits Analysis [8]. This benefit occurs in peak hours, and in airports where there is enough crosswind conditions to use CREDOS. The study considers an average delay of 4 minutes per aircraft with ICAO separations, which determines a minimum demand to calculate the delay [8].

The benefit of CREDOS appears from the reduction of the mentioned delay. Only some airports have enough traffic demand to reach the delay of 4 minutes per aircraft. Thus there is a break point in this study: 4 minutes delay/aircraft when the demand is exactly the number of departures for which practical capacity is reached using ICAO separations. In this point is where we know the delay reduction [8].

Table 2 Delay reduction

	EDDF	EHAM	LEBL	EGKK	EGLL	LEMD	EGCC	EDDM	LFPG	LIRF	LSZH
ICAO	51,6	53,5	36,3	34,1	32,1	34,9	34,8	35,6	53,2	35,7	54,8
4-min delay reduction [%]	29,9	16,8	26,5	28,9	29,9	28,4	28,8	28,6	17,2	28	16,5

Taking into account the above reflection, we can find the “break point” (in yellow) for each airport considered, depending of its future traffic demand, in the table below:

Table 3 One hour future traffic flow

	Average flow 1h 2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Break Point (Flights/Pick hour)
EDDF (Frankfurt)	36,7	37,4	38,0	38,6	39,1	39,7	40,2	41,1	42,0	42,9	43,9	44,8	45,8	46,8	47,9	48,9	50,0	51,1	52,2	53,4	54,5	51,6
EHAM (Amsterdam)	47	48,0	49,0	49,9	50,9	51,8	52,8	54,0	55,2	56,4	57,6	58,9	60,2	61,5	62,9	64,3	65,7	67,1	68,6	70,1	71,6	53,5
LEBL (Barcelona)	24	24,4	25,1	25,8	26,5	27,3	28,0	28,6	29,3	29,9	30,6	31,2	31,9	32,6	33,4	34,1	34,8	35,6	36,4	37,2	38,0	36,3
EGKK (Gatwick)	22,7	23,3	24,0	24,7	25,3	25,9	26,6	27,1	27,7	28,3	29,0	29,6	30,3	30,9	31,6	32,3	33,0	33,7	34,5	35,2	36,0	34,1
EGLL (Heathrow)	42	43,1	44,4	45,6	46,8	47,9	49,1	50,2	51,3	52,5	53,6	54,8	56,0	57,2	58,5	59,8	61,1	62,4	63,8	65,2	66,6	32,1
LEMD (Madrid)	39,7	40,4	41,5	42,6	43,9	45,1	46,4	47,4	48,4	49,5	50,6	51,7	52,8	54,0	55,2	56,4	57,6	58,9	60,2	61,5	62,9	34,9
EGCC (Manchester)	39,7	40,8	42,0	43,1	44,2	45,3	46,4	47,5	48,5	49,6	50,7	51,8	52,9	54,1	55,3	56,5	57,7	59,0	60,3	61,6	63,0	34,8
EDDM (Munich)	41,7	42,5	43,2	43,8	44,4	45,1	45,7	46,7	47,7	48,8	49,8	50,9	52,1	53,2	54,4	55,6	56,8	58,0	59,3	60,6	62,0	35,6
LFPG (Paris)	43,7	44,7	45,6	46,5	47,4	48,4	49,4	50,4	51,6	52,7	53,8	55,0	56,2	57,5	58,7	60,0	61,4	62,7	64,1	65,5	66,9	53,2
LIRF (Rome)	20,7	21,0	21,3	21,6	21,9	22,1	22,4	22,9	23,4	23,9	24,5	25,0	25,6	26,1	26,7	27,3	27,9	28,5	29,1	29,8	30,4	35,7
LSZH (Zurich)	21,7	22,2	22,6	23,1	23,6	24,0	24,5	25,0	25,6	26,2	26,7	27,3	27,9	28,5	29,2	29,8	30,5	31,1	31,8	32,5	33,2	54,8

Taking into account Table 3, we come to the conclusion that only four airports: **Gatwick, Heathrow, Madrid and Manchester** will have enough traffic demand to justify CREDOS implementation, at least, in the period of the study considered (2009-2028). Regarding costs, an assessment has been realized by means of expert judgment from experts within the project. The variability of possible implementations suggests that this is the most appropriate way for a high level analysis such as this.

3.3 Benefits in economic terms

One of the major benefits from the reduction of the delay, in economics terms, is the decrease of the operational cost of the aircraft which includes different costs as fuel, maintenance, crew, passenger compensation and passenger opportunity costs. This saving cost is recognised by the Aeronautic community as a valid value to develop economic studies. The estimated average cost of the delay per minute per aircraft is 51 € [20].

Another benefit from the reduction of the delay is the decrease in time at the queue due to CREDOS. This will mean a reduction of emission of contaminants from the airlines that will save from the reduction of the payment of the rights to contaminate. This will be a saving for the airlines taking into account the system of the CO₂ emissions trade (normative reached by the members of the EU). We study analyse different types of aircraft and offers the corresponding CO₂ emissions from the aircraft's fuel consumption: the combustion of a ton of fuel causes the emission of approximately 3.15 tons of CO₂ [20].

Table 4 Benefits in economic terms

		BENEFITS			Source
		High	Medium	Low	
DELAY REDUCTION	Saving Operational costs	56 €/min	51 €/min	46 €/min	Eurocontrol Standard Inputs for Eurcontrol 2007
	Environmental benefits: Decrease of the CO ₂ emissions	15,75 €/ton fuel burnt	13,15 €/ton fuel burnt	10,52 €/ton fuel burnt	web: pointcarbon.com (Jun 09 prices)

3.4 Cost in economic terms

These costs appear in the table below in two main categories: Investment (non recurring costs, in kEuro) and Operational (recurring costs, in kEuro per year). Figures are offered by expert opinion.

Table 5 Costs in economic terms (kEuro)

COSTS			
	High	Medium	Low
Investment	5500	5000	4500
Operational	1100	1000	900

3.5 Assumptions

Technical assumptions

- The operation of CREDOS assumes that it is not possible to offer extra capacity, only to reduce delay.
- The CREDOS system is either ON or OFF: when CREDOS is working (ON) the benefits are applicable to all heavy/medium aircraft pairs
- Wake vortex separation is only reduced when a Heavy is followed by a Medium or by a Heavy aircraft, and in case the CREDOS conditions (a.o. sufficient crosswind) are met.
- Four minutes of delay is assumed as a constant in the upcoming years, that is, ANSPs and Airports will build and offer new measures to keep at most this delay, regardless of the traffic demand increase.

