Operational Concepts Description

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RETINA

Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision

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Executive Summary

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.

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1. Introduction

1.1 RETINA project overview

The RETINA project consists of a research and innovation action that deals with the development of innovative tools for the airport control tower and, as such, relates to ER-06-2015 – High Performing Airport Operations – Improved Visualisation and Awareness.

The RETINA project takes the idea of augmented vision and investigates its application to on-site control towers. It investigates the placement of additional information such as flight tags, runway layout, and warning detection over the actual out the window view that the controller has. Therefore, RETINA builds upon the technology previously developed in SESAR and provide new overlays as well.

From a technological perspective, RETINA investigates two different augmented reality (AR) systems: Conformal Head-Up Displays (C-HUD, which could be made to coincide with the tower windows) and See-Through Head-Mounted Displays (ST-HMD). A dissimilar third tool, i.e. a virtual reality (VR) based Table-Top interface will be conceived as well.

RETINA will deal with application-oriented research and encourage innovative and visionary ideas, effectively contributing to the SESAR 2020 Research and Innovation (R&I) cycle.

1.2 Document Scope

This document defines comprehensive solutions to be implemented within RETINA (Chapter 5). First of all the sensing technologies and data provision standards are identified (Chapter 2), then the V/AR technologies that can be applied in a control tower are selected (Chapter 3) considering a wide range of alternatives that derives from the analysis reported in D1.1. 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 (Chapter 4).

1.3 Intended Audience

This document was developed as an output of the RETINA project describing comprehensive solutions that will exploit the concept of using selected Augmented Reality tools in the control tower.

Beneficiaries include airports interested in implementing these types of tools, air navigation service providers, and airport IT systems providers.

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1.4 Acronym List

Acronym	Definition
A-CDM	Airport Collaborative Decision Making
ADM	Arrival and Departure Monitor
ADS-B	Automatic Dependent Surveillance – Broadcast
AF	Abstract Function
AH	Abstraction Hierarchy
AHP	Analytic Hierarchy Process
ALT	Actual Landing Time
AOIS	Aeronautical Operational Information system
AR	Augmented Reality
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASR	Airport Surveillance RADAR
ATC	Air Traffic Control
ATCO	Air Traffic Control Operator
ATCR	Air Traffic Control RADAR
ATIS	Airline Travel Information System
ATM	Air Traffic Management
ATOT	Actual Take Off Time
ATZ	Aerodrome Traffic Zone
CFMU	Central Flow Management Unit
C-HUD	Conformal Head-Up Display
COO	Coordinator
CPU	Central Processing Unit
CTOT	Calculated Take Off Time
CWP	Controller Working Position
DBMS	Database Management System
DEL	Delivery
DEM	Digital Elevation Map
DOF	Degree of Freedom
DTD	Distance to Touch-Down
EID	Ecological Interface Design
EOBT	Estimated off Blocks Time
ER	Exploratory Research
ETOT	Estimated Take Off Time
FAA	Federal Aviation Administration
FDP	Flight Data Processing
FOV	Field of View

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FP	Functional Purpose
GF	Generalised Function
GND	Ground
GPU	Graphic Processing Unit
HMD	Head Mounted Display
HOQ	House of Quality
HUD	Head Up Display
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IHP	Intermediate Holding Point
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
JU	Joint Undertaking
LOC	Localizer
LOD	Level of detail
LVP	Low Visibility Procedure
LVTO	Low Visibility Take Off Operations
MCDM	Multi-Criteria Decision-Making
NASA	National Aeronautics and Space Administration
NMOC	Network Manager Operations Centre
NOTAM	NOtice To AirMen
PFn	Physical Function
PFo	Physical Form
PPI	Plan Position Indicator
PSR	Primary Surveillance RADAR
QFD	Quality Function Deployment
RETINA	Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision
RVR	Runway Visual Range
RWY	Runway
SESAR	Single European Sky ATM Research Programme
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking
SMR	Surface Movement RADAR
SRK	Skill-Rule-Knowledge
SSR	Secondary Surveillance RADAR
SWIM	System Wide Information Management
TDZ	Touch-Down Zone
TOBT	Target Off-Block Time
TTOT	Target Take-Off Time

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TWR	Tower
TWY	Taxiway
UCD	User-Centred Design
V/ARTT	Virtual/Augmented Reality Tower Tool
VFR	Visual Flight Rules
VMC	Visual Meteorological Condition
VR	Virtual Reality
WCAT	Wake Turbulence Category

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2 Selection of Sensing Technologies and Data Provision standards

2.1 Introduction

This chapter will survey a set of sensing technologies and data provisioning standards on which the V/ARTT could be built. These technologies and standards will be grouped into three major categories:

- Operational data: Information used by the controller as part of his/her tasks, such as aircraft positions and identifications, flight schedule information or weather data. This category encompasses the data sources already introduced in D1.1.
- User data: Input provided to the V/ARTT about the user's position, gaze or actions. This information is typically obtained from sensors worn by the user or installed inside the control tower.
- Auxiliary data: information which is not necessarily of direct use from an operational perspective, but which can provide context to other information, thus increasing the controller's situational awareness.

For each of these categories, a number of specific data sources will be discussed, with a focus on their applicability during the project's implementation phase. We will assess the added value of the data to the V/ARTT, the possibilities for integration with different display technologies and with other data sources, and the available data formats or standards that can be used to ingest the data into the system.

