RETINA Project Conclusions

Deliverable ID	D6.2
Project name:	RETINA
Grant:	699370
Call:	H2020-SESAR-2015-1
Topic:	Sesar-06-2015
Consortium coordinator:	UNIBO
Edition date:	30 August 2018
Edition:	00.01.02

Founding Members
EUROPEAN UNION
EUROCONTROL
SESAR JOINT UNDERTAKING

Authoring & Approval

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Document History

Edition	Date	Status	Author	Justification
00.00.01	23/01/2018	Draft	Sara Bagassi	
00.00.02	08/02/2018	Final	Sara Bagassi	
00.01.01	15/06/2018	Second Draft	Sara Bagassi	Revision SJU
00.01.02	30/08/2018	Third Draft	Sara Bagassi	Second Revision SJU

RETINA

Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision

This project has received funding from the SESAR JU under grant agreement No 699370.

Executive Summary

This document summarizes all the research activities performed in the framework of the RETINA project.

The RETINA project investigates the potential and applicability of Synthetic Vision (SV) tools and Virtual/Augmented Reality (V/AR) display techniques for the Air Traffic Control (ATC) service provision from the airport control tower.

In the two-year project the concept was developed, implemented and validated through human in the loop simulations where the external view is provided to the user in a semi-immersive virtual environment.

The results showed that the RETINA concept is a promising solution to improve the human performance in the control tower, increasing resiliency at airports to low visibility and preserving safety.

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1 Project Overview

1.1 Operational/Technical Context

RETINA investigates the potential and applicability of Virtual/Augmented Reality (V/AR) tools for the Air Traffic Control (ATC) service provision by the airport control tower.

Many consider airports as the bottleneck to increasing the capacity of the overall ATM system. While augmenting throughput in high performing airport operations, attention has rightly been placed on doing it in a safe manner. Many of the advances in airport operational safety come in the form of visualization tools for tower controllers. A-SMGCS based solutions, such as movement maps, conformance monitoring, and conflict detection are a few examples of these tools.

But there is a paradox in developing these tools to increase tower controller's situational awareness. By creating additional computer displays that show the runway and taxiway layout, aircraft and mobile position, and detect actual and foreseen conflicts, the controller's vision is pulled away out of the window view and the head-down time is increased. This reduces their situational awareness by forcing them mentally to switch repeatedly between these two ways of interpreting their working environment.

New developments in the realm of Augmented Reality (AR) may be able to address this paradox. AR differs from Virtual Reality (VR) insofar as it allows users to view the 'real' world along with superimposed or computer-generated information. This concept has become increasingly popular over the past decade and is being proficiently applied to many fields, such as entertainment, aviation, military & defense.

The RETINA project takes the idea of augmented vision and investigates its application to on-the-site control towers through the use of synthetic vision.

Several V/AR technologies were discussed and confronted in this research, including, but not limited to, Conformal Head-Up Displays (C-HUDs) and See-Through Head-Mounted Displays (ST-HMDs).

A 4D Aerodrome Traffic Zone (ATZ) model was developed and implemented as a validation platform, and, within the digital model, a symbolic representation of meteorological data was given as well.

1.2 Project Scope and Objectives

Overall, RETINA project contributes to improve working conditions for air traffic control operators in the control tower, developing a robust solution that filters only relevant information to be displayed on a single, head-up view. In this way, a reduction of head down time is pursued. Further, thanks to the use of V/ARTT, those tasks that can be negatively affected by poor visibility conditions, such as bad weather, fog, smoke, dust or any other kind of environmental occlusion, become weather-independent.

Finally, the RETINA project investigates the impact of the newly conceived tools on the control tower air traffic management procedures. For example, in low visibility or bad weather conditions, ad hoc Low Visibility Procedures (LVP) must be applied. In many airports, this entails the use of a Surface Movement Radar (SMR), which provides only primary positioning for the ground traffic (without any identification support system). Moreover, depending on the airport layout, Low Visibility Procedures might include constraints, such as taxiways that cannot be used, block spacing, limitation in pushback operations and use of a predefined runway. In this context the use of RETINA solutions possibly reduces restraints, producing benefits in terms of capacity and resiliency.

1.3 Work Performed

The project scientific and technical activities were carried out through four technical work packages and three transversal work packages. The following section summarizes the work performed in each technical work package.

WP1

The main activity carried out in this work package was the definition of the state of the art in terms of displays technologies, data sources and standards. Also, a task analysis of control tower working environment was performed in order to identify the needs and constraints for the future synthetic vision and V/AR tools. The task analysis covered both standard and low visibility conditions.