- The study does not take into account use of CREDOS in airports where demand does not reach the number of departures that would reach practical capacity with ICAO separations

Economical assumptions

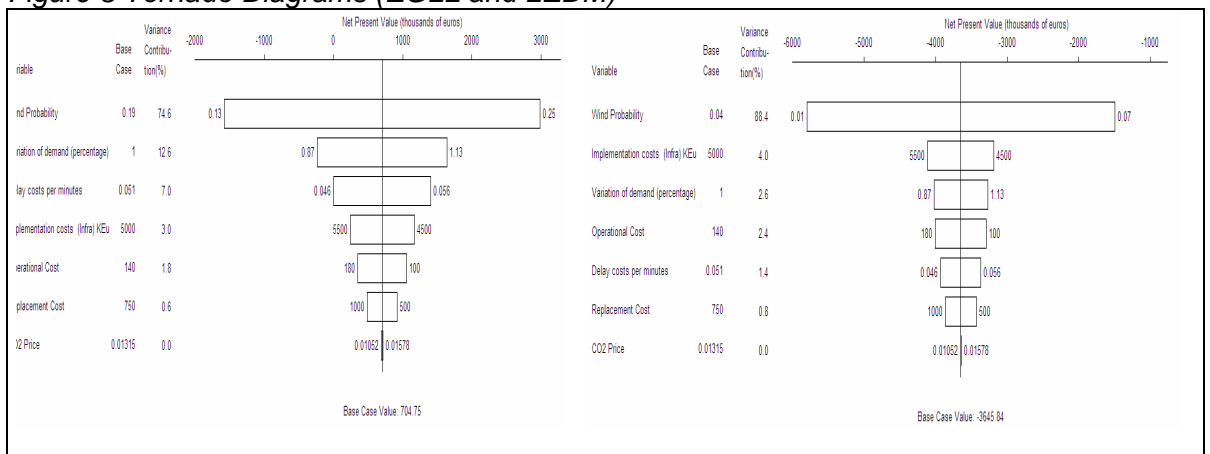
- The CBA is performed with the EMOSIA methodology recommendations and toolset.
- Time line into the CBA study takes 20 years.
- Constant prices referred to the year 2009 will be used, inflation and discount tax will not be included;
- Following the EMOSIA recommendations, an 8% discount will be applied;
- No external financing will exist, and therefore all resources will be the company's own resources;

Cost Benefit Analysis outputs

The CBA yields the NPV's airports chosen and their sensitivity analysis. A summary of the results of the CBA¹ are:

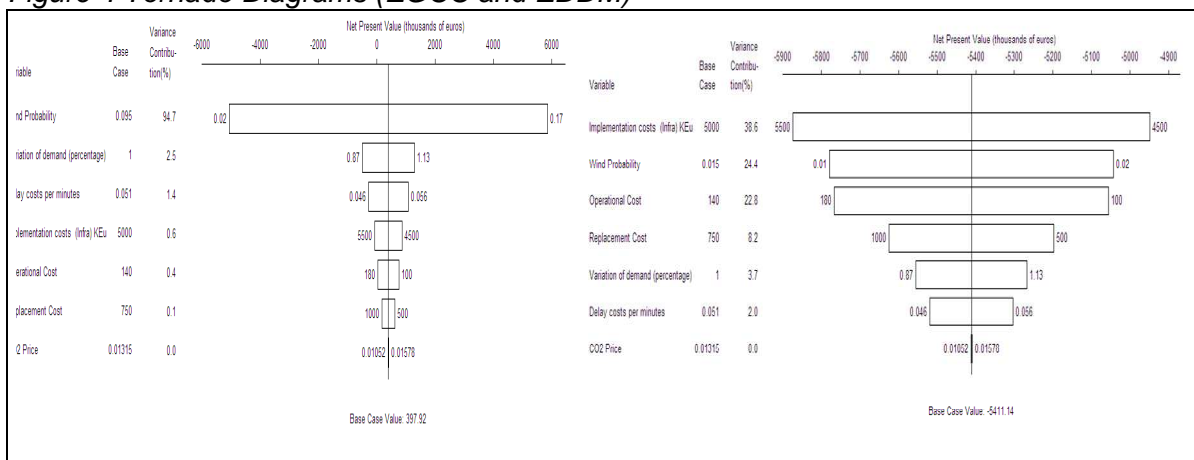
- The implementation of CREDOS would be recommendable at Heathrow airport, with NPV of 0.7M€.
- CREDOS is also recommendable at Manchester airport with a NPV equal to 0.39 M€, but with a higher risk than Heathrow.
- The implementation and operation of CREDOS would not recommendable at Madrid-Barajas airport and at Munich airport in the conditions analysed in this study because of the negative NPVs of (-3.6 M€) and (-5.4M€) obtained

Figure 3 Tornado Diagrams (EGLL and LEDM)



¹ These NPV results should be considered with a prudent perspective due to the current level of development of the Project and the fact that they are based upon the use of an analytical model. In further stages of development the CBA shall be recalculated using more detailed models and simulations which would yield more precise data.

Figure 4 Tornado Diagrams (EGCC and EDDM)



There are three variables which variance contribution is very important in the results of this economic study:

- Wind probability. This variable is the most critical variable on this CBA. Therefore it is recommendable to make an effort to analyze it in detail. The wind probability would be a decisive variable which determines the feasibility of the project in economical terms.
- Traffic demand. This variable also has a high variance contribution in this study. In fact, it is the second critical variable in Manchester and Heathrow and the third in Madrid. That means that the NPV is very sensitive to the variation of traffic demand.
- Cost of the infrastructure: This variable has a higher variance contribution in the Munich and Madrid studies than in the others. The cost of the infrastructure is very important when there is not enough demand and wind to justify a big investment.

In order to analyze in detail the impact of CREDOs in economical terms in Manchester and Heathrow, it is necessary to pay more attention to variables as the traffic demand. This variable is very important, but it cannot be altered or modified by our project, it is external to CREDOs. However, it could determine if the airport chosen for the implementation of CREDOs has enough conditions to obtain benefits or not. Finally, the cost of the infrastructure is a very relevant variable in the Munich and Madrid studies. This variable deserves our attention as its value is internal to the project. In this study we used the same value for all of cases. This is a conservative point of view. If CREDOs is already implemented in one airport, the rest of the airport network could profit by its experience and reduce the cost of infrastructure. The analyses undertaken fulfilled objective CE1 in half of the airports selected in this exercise, Heathrow and Manchester, highlighting the importance of having enough crosswind conditions for a positive result. This document can be considered as a guide to develop CBAs and economic analysis of the implementation of CREDOs or similar technologies in other scenarios.

4 Environmental case

4.1 Introduction

The following summarises the work performed by the High level Environmental Impact Assessment (EIA) of the CREDOS operational concept. The assessment follows the current E-OCVM v2.0 methodology [21] and parts of the, at the time immature, environmental case developed by the CAATS-II project [22]. The work was conducted in two stages: the first stage developed the exercises as referred to in the CREDOS Validation Strategy; while the second developed the Environmental case containing the Noise and Emissions Assessment from the results of the Validation exercises. The two main objectives stated by the CREDOS project for Environment were demonstrated through a qualitative analysis of the input available and a limited quantitative analysis which was only conducted for magnitude purposes (magnitude of environmental benefit for the emissions area) and not to give an exact value. The assessment highlights, from inputs coming from various sources with a different degree of depth and quality, how the CREDOS operations applied with the right crosswind conditions and in saturation conditions, can benefit emissions and fuel burn, but could have a double influence on noise distribution during certain periods of the day. A neutral effect during peak hours, when CREDOS is more suited to be used; while it has demonstrated to be a good tool to mitigate noise for delayed traffic making sure the noise goes back to the scheduled departures' value with a certain degree of rapidity. Noise on a daily basis, as shown by cumulative metrics along a whole day, does not change, since compared to the baseline there are no changes either in total number of aircraft. On the other hand it's true that cumulative metrics calculated only when CREDOS is operating may locally be higher than scheduled but lower than the delayed schedule giving more respite time to the population. The savings in fuel burn were assumed to be coming directly from spending less time (the difference among ICAO's and CREDOS delays) with engine on in the queue. A further relation exists between the amounts of NOx and CO produced, since their percentages are linked to engine temperature, but the assessment of these was out of the scope of the assessment. The main results of the assessment also highlighted three further characteristics affecting the use of CREDOS: weather (crosswind chance) is the main driver and variable which may hinder planning of the operations and the degree of benefit; noise and emissions have an interdependency by which the benefit of the second may affect the first; unbalance of the impacts around the airport due to wind direction can only be monitored. The interdependency between noise and emissions consists of having the greatest benefits in emissions and fuel burn delivered by the noisiest aircraft pairs HVY/HVY-MED (studied by the CREDOS operations). The assessment also brings to the

fore the limits of certain standard software assessment tools, which are not sensitive to crosswind thus do not show the noise footprint move with wind direction. Finally the environmental objectives of CREDOS were validated, but further analysis at airport level would be necessary in order to quantify the value of using CREDOS operations based on the local weather pattern and population distribution.

4.2 CREDOS Project Environmental objectives

The overall Environmental objectives of the CREDOS project are to demonstrate that:

- The application of the crosswind departures concept will not increase the current noise levels (EN1)
- The application of the crosswind departures concept will not increase the current emissions levels (EN2)

4.3 Purpose of this High level Environmental Assessment (EIA)

An **EIA** is an assessment of the possible impact—positive or negative—that a proposed project may have on the natural environment. The purpose of the high-level environmental impact assessment (H-I EIA) performed inside CREDOS, is to evaluate if the overall environmental objectives of the project (EN1 and 2) are met when the CREDOS operational concept is applied.

4.4 Assumptions coming from the CREDOS Operational Benefits Analysis

Implementing CREDOS separations will be most beneficial for those airports already operating at capacity for a good part of the day, with departure queues that can feed the departure runway(s) continuously, and which have at least one departure runway that is often operated under crosswind conditions.

Limitations in the study

It should be noted that other operational constraints beyond probability of crosswind occurrences will influence the actual benefits that can be achieved. Among others, these constraints include availability of suitable departure routes throughout the day (could be influenced by noise abatement procedures, etc.), or ground infrastructure (availability of taxiways, gates, etc.). These constraints can become quite complex and have not be considered in the scope of this analysis

4.5 Work performed

The work conducted by this task was divided into four parts:

- 1) Analysis of the CREDOS concept: description of the scenario, background and main

- operating assumptions and objectives (including the Environmental);
- 2) Performance of the validation exercises: development and results of the validation exercises as outlined in the CREDOS Validation Strategy;
 - 3) Environmental Assessment: consisting of the Noise and Emissions Assessments
 - 4) Verification of the CREDOS EN objectives from the results of the CREDOS EIA.

Part 1

The work performed in this part analysed information coming from three documents:

- CREDOS_410_ECTL_DLV_4-2_conopsB_v0e.doc
- EUROBEN WP3 Report
- CREDOS D4 8 Operational Benefits Analysis v0f.doc

Part 2

Work performed in this part followed the Environmental Validation Strategy which consisted in developing the exercises detailed in CREDOS_421_ECTL_DLV_D4-3_Validation_Strategy_and_Plan.pdf and determining among other things the depth of the study, based on:

- the information and data that would be available,
- the changes the operational concept brings and possible impacts on environment;
- the metrics necessary to evaluate the impact;
- the capability of the current assessing tools in characterising and assessing the CREDOS concept.

Part 3

Work performed in this part consisted of the Noise and Emissions assessment of the CREDOS concept when applied to an operational scenario. The task, based on the information obtained through the previous tasks, produces the results of the HLEIA for both KPIs. The Noise and Emissions assessments also included two quantitative exercises aimed to give a taste of the magnitude of the impacts/benefits (emissions) and the influence of traffic distribution on the cumulative noise metrics.

Part 4

Conclusions of the High level EIA and validation of the environmental objectives of CREDOS.

4.6 Synthesis of the work performed in the EIA

The main parts of the EIA are here summarised, leaving to the reader the freedom of looking into the main document for more in depth information.



Determine the areas of environmental impact:

- Noise specifically in Taxi and Departures)
- Emissions (Local Air Quality-LAQ)

Scope of the assessment:

The application of CREDOS concept which changes the following parameters:

- Frequency of TOs
- Taxi time and delay

Assessment of these changes on the noise and emissions’ domain

The first parameter influences noise directly since it increases the frequency between TOs with less delay among them. The second parameter is important when we analyse the distribution of the traffic among the periods of the day: the higher the delay then the higher the probability of TOs occurring out of schedule thus invading more sensitive periods of the day (i.e. a shift between day, evening and night). **(Noise assessment).**

The second parameter directly influences fuel burn; thus a saving in delay translates directly to savings in fuel burn and emissions. **(Emissions Assessment).**

Evaluation of the impact this may cause on the environment based on the operational benefits analysis done on 11 Airports.