As far as the state of the art is concerned, the results of a review of the current state of the art of sensing technologies and data provision standards were reported in D1.1. For traffic information well-established ATM surveillance systems (e.g. SMR, ASR, etc.) were addressed, along with recent technology developed for Remote Tower Operations (e.g. standard and infrared cameras). For weather related information and digital NOTAM the project looked at SWIM. Also, technologies to sense the controllers' presence, position and line of sight within the working environment were included.

A review of the current means to provide augment reality, either through display screens or head mounted displays, was presented. A list of technologies was included addressing the benefits and drawbacks of each one as it applies to the RETINA concept. An analysis of the various technologies listed was performed to investigate the ergonomic viability and risks and benefits of each from a human factors perspective.

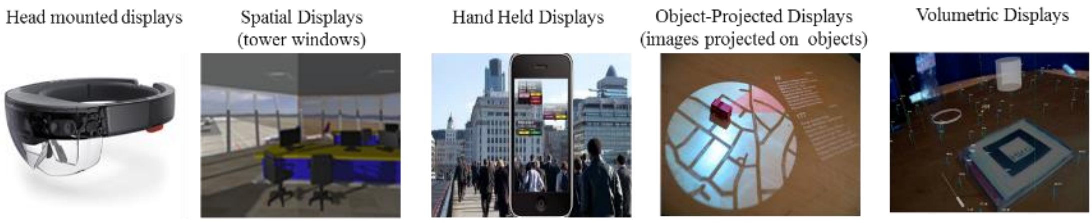

Figure 1 Augmented Reality Technologies identified for the airport control tower

Furthermore, a task analysis of the provision of ATC service from the control tower in both standard and low visibility conditions, focusing on how the RETINA concept would impact them, was performed. This review produced operational requirements for the synthetic vision systems and concepts subsequently developed in WP2.

WP2

The activities performed in WP2 aimed at defining comprehensive solutions to be implemented within RETINA. First of all the sensing technologies and data provision standards were identified , then the V/AR technologies that can be applied in a control tower were selected considering a wide range of alternatives that derives from the analysis reported in D1.1.

The conceptual solutions were developed applying the principles of Ecological Interface Design. Specifically, the Skill Rule Knowledge taxonomy was applied to the control tower tasks providing different results according to the working condition, the control tower equipment and the procedures in use.

Finally, the conceptual solutions were described in D2.1 [2]. The document describes how the V/ARTT should fit into the control tower environment and procedures identifying when, why and how the controllers will make use of augmented visual observation in order to manage the aerodrome traffic.

Figure 2 The RETINA concept

WP3

The implementation work carried out as part of the RETINA project includes the definition of the architecture, the development of a 4D airport model, and the exploitation of this model in the development of the RETINA proof of concept [D3.1].

The proof of concept consists of two principal components: an ATCO post and a pseudopilot post. The ATCO post provides an interactive simulation of the Bologna airport control tower. The simulation consists of a 4D model of the airport and the air traffic, visualized in an immersive CAVE-like environment. The RETINA augmented reality solutions are also deployed within this environment, allowing it to be used for validation exercises as discussed later in this document. The pseudopilot application is responsible for managing the traffic situation around the airport. Generally speaking, the pseudopilot operator takes voice commands from the ATCO and can use the pseudopilot application to input commands that manipulate the 4D model shown in the ATCO post.

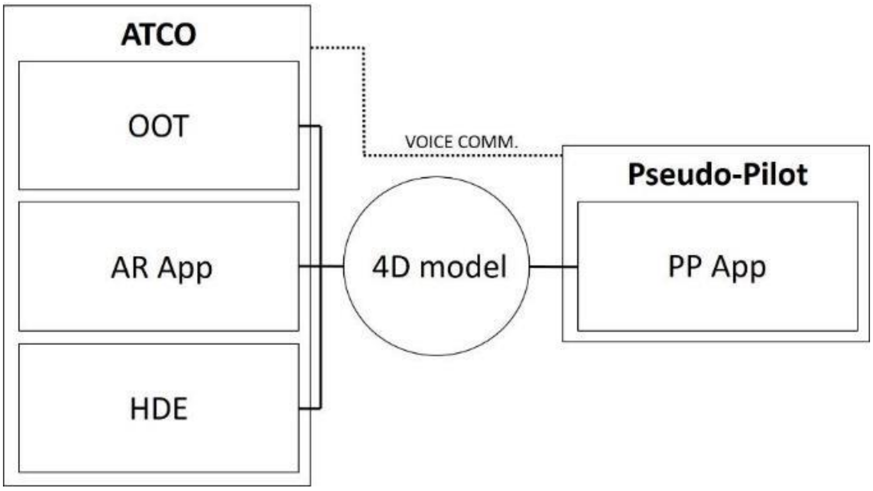

Figure 3 The proof of concept consists of two principal components: an ATCO post and a pseudopilot post. The core system is the 4D model of the reference scenario which communicates through data exchange protocols with Out of the Tower View Generator (OOT), Augmented Reality Overlay Application (AR App), Head Down Equipment (HDE) and Pseudo-pilot application (PP App).