- Analysis of metrics to be used for the evaluation of the impacts: “Lden” for noise and Fuel burn and “CO2 amount” for emissions were chosen as metrics for comparison between CREDOS and ICAO operations.
- Noise exercise (independent of the airport): Lden comparison between ICAO and CREDOS
- Emissions exercise based on comparison between ICAO and CREDOS.

NOISE Results

Exercise III: can the LAeq change if done only for certain hours?

Capacity values or TO rates are used to simplify the example.

Table 6 CREDOS mitigation on LAeq

Hourly Flight distributions Summary					
	10-11:00	11-12:00	12-13:00	13-14:00	14-15:00
Scheduled Flight	42	42	40	10	10
ICAO PC	32/10	32/10+10	32/20+8	32/28+10=+6	16/0
CREDOS	36/6	36/6+6	36/12+4	26/16+10	10

Table 4 shows how CREDOS actually mitigates, in a faster way, the noise which is caused by delayed aircraft entering lower schedule hours. It can be said that during peak hours the noise is higher than the ICAO PC but is still lower than the scheduled one. So CREDOS operations may relatively increase the noise but not absolutely (Lden remains the same), and turns out to be a good way to actually mitigate it.

EMISSIONS Results

Table 7 Saved Fuel and relative CO2 emissions for one hour of CREDOS operations.

	EDDF	EGLL	LEMD	EDDM	EGCC	EHAM	LFPG	UNIT
ICAO flow rate@ PC	52	32.1	34.9	35.6	34.8	53.5	53.2	(a/c/hr)
Δ delay(s)*	3732	2303	2379	2444	2405	2157	2196	(s)
n°. of a/c	62.2	38.4	39.6	40.7	40.1	36.0	36.6	(Min)
Saved Fuel	664	419	382	380	388	363	375	(Kg)
CREDOS	0.66	0.42	0.38	0.38	0.388	0.36	0.38	(ton.)
Saved CO2	2092	1321	1204	1196	1220	1143	1182	(Kg)
CREDOS	2.092	1.321	1.204	1.196	1.22	1.143	1.182	(ton.)

The values are calculated and based on the savings obtained by maintaining the ICAO flow rate of take offs but with CREDOS in operation. The values are for one hour of use. The results show the fuel and CO2 saved by each airport during one hour of CREDOS maintaining the ICAO flow rate for practical capacity. The results coming from the emissions exercise show that in one hour of CREDOS the amount of fuel saved and thus the decrease in CO2 emissions are significant.

4.7 Conclusions

The following high level objectives are identified:

- EN1** The application of the crosswind departures concept will not increase the current noise levels.
- EN2** The application of the crosswind departures concept will not increase the current emission levels.

Taking into account that the current levels of noise and emissions calculated are those corresponding to the scheduled flights, we may say that the High Level EIA demonstrates that *“the application of the crosswind departures concept (CREDOS) will not increase Emissions or Noise”*. Thus EN1 and EN2 are validated. In the case of emissions CREDOS



may actually exceed the objective since it clearly delivers some level of benefit (fuel saving+CO2 emissions saving), the magnitude of which was only calculated for one hour and with a savings in delay corresponding to the Practical Capacity Flow rate. Looking at the delay functions for ICAO and CREDOS separations (limited to the assessments done with the FAA RWY capacity tool and the single SIMMOD Simulation) it can also be said that further benefits are envisioned at higher flow rates, based on the tendency of the functions. Noise levels would daily (Lden metric) remain the same, with the only exception of its distribution (LAeq). Localized increases could be noticed but the CREDOS operation proves to actually mitigate the consequences of a delayed schedule.

Interdependency

As in many other cases, the use of CREDOS during saturation leads to interdependency issues between the emissions and noise. Specifically, the more HVY/MED pairs we have during crosswind, the larger the benefit on fuel consumption, thus fewer emissions. On the other hand the bigger aircraft are those that drive the Leq metric: increasing the number of TOs during the CREDOS activation and the number of emissions-beneficial pairing, we are actually increasing the noise. This affects only the CREDOS operation time and not the overall daily metrics, which are not influenced by CREDOS because the total n°. of aircraft taking off on that day remains constant.

It is thus true that for those airports where noise is a big issue and/or TOs are restricted either by number per RWY or by specific hourly LAeqs, CREDOS may not deliver to its full extent its benefits or may actually deliver a benefit at the cost of an impact (Emissions vs. Noise).

Magnitude

Magnitude of the benefits going to fuel burn and emissions depends mostly on the local operations and weather conditions. It is foreseeable that local airport studies can answer better this question thanks to more detailed data. The CREDOS concept applied and validated for one RWY is scalable to any airport. But the assumptions made inside the study need to be read carefully before applying the results.

5 Safety case

5.1 Introduction

A generic safety argument for CREDOS has been established. It covers the various parts of the life cycle including specification, implementation, transition to operational service, and operational service. As part of the CREDOS research activities mainly the safety argument for the specification phase has been further elaborated. The CREDOS wake vortex safety management recommendations [9] provide guidelines in support of the satisfying the argument for the situation with CREDOS in operational service. The generic safety argument for the specification phase of CREDOS deals with:

- Intrinsic safety of the concept;
- Design completeness;
- Design correctness;
- Design robustness;
- Mitigation of internal failures.

Safety validation exercises specified in the CREDOS Validation strategy and plan [3] have been performed with the aim to gather the evidence to show that each of the five sub-arguments is satisfied. The main observations and findings are:

- Operational evaluation of the CREDOS concept and system design through real-time simulations seems to have provided sufficient safety evidence regarding the arguments for system design completeness, correctness and robustness;
- Additional safety activities will be needed to fully satisfy the arguments for intrinsic safety (so far only the Airbus A320 was fully considered as follower aircraft) and mitigation of internal failures (the safety requirements may be too demanding).

5.2 Intrinsic safety of the concept

In view of the aim to provide a 'generic' concept of operations [11] with a *high-level* operational context and scope, it can be concluded that the operational context and scope has been clearly described. However, in case of local implementation, specifics of the targeted air traffic control environment will have to be considered in more detail.

A preliminary crosswind criterion has been determined using data collected during two measurement campaigns for wake vortices generated by departing aircraft at Frankfurt airport [27]. Assuming a corridor width of 200 m crosswinds of about 7 knots are necessary to clear the corridor for a 60 s separation from wake vortices on a 95 % probability. Risk assessment simulation results confirm this initial crosswind criterion

obtained [28, 29]. As long as only straight-out departures are considered, a crosswind threshold of 8 knots seems to be necessary to sufficiently reduce the wake encounter risk up to an altitude of 3000 ft when the separation shall be reduced down to 60s. For altitudes up to only 300 ft a crosswind of 6 knots or more is already sufficient. It has to be noted for this specific wake encounter risk assessment no constraints on the SID combinations of leading and following aircraft have been assumed. It is to be expected that by additionally ensuring the following aircraft is starting on an upwind route (see also section 2), the encounter risk would significantly be further reduced. Simulations explicitly taking this constraint into account should confirm this assumption. It also has to be noted that the risk assessment has been performed only for the case with an Airbus A320 as follower aircraft. Other aircraft types have not yet been evaluated.