WP4

The aim of the validation activities is to demonstrate the positive impact of the concept proposed by RETINA in the air service navigation provision in terms of human performance, efficiency and resiliency, safety, with the final target of achieving V1 [D4.1].

For each RETINA solution identified in the Operational Concepts Description [D2.1], namely Head Mounted Display and Spatial Display, a proof-of-concept was implemented and validated in a laboratory environment by means of human in the loop real-time simulations where the external view was provided to the user through a high fidelity 4D model in an immersive environment that replicated the out-of-the tower view.

Figure 4 RETINA Validation Platform. The AR App derives the relevant Augmented Reality Overlays and deploys them on the appropriate ATCO Head-Up Interface (being either Spatial Display or Head Mounted Display). The baseline equipment serves to compare data obtained vs success criteria and validation targets identified below.

During the validation both subjective qualitative information and objective quantitative data were collected and analysed to assess the RETINA concept. In addition, a usability test was performed on a simplified validation platform.

The results showed that the RETINA concept is a promising solution to improve the human performance in the control tower, increasing resiliency at airports to low visibility and preserving safety [D4.3].

Nevertheless, the Augmented Reality technology is not yet mature enough for full deployment in a safety critical environment. Thus, further research is required to demonstrate the most mature RETINA conceptual solution, i.e. Head Mounted Display, in a real environment.

Finally, an update of the operational concepts described in D2.1 was performed. It reviews both the SRK taxonomy and the operational concepts according to the results obtained in WP4 Validation. The comprehensive solutions defined in the RETINA Project were analysed and updated in order to meet the recommendations collected during the validation [D4.2].

1.4 Key Project Results

The following section lists the key results achieved during the project from an operational, methodological, and technical perspective.

1.4.1 Operational Results

- The RETINA concept has a clear effect in stimulating the ATCO to work in a head-up position more than in a head-down position [D4.3].
- The ATCO is provided with a unique conformal representation of all the needed information that is currently provided by means of several visual inputs [D4.3].
- When low visibility conditions apply, the use of RETINA tools provides the ATCO with a head up conformal view of all needed information, leading to the reduction of current restrictions due to LVP [D4.3].
- The operational benefits provided by the two conceptual solutions explored, namely HMD and SD, are comparable [D4.3 and D 4.2]. More specifically, in the usability test performed on HMD the controllers were quite optimistic about the operational benefits regarding the use of this solution. One of the controllers in RTS11 wrote "At the cognitive level, the sense of workload was reduced because I did not have to take a look at my flight strips or the distance radar to check who an aircraft was." Another wrote regarding the use in LVC, "That would be, in fact, the perfect fit for a first application, and with a significant reduction of workload." [D4.3]

1.4.2 Methodological Results

- The methodology used to select the most suitable AR technology [D2.1] – based on an integrated approach between QFD (Quality Function Deployment) and AHP (Analytic Hierarchy Process) – has proved to be effective.
- The methodology used to design the interface [D2.1 and D4.2], based on EID (Ecological Interface Design) principles and SRK (Skill-Rule-Knowledge) taxonomy, has proved to be effective. From a methodological perspective, this approach is one of the aspect of novelty of the project as it applies a rather recent interface design tool, i.e. SRK (Skill-Rule-Knowledge) taxonomy, to a working environment which was not explored through this tool so far, i.e. the airport control tower. This may be considered for the exploitation of ER results in future related projects.

1.4.3 Technical Results

- For each RETINA technical enabler, namely Head Mounted Display and Spatial Display, a proof-of-concept was implemented and validated in a laboratory environment, where the external view was provided to the user through a high fidelity 4D model in an immersive environment that replicated the out-of-the tower view [D3.1].
- The 4D model implemented for the proof-of-concept has a high degree of realism, enhanced by the possibility to integrate the head-tracking signal.

- The head tracking was successfully implemented with no need for invasive markers/sensors.
- On one hand, the validation platform developed for the project proved to work effectively for the purpose of the validation and, on the other hand, it proved to be both flexible and open enough to integrate potential new modules. This may be considered for the exploitation of ER results in future related projects [D4.3].

1.5 Technical Deliverables

The following section lists all technical deliverables that were produced for the project. Public deliverables are available at the RETINA project website.