Key functionality of the CREDOS concept is to reduce spacing between subsequent departing aircraft in case of favourable crosswind conditions. As the dependence of the resulting spacing on both the determination of the WTSSAV size and the quality and reliability of the local validation campaign is quite complex, it is difficult to state that this identified key functionality has already been *shown* to be consistent with safety criteria.

5.3 Design completeness

The objective is to demonstrate that all necessary Safety Requirements have been specified, or assumptions have been stated, to cover all elements, in terms of system design, that are necessary to fully implement CREDOS operations. Related operations and functions are described and high-level requirements and assumptions have been specified for both the internal and external system elements. A high level concept safety validation requirement has been specified and has been broken down into two low-level safety validation objectives as baseline for a CREDOS safety assessment [3].

5.4 Design correctness

The objective is to show that the concept of the system design functions correctly and coherently under all normal environmental conditions. Real time simulations have indicated that there are few issues to be resolved before implementation. The overall concept of CREDOS was well received by the air traffic controllers participating in the simulation. There are four main issues for which recommendations should be taken into account when considering local implementation of CREDOS:

- In cases where a basic advisory tool is used at the airport (only Go/No-go display), the procedure for the runway controller should include mandatory transmission of wind information in take-off clearance for all aircraft. This would introduce a safety net that

enables runway controller to always be aware of wind conditions while applying reduced separations and cross check an eventual discrepancy displayed.

- Procedures for controllers should be well defined in case of wrong turn, i.e. if the departure controller should act first and then inform the runway controller or the other way around.
- The proposed phraseology for non-nominal events would need to be refined.
- A status indicator that takes into consideration the assigned SIDs for leading and following aircraft could assist the controller and reduce the risk of mistake.

5.5 Design robustness

The objective is to show that the application system design is robust against external abnormalities in the operational environment. Evidence is required to show that the system can continue to operate effectively and that such abnormalities do not cause the system to behave in a way which could induce risks that would otherwise not have been present.

Five external abnormalities have been considered:

- Aircraft failure (e.g. engine failure)
- Voice communication system failure
- Degradation of surveillance systems information
- Degradation of meteorological systems information
- Degradation of flight data and/or information

The CREDOS system can handle all the above external abnormalities in a robust way. However, should a sudden unexpected strong wind change (towards decreased crosswind) occur, then an aircraft could be exposed to higher wake encounter risk than anticipated. The use of wind monitoring systems up to about 2000 feet is therefore strongly recommended. Care should be taken to ensure that CREDOS system would not be less robust to extreme weather conditions than the current operational system.

5.6 Mitigation of internal failures

To show that all risks from internal failures have been assessed and mitigated sufficiently, the EUROCONTROL Safety Assessment Methodology (SAM) [25] has been applied. A FHA and a PSSA have been performed, using intermediate versions of the CREDOS Concept. These intermediate concept versions are not fully the same as the final CREDOS concept of operation version [11] that has recently been published.



The CREDOS FHA delivered six functional hazards with corresponding safety objectives. As part of the PSSA, fault trees were developed based on the proposed system architecture and the task descriptions to represent the cause/hazard relations for each of the identified hazards. The fault trees were reviewed by safety experts and operational experts in two workshops. From these fault trees, and using the safety objectives set during the FHA, a total of 22 safety requirements were derived: 5 for CREDOS system elements, 13 for human operators and 4 for procedures [7].

As a result of some safety requirements set for human operators being too demanding and hence considered unachievable, the current safety assessment does not yet provide a basis for the safe operational introduction of the CREDOS concept. Revisiting the derivation of the safety objectives is recommended, as they have initially been developed on the basis of the 'worst case' outcome, instead of a 'worst credible case' outcome. Reconsideration of the FHA safety objectives is recommended, and should focus on quantification of the barriers in the event trees: how likely is it that the hazard will evolve into its worst credible outcome. The PSSA itself has also been set up in a conservative way. So far, little credit has been given to mitigating factors present in the CREDOS concept. A review of the CREDOS system design, of the human tasks and of the operational procedures is recommended to better describe possible mitigations. Subsequently, the fault trees should be adapted to account for these mitigations. Finally, it is suggested to readdress the FHA and PSSA on the basis of the final concept of operations for CREDOS [11]. The current PSSA primarily considers failures within the CREDOS operational concept. Readdressing the FHA and PSSA should then also better include performance of the CREDOS system and human performance aspects such as controller workload and radiotelephony usage.

6 Human Factors Case

6.1 Introduction

The EUROCONTROL HF Case provides a framework to identify, understand and manage the Human Factors issues in the design and development of a new concept. ATM is a human centric system; therefore development of a new concept must be based on a solid understanding of the impact of CREDOS on controllers' roles and tasks. Human performance issues must be identified and considered in the design and development of the CREDOS concept to ensure that it both achieves the proposed system performance benefits and is acceptable to the end users. The EUROCONTROL HF Case consists of five stages, only the first four are of direct relevance to the development and evaluation of the CREDOS concept (the fifth stage involves a review and identification of improvements to the HF Case methodology):

6.2 Stage 1 – Fact Finding

The aim of this stage is to scope the project from a Human Factors perspective by identifying what will change, who will be affected and how. This initial assessment, conducted in April 2007, indicated that the implementation of CREDOS would mainly impact three Human Factors work categories:

- *Procedures, Roles and Responsibilities*; It was identified that CREDOS would impact to varying degrees the tasks and working methods of the runway controller, supervisor, ground controller and aircrew.
- *Human in the System relating to HMI design*; The implementation of CREDOS would require additional CREDOS related information to be displayed to the runway controller and supervisor.
- *Teams and Communications*; CREDOS specific phraseology would need to be developed to inform the air crew that CREDOS is to be used.

6.3 Stage 2 – Human Factors Issue Analysis (HFIA)

The HFIA is a structured brainstorm that is used to identify and prioritise specific HF issues relating to CREDOS and consider their potential impact on human performance and the system. The HFIA workshop was performed in May 2007 with five participants including operational experts (4 controllers and 1 pilot) plus safety and HF specialists. A total of 29 HF related issues were identified in total. The three most likely impacts of the HF issues identified were found to be: 1) *Human error*, 2) *Lack of trust and non - acceptance of the new tools and procedures*, and 3) *Additional workload and increasing cognitive processing demands*

In addition it was also recognised from the HFIA that the roles, tasks and responsibilities of the TMA controllers would also be affected by the introduction of CREDOS.

As a result of the issues identified and the level of maturity of the CREDOS concept the main HF objectives for the CREDOS project were twofold:

- to support the design of CREDOS procedures and HMI and;
- to assess the impact of the CREDOS procedures and HMI on controller human error; acceptance and trust; workload & cognitive processing demands.

6.4 Stage 3 – Action Plan

The aim of stage 3 of the HF Case is to select and describe the HF validation activities required to address the HF issues identified and develop an action plan. Eight activities were identified as necessary, these were:

- *Task analysis*. The objective of the CREDOS task analysis was to identify the changes to tower controllers' tasks under CREDOS operations compared to current day operations and to assess the impact of CREDOS on the controllers' work using a structured approach.
- *Cognitive Task analysis (CTA)*. The cognitive task analysis built on the task analysis developed in Activity 1. The aim of the cognitive task analysis was to better understand whether or not the introduction of CREDOS would result in any significant cognitive changes to controllers work, for example in terms of the way controllers make decisions, plan their work etc. From the CTA the impact of CREDOS on human error potential, workload and team interaction can be better understood and specific CREDOS-related issues can be identified. The CTA is also used to support the identification of CREDOS HMI information and procedural requirements.
- *Stakeholder workshop*. The aim of the workshop was to support the development of the CREDOS procedures and HMI design by consulting the potential users e.g. controllers, aircrew, that would be directly affected by the introduction of CREDOS. The involvement of the potential end users relatively early in the concept development process should not only lead to a better design but also helps to ensure acceptance of the concept.
- *Field studies*. A study of current tower control working practices was planned to gain a good understanding of the current equipment available in European tower control centres and also current working practice. This was seen as necessary as CREDOS is a short term project with implementation proposed in the near terms (around 2012). The survey would help to ensure that the HMI developed and the proposed support tools for CREDOS are feasible in today's current systems. In addition, the survey

would also enable a better understanding of how certain procedures are undertaken in towers and TMAs across Europe today in order to provide a better basis for design of the CREDOS separation procedures.

- *HF input into HMI Development.* HMI requirements identified from the cognitive task analysis, stakeholder workshop were used together with HF design standards and guidelines to develop and refine initial HMI solutions for CREDOS. The utility and usability of selected CREDOS HMI prototypes would be later assessed in both a part-task and full real time simulation (see activity 8).
- *Human Factors input into Procedural Development.* Findings from the CREDOS task analysis / cognitive task analysis and feedback from the stakeholder workshop were used to inform the development of the CREDOS operational procedures for the tower and TMA controllers. A Human Error Analysis was recommended to identify potential human errors that may result due to the CREDOS procedures. A part task and full real time simulation would assess the proposed CREDOS procedures (see activity 8).
- *Phraseology development.* Phraseology is a sub-set of activity 6 (Procedure Development). The aim of this activity was to develop clear and concise phraseology for CREDOS operations.
- *Real Time Simulations* - The objective of the real time simulations was to present the CREDOS concept to controllers in a realistic setting and evaluate whether or not the CREDOS concept impacts controller performance with regards to workload, human error, trust, acceptance and cognitive processing. The simulations would also be used to assess the utility and usability of the CREDOS HMI and procedures, and hence further identify CREDOS related HMI and procedural requirements. A part task simulation followed by a full task simulation was planned using the NARSIM tower simulator at NLR in the Netherlands.

Two additional activities were defined as a result of issues identified during the HFIA, namely: 1) controller and aircrew related training and; 2) post implementation monitoring and benefit study. However, given the level of maturity of the concept these activities were out of the scope of the current CREDOS project, but would need to be considered and defined in more detail later on in concept development life cycle.

6.5 Stage 4 – Action Implementation

The HF validation activities defined in Stage 3 - were conducted between September 2007 and May 2009. The findings from each these activities gave rise to design recommendations mainly relating to the CREDOS procedures and HMI. These design recommendations were used to inform and develop the CREDOS Concept of operations. Other recommendations not specific to the CREDOS procedures or HMI were also



proposed to help ensure acceptance of the CREDOS concept by both controllers and pilots. The main findings from the HF validation activities relating are presented in the section below.

6.6 Summary of findings and recommendations

It should be noted that the CREDOS project is a research project and the CREDOS concept of operations is at a conceptual (generic) level hence the HF issues and findings are also generic in nature. Thus they act as a check list or guide for local ANSPs when implementing the CREDOS concept in a local environment. Therefore they will help to ensure that specific HF issues are considered and addressed when CREDOS is implemented locally.

The HFIA conducted in Stage 2 was based on an initial version of the concept of operations (version A). As the validation process progressed the findings from the various HF and other validation activities conducted were used to better understand the issues relating to the CREDOS concept and develop and evolve the CREDOS concept of operations. Therefore, the final version of the CREDOS Concept of operations (version E) has incorporated the findings and recommendations from the HF validation activities as described in the HF action plan as well as other activities conducted as part of the concept of operations validation process.

A summary of the main findings and recommendations from the HF validation activities conducted are listed in the table below. The recommendations for CREDOS procedures, HMI and acceptance are given for each relevant 'actor', e.g. tower controller, departure controller, supervisor and aircrew.