Reference	Title	Delivery Date[1]	Dissemination Level[2]
	Description		
D1.1	State of Art and Initial Concept Requirements	10/02/2016	Public
This document sets up the baseline for the other project work packages, identifying the state of the art in terms of displays technologies, data sources and standards. Also, a task analysis of control tower working environment is presented in order to identify the needs and constraints for the future synthetic vision and V/AR tools. The task analysis covers both standard and low visibility conditions. This document also lists operational procedures, requirements and guidelines from a human factors and ergonomic perspective. All of these results will serve as input to the concept development performed in WP2			
D2.1	Operational Concepts Description	28/02/2017	Public
This document defines comprehensive solutions to be implemented within RETINA. First of all the sensing technologies and data provision standards are identified, then the V/AR technologies that can be applied in a control tower are selected. The document defines how the V/ARTT should fit into the control tower environment and procedures identifying when, why and how the controllers will make use of augmented visual observation in order to manage the aerodrome traffic			
D3.1	Proof of Concept	19/09/2017	Confidential
This deliverable documents the implementation work carried out as part of the RETINA project. Specifically, this comprises the development of a 4D airport model and its integration with two interconnected software systems: i) an ATCO post provides a human-in-the-loop simulation of an airport control tower; ii) a pseudopilot post provides external control over the aforementioned simulation. In addition to discussing the requirements and architecture of these two systems, the document also looks forward at how the systems will be used in the subsequent validation phase of the RETINA project.			
D4.1	Validation Plan	04/10/2017	Public
This validation plan (VALP) describes the validation activities planned for the RETINA project: validation approach and context, the validation objectives, scenarios and validation exercises are described in the document.			
D4.2	Operational Concepts Description Update	30/01/2018	Public
This document is the update of the operational concepts described in deliverable D2.1[2]. It reviews both the SRK taxonomy and the operational concepts according to the results obtained in WP4 Validation. The comprehensive solutions defined in the RETINA Project are analysed and updated in order to meet the recommendations collected during the validation.			

[1] Delivery data of latest edition

[2] Public or Confidential

D4.3	Validation report	15/01/2018	Public
The document provides a review of the validation activities that were carried out in the RETINA project and supplies detailed information on the results of the eleven validation exercises run at the UNIBO and CRIDA facilities.			

Table 1: Project Deliverables

2 Links to SESAR Programme

2.1 Contribution to the ATM Master Plan

Based on the results achieved the RETINA consortium identified a need for an Operational Improvement Step in the roadmap. This is based on an existing AO-0212 taken from the Airport STEP3 DOD delivered and accepted by the SJU in December 2012. The request for change (Table 2) is motivated by the possibility of using See-Through Head Mounted displays as an alternative to Conformal Head-Up Displays.

RETINA results contribute to the achievement of V1 for this new OI step.

Table 2 OI STEP Request

CR 01362 Create AO-0212 (RETINA) - OI Step	
CR Description	The S2020 ER Project RETINA has identified a need for an OI in the roadmap (V1 on-going). See also in comments.
Originating Project:	PJ.03a SUMO
Pre-coordination Status:	SJU
Pre-coordination Description:	SJU: to be done
OI Step Code:	AO-0212
OI Step Title:	Equivalent Visual Operations for Tower Control in Low Visibility
OI Step Description:	Enhanced situational awareness for the controllers is achieved through a provision of an equivalent visual operations in the Tower in low (nearly zero) visibility. This is achieved by providing ATCO with an enhanced vision through digitalised means. Benefits are mainly in low and reduced visibility conditions (fog, night, snow) since the separation minima can then be enhanced and the runway throughput maintained.
Master Plan Rationale:	As already under study on the airborne side, there is a need for an equivalent of military pilot glasses where the out of window could be replaced by an overlay displayed on an ATCO glasses or by any other digitalised means.
Maturity Level:	V1
V3 forecast:	12/31/2025

Impacted Environment:	Airport
CR Cluster	CRC2
Status	Updated
Fix Version	EATMA Draft
Affects Version	DataSet 18a
Reporter:	INARD Anthony
Assignee:	INARD Anthony
Resolution:	CR Initialized (CR 01362 Create AO-0212 (RETINA))

Table 3 OI step maturity

Code	Name	Project contribution	Maturity at project start	Maturity at project end
AO 0212	Equivalent Visual Operations for Tower Control in Low Visibility	The request for change is motivated by the possibility of using See-Through Head Mounted displays as an alternative to Conformal Head-Up Displays. RETINA results contribute to the achievement of V1 for this new OI step.	TRL1	TRL3

2.2 Maturity Assessment

The initial maturity level for the RETINA concept was assessed as TRL 1 as the basic principles of using synthetic vision and augmented reality tools in a Control Tower were observed. The analysis of target maturity level was performed on both RETINA concept and associated technical enablers: Spatial Display and Head Mounted Display (Table 4).

Table 4 Maturity Levels in terms of E-OCVM and technical enablers

Concept solution	Initial Maturity level	Target Maturity level	E-OCVM
RETINA concept			V1
RETINA solution1 with HMD	TRL1	TRL3	
RETINA solution2 with SD	TRL1	TRL2	

The following table (Table 5) is based on the maturity assessment tool provided by SESAR JU for ER/IR gate and it refers to the RETINA concept, which is defined as the *provision of conformal head-up information overlapped to the real world in the airport control tower by means of Synthetic Vision/Augmented Reality tools*. Further maturity assessment was performed for the same concept using the V1 criteria and the results are reported in Table 6.

Table 5 Maturity Assessment for ER/IR gate

Thread	ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS	OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	Achieved	The concept developed by the project employs the principles novel augmented reality technology is based on. Basically, the concept is based on the possibility to provide conformal head-up information overlapped to the real world. Specifically, this principle is applied to ATCO operating in airport control towers.
OPS	OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	Achieved	Described in D1.1 with additional information from the validations in D2.1.

OPS	OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	Achieved	The analysis of the state of the art [D1.1] shows that the concept proposed fills the need of providing ATCOs with synthetic vision tools to operate in all weather conditions, similarly to what is currently adopted in modern cockpits.
OPS	OPS.ER.4	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?	Achieved	The concept is exhaustively described in D2.1, D3.1, and D4.2. The development of the RETINA concept potentially leads to the capability for ATCOs to have all operative information on the out-of-view resulting in an easier working method that makes it possible to increase situational awareness and safety in low visibility conditions without jeopardizing airport capacity.
OPS	OPS.ER.5	Are the relevant stakeholders and their expectations identified?	Achieved	Initial list of stakeholders and their expectations provided in D5.1.
OPS	OPS.ER.6	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?	Achieved	The most important performance benefits are identified in terms of human performance in Control Tower for high-density aiports, and in terms of efficiency, capacity and resiliency for airports affected by low visibility conditions.
SYS	SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	Partial - Non Blocking	RETINA identified two candidate technologies to support the concept: head-mounted display (HMD) and spatial display (SD), the latter being less mature. Both technologies have been described in detail and tested in RETINA's validations. Considering the level of maturity of the concept, it is considered as sufficient. The impact on the target architecture will have to be assessed in the next maturity level.
SYS	SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?	Achieved	The study was conducted considering the current levels of automation for the systems involved.

SYS	SYS.ER.3	Have initial functional requirements been documented?	Achieved	The operational requirements for the augmented reality technology are described in D2.1.
PER	PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	Achieved	The new concept was developed as a proof of concept [D3.1]
PER	PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	Not Achieved	No benefit and cost mechanisms / influence factors. The cost of the technology in the future cannot be estimated as it will likely drop significantly by the time the concept can be deployed.
PER	PER.ER.3	Has an initial cost / benefit assessment been produced?	Partial - Non Blocking	Benefits were assessed with reference of the validation targets identified in the following KPA: Human Performance, Efficiency and Safety [D4.1]. The costs of the proposed solutions were not assessed as they may significantly vary in the next future.
PER	PER.ER.4	Have the conceptual safety benefits and risks been identified?	Partial - Non Blocking	Initial safety work has not considered the failure of the new equipment and no consideration of the safety requirements put on the new HMD or SD equipment.
PER	PER.ER.5	Have the conceptual security risks and benefits been identified?	Not Achieved	Security has not been considered at this stage.

PER	PER.ER.6	Have the conceptual environmental impacts been identified?	Partial - Non Blocking	No conceptual environmental impact in RETINA deliverables. However, the concept leads to the removal of limitations in low visibility conditions with positive effect on airport capacity and throughput. This implies a direct effect on the delay reduction with positive impact on the environment mainly due to fuel savings.
PER	PER.ER.7	Have the conceptual Human Performance aspects been identified?	Achieved	The concept was successfully validated against several human performance criteria, namely mental workload, physical workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time.
VAL	VAL.ER.1	Are the relevant R&D needs identified and documented?	Achieved	The main R&D needs are listed in the "recommendations" section of D4.3 and reported in the project conclusions.
TRA	TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	Achieved	D4.3 and D6.2 identify recommendations for the next R&D phase.

Table 6 Maturity Assessment for V1 gate

Thread	ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS	OPS.V1.1	Is the initial documented description of the concept consistent with the SESAR 2020 CONOPS?	Partial - Non Blocking	The RETINA HMD concept does not contradict the Transition ConOps but the ConOps does not identfy enhanced visual operations in the Tower.
OPS	OPS.V1.2	Is there an initial identification and description of the SESAR Solution and related OI steps available in EATMA (Integrated Roadmap)?	Partial - Non Blocking	CR proposed for a new OI in DS18a. The impact of the augmented reality information on the TWR operations would deserve more attention in V1.
OPS	OPS.V1.3	Are the different concept variants (if any) described?	Partial - Blocking	The different TWR ATCO positions are not described.
OPS	OPS.V1.4	Have potential (sub)operating environments been identified where, if deployed, the SESAR Solution could bring performance benefits?	Partial - Blocking	No identification in EATMA
OPS	OPS.V1.5	Have all stakeholders been identified, their needs and expectations for the	Partial - Blocking	The different TWR ATCO positions are not described.