Summary of main findings /recommendations from HF activities conducted	
Procedures structure & format	<p>To ensure the CREDOS procedures are easy to apply and minimise the potential for human error:</p> <p>Runway controller (RWY):</p> <ul style="list-style-type: none"> • The CREDOS procedures must be consistent and integrate well into existing operational procedures & working methods both for nominal and non-nominal events. Hence when CREDOS is implemented at a local level existing operational procedures must be considered. Thus, for local implementation the CREDOS procedures would depend to an extent on existing operational procedures. • It is recommended that controllers give wind information to aircrew when giving a departure clearance, this helps to ensure that the RWY checks the CREDOS status before giving the CREDOS clearance, (in order for this to be the case the crosswind information should be situated next to the CREDOS status indication). • The aircraft departure time must be noted on the strip to enable controllers to calculate required spacing if CREDOS status changes to NOGO • Controllers have to be able to deliver 3NM consistently. Regulation for CREDOS separation procedures could be a means to ensure CREDOS procedures are adhered to and applied consistently <p>Departure controller (DEP):</p> <ul style="list-style-type: none"> • Verbal transfer of a/c required to ensure everyone knows who has responsibility for a/c. <p>Supervisor (SUP):</p> <ul style="list-style-type: none"> • SUP is ultimately responsible for making the decision that CREDOS operations are activated or deactivated and hence whether CREDOS can be used or not. • It is recommended that the tower supervisor checks with the departure supervisor before activating CREDOS. The tower supervisor must also inform the departure supervisor when s/he decides to deactivate CREDOS • The tower supervisor must inform the tower controllers verbally that CREDOS will be activated and/or deactivated. (The change in status will also be visible on each controller's CWP). The departure supervisor will inform departure controllers that CREDOS will be activated or deactivated <p>Aircrew:</p> <ul style="list-style-type: none"> • Aircrew need to be informed asap that CREDOS is active and they may be given a CREDOS clearance when departing. It is suggested that this initial information regarding CREDOS active status is given via ATIS. • Aircrew must also inform controllers if they are not willing to accept a CREDOS departure well in advance, to avoid situation where CREDOS clearance is refused when aircraft on runway as this may adversely affect efficiency and runway throughput. • Aircrew must inform the controller that is on-frequency if WV is encountered.

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HMI requirements

To ensure the CREDOS HMI supports the controllers in their work, is intuitive, easy to use and mitigates the potential for human error:

Runway and Departure Controllers:

- The CREDOS HMI must integrate well and be consistent with the existing system into which CREDOS is being implemented. Therefore, there is no 'One fits all' HMI solution for CREDOS.
- The RWY and DEP need to be informed of CREDOS status for each active departure runway. The information should be given on a case by case basis, i.e. for each departing a/c. It is recommended that four states be displayed to controllers:
 - CREDOS NOT ACTIVE (not activated by SUP);
 - CREDOS ACTIVE and NO GO (i.e. CREDOS activated by SUP but CREDOS requirements not met e.g. crosswind component below threshold);
 - CREDOS ACTIVE and GO (i.e. CREDOS activated by SUP and requirements for CREDOS application met);
 - System error. Controllers should also be informed of any detected system errors relating to the CREDOS equipment.
- The type of information that needs to be incorporated in the CREDOS status indicator depends on the airport environment.
 - If SIDs do NOT diverge near the runway (i.e. >4NM) the minimum requirement would be a case by case CREDOS status indicator that would inform controllers that CREDOS can be applied based on the fact that CREDOS status is active and crosswind component value is above the threshold for the next departure.
 - If SIDs diverge near the runway (approx <4NM) the CREDOS status indicator would have to take into consideration the assigned SIDs for the leading and following aircrafts. This would help to prevent CREDOS being applied when SID is not appropriate, and also help to ensure controller workload does not increase too much under CREDOS operations. However, this more advanced CREDOS status indicator can only be implemented if EFS or DMAN are present.
- A buffer is required in the CREDOS status indicator algorithm to ensure that the status does not continuously fluctuate from one mode to another (i.e. CREDOS GO to NO GO and vice versa).
- Crosswind information for each runway displayed near the CREDOS status indicator so they can verify easily CREDOS status. This crosswind information presented should include the crosswind component and direction (Left or Right).
- Controllers should be alerted to any changes in CREDOS status by some means e.g. flashing icon or auditory signal depending on HMI /alarm design principles adopted in the tower /TMA centre. To minimise number of alerts it is more important that controllers are signalled to a change in CREDOS status from GO to NOGO than NOGO to GO, as there will be safety implications if controller applies CREDOS when it can not be applied.
- Controllers should have on their CWP the function to be able to inform other controllers that CREDOS reduced spacings should be stopped, this may be used if a non-nominal event occurs. This function should be in addition to R/T or the telephone in case the lines are blocked



	<p>Runway controller</p> <ul style="list-style-type: none">• Runway controllers require a radar display screen (and licence) as under CREDOS they have to monitor aircraft for longer in the climb phase• A spacing support tool is necessary to help ensure required ICAO separation achieved at handover. Three types of spacing support tool have been proposed and investigated during the HF validation activities (i.e. an automated timer, a count down manual timer & a static take off trigger advisory (TTA)).<ul style="list-style-type: none">○ The automated timer required EFS and A-SMGCS. Feedback from the stakeholder workshop varied – the automated timer was thought to be too complex by some controllers. Recommendation was to develop a simpler spacing support tool that could be used in an environment that did not have EFS & A-SMGCS. However, it is recommended that the automated timer should be evaluated in a realistic operational environment to see whether it is a feasible solution or not.○ The manual timer was found to increase workload as activation of timer was considered another action to perform. Further controllers often forgot to time or started timer too late.○ The static takeoff trigger advisory (TTA) was used to support controllers achieve the required spacing. The takeoff trigger advisory was generally very well received and considered intuitive and easy to use by the majority of controllers. One concern was that controllers were not using it as an advisory and so were not taking into consideration a/c performance when using the static TTA as they should. It is suggested that a dynamic TTA that would move depending on aircraft performance and crosswind strength could be a potential solution. <p>Departure controller</p> <ul style="list-style-type: none">• The DEP controller should have the option to select exactly what CREDOS related information is displayed, e.g. takeoff trigger advisory, auditory alarms, so that each controller can tailor his CWP and display the information s/he requires. Although as a minimum the CREDOS status indicator should be displayed. <p>Supervisor</p> <ul style="list-style-type: none">• At a minimum the supervisor will need to have, in addition to the usual information displayed on the supervisor CWP, an indication of CREDOS status plus additional crosswind forecast information to help determine when CREDOS should be activated and deactivated.
Acceptability and Trust	<p>Controllers:</p> <p>To aid acceptance and controller trust:</p> <ul style="list-style-type: none">• The CREDOS concept must have a strong safety case to re-assure controllers the concept is safe and does not increase potential risk of safety occurrences compared to current operations.• The CREDOS concept must be validated in a real operational environment for controllers to accept the concept.



- Transparency in HMI design is necessary: controllers must understand algorithms that underlie the different CREDOS status indications & other support tools presented in the CWP.
- Crosswind information should be present on CWP near CREDOS status indication so controllers can easily crosscheck CREDOS status.
- Clear procedures & phraseology for non-nominal events e.g. WV encounter, must be developed so controllers know and are trained to deal with such situations
- Sufficient training on CREDOS and WV behaviour must be given before concept is introduced and at regular intervals (e.g. on an annual basis) to ensure controllers are familiar and comfortable with CREDOS procedures for both nominal and non-nominal CREDOS related situations.
- If possible the application of CREDOS and spacing achieved between a/c should be recorded. In an advanced technology environment equipped with electronic flight strip (EFS) and A-SMGCS controllers could be required to input into the EFS whether a CREDOS clearance was given or not and the commence of roll could be automatically recorded. This will also help in case there is a WV encounter & subsequent investigation. In a simpler environment that uses paper strips controllers should be required to note whether CREDOS applied & time of commence of roll on paper strip.