		SESAR solution discussed and documented?		
SYS	SYS.V1.1	Has the potential impact of the concept on the target architecture been identified?	Partial - Non Blocking	CR proposed for a new OI in DS18a. RETINA identified two candidate technologies to support the concept: head-mounted display (HMD) and spatial display (SD), the latter being less mature. Both technologies have been described in detail and tested in RETINA's validations. Considering the level of maturity of the concept, it is considered as sufficient. The impact on the target architecture will have to be assessed in the future R&D activities.
SYS	SYS.V1.2	Is there a clear identification and description of the impacted Functional Blocks by the SESAR Solution in EATMA (Integrated Roadmap / ADD)?	Not Achieved	No work on EATMA done yet.
SYS	SYS.V1.3	Have any architectural constraints been identified?	Not Achieved	No work on EATMA done yet.
SYS	SYS.V1.4	Are different supporting technological alternatives defined, if any?	Not Applicable	HMD is the only available technology.
SYS	SYS.V1.5	Are there needs for supporting CNS infrastructure (if any) adequately identified and justified for the different (sub)operating environments relevant for the SESAR Solution?	Partial - Non Blocking	Clearer definition of the required CNS infrastructure should be given in the future R&D activities.

PER	PER.V1.1	Has a V1 Human Performance assessment been performed and documented following PJ19 SESAR HP Reference Material?	Partial - Non Blocking	The concept was successfully validated against several human performance criteria, namely mental workload, physical workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time. However, no full V1 HP assessment was performed as per the SESAR 2020 HP reference material.
		Have all relevant HP arguments been identified (through the screening) and addressed at the level required in V1?	Achieved	The concept was successfully validated against several human performance criteria, namely mental workload, physical workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time.
		Are the benefits and issues in terms of human performance and operability related to the proposed SESAR solution identified and sufficiently assessed at the level required for V1?	Achieved	The concept was successfully validated against several human performance criteria, namely mental workload, physical workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time.
		Have potential interactions with related SESAR Solutions been considered?	Partial - Blocking	D5.1 identifies the possibility to use RETINA's results in PJ03a and in PJ05 and different communication and dissemination actions have been taken toward the airport solution projects in SESAR 2020 IR Wave 1. However, the identification of the interactions with other SESAR solutions is missing.
		Is the level of human performance needed to achieve the desired system performance for the proposed SESAR	Achieved	The concept was successfully validated against several human performance criteria, namely mental workload, physical workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time.

		solution consistent with human capabilities?		
		Have the major factors been identified that influence the transition feasibility (e.g. changes in automation levels, competence requirements, training needs of human actors, changes in staff requirements, need for relocation of the workforce)? Are there any potential mitigation identify on how to overcome these issues?	Not Achieved	
		Have any impacts been identified that may require changes to regulation in the area of HP/ATM? This includes changes in roles & responsibilities, competence requirements, or the task allocation between human & machine.	Partial - Blocking	Initial work on the need to change LVPs has been identified but no work has been initiated on the regulatory aspects.
PER	PER.V1.2	Has a V1 Performance Assessment been performed and documented following PJ19 SESAR Performance Reference Material?	Partial - Blocking	Benefits were assessed with reference of the validation targets identified in the following KPA: Human Performance, Efficiency and Safety [D4.1]. However, no full V1 performance assessment was performed as per the SESAR 2020 performance reference material.
		Is there a documented analysis and description of the benefit Impact mechanisms (BIMs) and associated	Not Achieved	No BIMs and influence factors provided.

		Influence Factors (and the rationale for their selection) for the different alternatives to the solution, aligned with SESAR guidelines e.g. Performance Framework KPAs and KPIs?		
		Do validation results provide the qualitative and quantitative (if possible, or at least estimated) evidences about impact on all KPAs which are relevant (e.g. Capacity, Operational Efficiency, Cost-efficiency, Predictability, Flexibility etc.), using KPIs/PIs from SESAR Performance Framework for the different alternatives to the solution?	Partial - Blocking	Only capacity (through runway throughput) has been properly addressed so far.
		Are Baseline, Reference and Solution scenarios aligned with SESAR guidelines?	Achieved	See D4.3.
		Did the validation activities at V1 level address all the expectations for V1 set at VALS level e.g. Validation Targets at solution level?	Not Achieved	No VALS Target for this solution.
PER	PER.V1.3	Has an outline CBA been developed and documented in line with PJ19 Reference Material including: (1) Description of Cost and Benefit mechanisms with links to the SESAR KPA Indicators and Stakeholders	Not Achieved	

		impacted (2) First description of alternatives to the solution and the CBA scenarios with links to validation plans so that the validation exercises gather factual data to measure the benefits in the CBA (3) Qualitative assessment or orders of magnitude of deployment costs and/or benefits to rank alternatives		
PER	PER.V1.4	Has a V1 safety assessment been performed and document following SESAR PJ19 SESAR Safety Reference Material?	Not Achieved	
		Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) describe the key properties of the Operational Environment that are relevant to the safety assessment?	Not Achieved	
		Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) identify the pre-existing hazards that are inherent in aviation within the scope of the Solution operations?	Not Achieved	
		Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) determine the	Not Achieved	

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		operational services that support the Solution operations?		
		Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) contain a list of suitable Safety Criteria for the Solution operations?	Not Achieved	
PER	PER.V1.5	Has the V1 security assessment been carried out and documented in conformance with the SESAR Security Reference Material?	Not Achieved	
		Have the security risk assessment scope and security assumptions on the environment been documented?	Not Achieved	
		Have primary assets been documented?	Not Achieved	
		Has the primary assets impact assesment been documented?	Not Achieved	
PER	PER.V1.6	Has been a V1 environmental assessment been performed following SESAR PJ19 Environmental Reference Material?	Partial - Blocking	Reference made to potential environmental benefits but methodology not followed.

		Have the SESAR Solution environmental benefits and risks mechanisms been identified?	Not Achieved	
		Have the environmental impacts (Noise, Local and Global emissions) that should be investigated for the SESAR Solution been identified?	Partial - Blocking	No conceptual environmental impact in RETINA deliverables. However, the concept leads to the removal of limitations in low visibility conditions with positive effect on airport capacity and throughput. This implies a direct effect on the delay reduction with positive impact on the environment mainly due to fuel savings.
STD & REG	S&R.V1.1	Have Standardisation needs been identified?	Partial - Blocking	Need for standardised digital database for the airport layout identified. However, there is a need for performance requirement standards for the new HMD device.
TRA	TRA.V1.1	Are there any major transition issues identified e.g. institutional changes, infrastructure changes, training, etc.?	Partial - Non Blocking	Assuming the physical workload issues are solved with the evolution of the HMD technology, the training aspects still need to be better identified in V1.
TRA	TRA.V1.2	Are there recommendations proposed to be addressed during V2 related activities? E.g. additional testing conditions, open HP issues to be addressed in V2,…	Not Achieved	The identified recommendations are more relevant to V1 than V2.
VAL	VAL.V1.1	Do the validation activities (e.g. validation objectives) at V1 conform to the VALS	Not Achieved	No VALS objectives.

		content apportioned to the SESAR Solution?		
VAL	VAL.V1.2	Are the relevant R&D needs identified and documented? Have the validation objectives covered by V1 validation activities addressed the relevant and Key SESAR Solution R&D needs?	Partial - Blocking	The different TWR ATCO positions are not described.
PRG	PRG.V1.1	Is there a clear identification of the corresponding baseline (applicable EATMA version and/or aplicable Integrated Roadmap Dataset version e.g.SESAR Solution, OI steps, Functional Blocks)	Achieved	CR identified based on DS17b.
PRG	PRG.V1.2	Have related SESAR Solutions (and relevant OI steps & enablers) been identified and their interdependencies documented?	Partial - Blocking	D5.1 identifies the possibility to use RETINA's results in PJ03a and in PJ05 and different communication and dissemination actions have been taken toward the airport solution projects in SESAR 2020 IR Wave 1. However, the identification of the interactions with other SESAR solutions is missing.
PRG	PRG.V1.3	Are there evidences that the inter-dependent SESAR Solutions (and	Not Achieved	

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		relevant OI steps & enablers) are at the expected level of maturity?		

3 Conclusion and Lessons Learned

3.1 Conclusions

This section captures the main conclusions of the RETINA project.

On the whole, in the two-year project the RETINA concept was developed, implemented and validated through human in the loop simulations where the external view was provided to the user in a semi-immersive virtual environment.

The implementation in a laboratory environment of both conceptual solutions served as proof of concept. Moreover, a usability test was performed on a simplified platform.

Firstly, the following **technical** issues were achieved with the current validation:

- Compatibility of the technology used with the current data provision format;
- Capability of non-invasive tracking of the user position;
- Capability of providing the user with a conformal head-up view of synthetic information overlapped to the out of the tower view.

Secondly, from a **methodological** perspective, the project proved that the application of the principles of Ecological Interface Design, SRK taxonomy in particular, is effective.

Noticeably, the most important contribution provided by the project concerns **operational** benefits in three main Key Performance Areas: Human Performance, Capacity, and Safety.