Flightcrew:

To help ensure aircrew accept the CREDOS concept:

- An information campaign is required to inform aircrew & airlines of CREDOS and potential benefits to be gained. Ideally airlines would lead the campaign, as if airlines are behind the CREDOS campaign aircrew are more likely to accept CREDOS.
- Presence of wind sock on runway may help so aircrew can crosscheck crosswind / CREDOS instruction.
- Attention All Users notices (AAUs) have been used at airports in the USA to inform aircrew of the new procedures operational at an airport. The AAU notice informs aircrew at their request what to expect regarding the new procedures and what to do.

Table 8 Summary of main findings & recommendations relating to the impact of CREDOS on human performance

7 Conclusions

Work performed

The CREDOS project aims to demonstrate the feasibility of a departure operation whereby the wake turbulence separations between successive aircraft are temporarily suspended under specific (favourable) crosswind conditions. The present report constitutes the Final Report of Work Package 4 "Operational Concept and Validation", which has three tasks:

- WP4.1 concerns the definition of the concept of operations, the refinement of this concept based on the CREDOS modelling and validation results, and requirements for the system (the procedures, user requirements, and system requirements);
- WP4.2 concerns the development of the validation strategy and plan, the execution of the different validation cases (business case, environmental case, safety case, and human factors case and other activities necessary for safe introduction of CREDOS);
- WP4.3 concerns the validation of the concept of operations and Human Machine Interface requirements through the use of real-time simulation (with support of intermediate recommendations resulting from the human factors and safety activities).

CREDOS concept

The basic idea behind CREDOS is that, for departures, the wake turbulence separation criterion may be relaxed on the runway and for the first part of the climb path when the crosswind is such that the wake turbulence generated by the preceding aircraft will have been blown out of the departure track of the succeeding aircraft. The benefits of the proposed concept would be a temporarily increase of the departure runway throughput in such a way that it absorbs capacity peaks or reduces departure delays. This increase occurs only when an aircraft of lighter wake category directly follows a heavier one and the CREDOS criteria are met. Only in such cases is there a potential for reducing the spacing between that aircraft pair compared to the wake turbulence separation that would otherwise have to be applied. The actual benefits would then also be dependent on traffic composition, usage of the runway and the SID structure. So far, the concept focuses only on the suspension of the 2-minute (5/6 NM) start interval applicable for HEAVY – MEDIUM, HEAVY – LIGHT or MEDIUM – LIGHT aircraft combinations. The concept is based on today's technical environment and does not require advanced tools such as DMAN or electronic flight strips. Nevertheless, the safe application of CREDOS separation suspension would require new information to be considered by controllers. It is therefore recommended that dedicated Human Machine Interface and support tools be developed.



CREDOS requirements

CREDOS is a wind-dependent concept. Consequently, the safe application of the concept requires the wind conditions to be monitored in the area surrounding the aircraft departure path. The range of the concept applicability is thus dependent on the wind monitoring capabilities of the airport (wind measurements, wind nowcast and/or forecast). The monitoring capabilities limitation leads to the definition of a volume surrounding the aircraft departure path within which the wind can be monitored and within which the wake turbulence separation may be suspended (the 'Wake Turbulence Separations Suspension Airspace Volume' (WTSSAV)). Indirectly, it also implies that the definition of CREDOS spacing (either expressed as a time interval or a distance one or both) will satisfy all CREDOS requirements. It is for those in charge of local implementation to determine the underlying algorithms that define the CREDOS wind level. From the controllers' point of view, the only major change in the roles and procedures of controllers introduced by the CREDOS concept is that when it is applied, it is presumed that it is the runway controller who is responsible for ensuring aircraft separation after departure, including the monitoring of the transition from CREDOS-reduced separation to the ICAO standard wake turbulence distance separations. It is important that new procedures and Human Machine Interfaces are well integrated in existing systems at any given airport that wants to deploy CREDOS. The HMI and procedures need to be clear and simple and easy to use. Perceived ambiguity or flickering in applicability of the concept should be mitigated as far as possible. It is foreseen that before CREDOS can be put in operational use it is necessary to provide airlines and air crews with detailed information about the concept and system and an awareness campaign will be needed before actual operational implementation.

CREDOS Validation cases

The different validation cases have shown that, although there is clear potential from a Business Case, Environmental Case and Human Factors point of view, further work in the area of safety is needed. It is also concluded that the next step for crosswind concept validation should be aimed at performing one or more local implementation cases.

Future options

At this stage, the CREDOS concept has been kept as generic and as simple as possible. This document is thus to be considered rather as guidance material than as a description of one particular endorsed solution. A number of improvements are also envisaged for the future. For instance, an enhanced HMI able to take into account the wake turbulence categories of aircraft and their respective SID, in addition to the crosswind criterion, integrated into the GO/NO-GO indicator could ease the task of controllers. In the same way, the use of electronic flight strips would also ease the controller tasks and therefore



reduce workload. The use of a modified DMAN that is able to account for CREDOS suspension of separation minima would be beneficial for the more tactical planning of runway capacity. By exploiting A-SMGCS, an automatic detection of aircraft take-off roll could be linked to the spacing between departures. By using flight plan data and even more detailed aircraft data (down-linked) such as current take-off weight and expected climb profiles, the trajectories of each departure could be calculated and fed into the controller HMI tools such as the trigger advisory line. This would allow for shorter distances between departures and dynamic spacing, pair by pair, as buffers could be decreased when accuracy for each aircraft involved increases. The deployment of enhanced weather-monitoring equipment with extended capabilities, such as LIDAR, would allow the WTSSAV to be extended and therefore to increase the benefits of CREDOS. Real-time down-linking of wind conditions from departing aircraft may be considered as another solution for enlarging the WTSSAV. Wider look-ahead accurate weather forecasts would also increase the benefits of CREDOS and would make the use of CREDOS more predictable. So far, super HEAVY aircraft and intersection departures have been disregarded in the concept development. Incorporating them into the concept could be considered as an option for future development of CREDOS. The concept is focussing on the suspension of wake turbulence minima on a single runway used in segregated mode for departure. The extension of the concept to mix-mode and for arrivals is also of major interest for improving efficiency of airport operations in the future.

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