- *Human Performance*: the proposed concept provides quantified benefits in terms of mental workload, temporal workload, performance, effort, frustration, information accessibility, and head-down time.
- *Capacity*: the solution leads to the removal of some restrictions in low visibility conditions with positive effect on airport capacity and throughput. This effect was quantified for a specific test-case on Bologna Airport by means of HIL simulations during the validation. It is worth mentioning that this benefit is subject to the assumption that comparable enhanced vision systems are available for pilots in the cockpit. Moreover, the increase of capacity in LVC implies a direct effect on the delay reduction with positive effect on punctuality, predictability and resilience.
- *Safety*: the solution is contributing to safety improvement as it enhances situational awareness.

Finally, it is worth remembering that, as far as the SD solution is concerned, the Augmented Reality technology for this solution is not yet available, thus this solution achieves TRL2. On the other hand, since the HMD Augmented Reality technology is more mature, its application does achieve TRL3. However, since this technology is not yet mature enough for full deployment in a safety critical environment, further research is required to demonstrate it in a real environment.

3.2 Technical Lessons Learned and Plan for next R&D phase

This section summarizes the main recommendations to improve the technical feasibility of the process and potential applications:

- Test the most mature solution, i.e. Head Mounted Display, in a real control tower under real operative and visibility conditions. This would improve the maturity of the solution, validating it in a real environment in order to achieve TRL5-6 (V2).
- Continue testing the less mature solution in a simulated environment, i.e. Spatial Display, considering different evolution scenarios for this technology, and including multi-user operations.
- For the most mature solution, i.e. Head Mounted Display, analyse safety requirements for the introduction of the technology in the airport control tower, including the availability of safety-critical graphical libraries, safety-critical devices, redundancy of information and systems.
- Investigate the impact of the shift in visibility conditions – provided by the RETINA concept- on the tasks performed by both pilots and ATCOs.
- Set the performance requirements needed for certification purposes of the enabling technologies. This should be set for the most mature technology (HMD) first, keeping monitored the gap between current performance and certification requirements in order to make the estimated time needed for full deployment more clear-cut.
- Further investigate the possible failure cases and recovery procedures for the operational concept, paying great attention to the critical sub-case in which some LVP restrictions are removed due to the use of RETINA tools and a failure case occurs.
- Study the interaction options offered by the two technical solutions, considering multi-modal interaction (vocal + gestural +gaze) as well.

As far as the Interface Design is concerned, the following refinements are recommended:

- Study the option to have the flight tags avoid each other so that they do not overlap at any time and they do not obstruct any relevant point in the airport. Consider billboard's transparency as an option;
- Refine the size of the flight tags. Make the tags expand to show the useful information when requested, but just the flight ID otherwise. Customize the flight tags information based on the phase of flight;
- In the Head Mounted Display solution, change the METAR display to make the wind direction more readable, and make it fixable to a location in the scene.

- Change the colours so that there is a more uniform colour, but still differentiate between arrivals and departures. Remove the red and only use it in cases of warnings.

Finally, although several benefits were observed/recorded or inferred by the simulation activities, a few 'issues' were also noted, which, if the concept were to be developed, would need to be addressed.

These include but are not limited to:

- In its present version, the Head Mounted Display used for the validation should not be used continuously for a long time. Further study should investigate what time limit, if any, should apply for the continuous use of such a device in the control tower.

- The AR technology for Spatial Display is not yet mature. The main limitations for this technology are screen size, costs, and the possibility to provide AR holograms to multiple users looking at the same device. While the first two issues will be likely overcome in the next decade, the latter might take more time to get over. This being said, further testing of the concept should continue in a simulated environment to further develop the concept.

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Appendix A

A.1 Acronyms and Terminology

Term	Definition
ANSP	Air Navigation Service Provider
AR	Augmented Reality
ASR	Airport Surveillance Radar
A-SMGCS	Advanced-Surface guidance and control system
ATC	Air traffic Control
ATCO	Air traffic Control Officer
ATM	Air Traffic Management
ATZ	Aerodrome Traffic Zone
C-HUD	Conformal Head Up Display
EID	Ecological Interface Design
HMD	Head mounted Display
KPA	Key Performance Area
LVC	Low Visibility Condition
LVP	Low Visibilities Procedures
OI	Operational Improvement
SD	Spatial Display
SESAR	Single European Sky ATM Research Programme
SMR	Surveillance Movement Radar
SRK	Skill Rule Knowledge
ST-HMD	See Through Head Mounted Display
SV	Synthetic Vision
TRL	Technology Readiness Level
TWR	Tower

VALP	Validation Plan
V/A	Virtual/Augmented
V/ARTT	Virtual/Augmented Reality Tower Tools
VR	Virtual reality

Table 7: Acronyms and technology

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