SWIM[1] (System Wide Information Management) is a SESAR initiative which creates an all-encompassing set of data exchange standards for the ATM domain. SWIM strives to improve the safety and cost efficiency of ATM operations by sharing information between stakeholders in a uniform, standardized way. SWIM also aims to reduce the environmental impact of ATM operations by enabling optimized air traffic movement and infrastructure usage.

In the context of RETINA, SWIM standards will be considered wherever relevant. This will ensure optimal interoperability between the V/ARTT and external systems or services.

[1] http://www.eurocontrol.int/swim

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Note that since the RETINA assessment will have to be based on a simulated environment, the availability of real data may need to be overcome by the use of simulated data. Nevertheless, the consortium is putting every effort into considering real data. This will facilitate further development of the concept, such as the validation in a real control tower.

2.2 Basic requirements for implementation phase

In order to take advantage of the concept, an airport shall meet some basic requirements useful for applications of V/ARTT. These requirements are related to the equipment, airport layout, traffic and ATC procedures and have at least the following features:

- Primary Surveillance RADAR and Secondary Surveillance RADAR (PSR/SSR) equipped;
- Surface Movement RADAR (SMR) equipped;
- Low Visibility Procedures able to manage more than one aircraft at the same time implemented;
- ILS CAT 3B equipped;
- Moderate complexity (one runway, several taxiway, more than one apron);
- Moderate traffic: volume of 200/300 movement per day;
- Apron Management Procedures available;
- Meteorological sensing systems (winds, temperature, pressure, visibility, RVR – Runway Visual Range, cloud base).

2.3 Data sources for operational application

2.3.1 Traceability Matrix

This section provides a mapping between data sources and different V/ARTT. Taking into account that each data source could be used as input for the investigated V/ARTT, Table aims to highlight the potential operational application of V/ARTT having as input the identified data sources. In the next paragraphs, the integration and operational application is detailed for each identified data source.

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Data source vs V/ARTT	Head Mounted Displays	Hand Held Displays	Spatial Displays	Projected Displays	Volumetric Displays
RADAR	✓	!	✓	X	✓
ADS-B	✓	!	✓	X	✓
Visible/Infrared camera	✓	!	✓	X	✓
Data supporting system	✓	!	!	X	!
Meteo sensing	✓	!	!	X	!
User data	✓	!	✓	X	X
Auxiliary data	✓	!	✓	X	✓

Table 1: Traceability Matrix

LEGEND

✓	Operational application with potential benefits
X	Operational application without significant benefits
!	Operational application with limited potential benefits

2.3.2 Operational data

2.3.2.1 RADAR

The position and identification information of the aircraft is very important in a Control Tower environment. The Aerodrome Traffic Control Service is provided using the controller's vision: the RADAR is a supporting tool that becomes essential only during low visibility conditions. This is quite different from the Approach and Area control services, where the regulation fully relies on the use of the RADAR. In this context, the provision of position and identification information provided via V/ARTT to a Tower Controller increases and improves the use of its main "working tool", i.e., the controller's vision. In Low Visibility Conditions, this becomes very important since it combines information available from RADAR data sources with working methods for "normal conditions". In other words, in normal weather conditions, the controller works while looking out the tower window; in this situation, the provision of position and identification information via the V/ARTT could improve the situational awareness by reducing the head down operations (or the operations that looking at the screen prevents the out of window control). Similarly, in Low Visibility Conditions

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the availability of V/ARTT makes it possible to improve the out of window control by reducing head down operations.

Operational application of RADAR data combined with V/ARTT and others data sources could be as input of “Volumetric Displays”, “Spatial Display” and “Head Mounted Displays”:

- “Volumetric Display”: Position and identification information integrated in an Airport map (including 3D mapping of the obstacles) provides the controller with a real picture of the airport, including areas that are not visible from the tower due to physical constraints. The presence of physical obstacles (such as buildings, trees, etc.) is a problem for the visual control in many airports, which can be mitigated using V/ARTT.
- “Spatial Display”: Position and identification information are overlaid on an additional and transparent display, to be integrated into the controller working position and used as an additional layer in the controller vision line monitoring through the windows. This provides the controller with a complete situational awareness without losing any information coming from other tools.
- “Head Mounted Displays”: Position and identification information shown in an optical See-Through HMD can improve the situational awareness of the controller and reduce the head down operation. This is particularly true if such information is combined with other information coming from supporting tools.

The EUROCONTROL standard for exchanging ATM surveillance data (including RADAR) is ASTERIX[2]. ASTERIX category 240 defines the transmission format for raw RADAR video. Visualizations of ASTERIX cat 240 data typically mimic a Plan Position Indicator (PPI) display, which is of limited use to the V/ARTT. Other ASTERIX data categories such as 010 and 048 provide interpreted data which is more suitable to support the use cases described above.

2.3.2.2 ADS-B

ADS-B (Automatic Dependent Surveillance – Broadcast) provides many benefits to both pilots and air traffic control improving both safety and efficiency of flight by providing the following information:

- geographical position,
- pressure altitude data,
- positional integrity measures,
- flight identity,
- 24-bit aircraft address,
- velocity and other data which have been determined by airborne sensors.

The most important information provided by ADS-B to a Control Tower environment is the aircraft position and identification. The position information is already provided by RADAR. Therefore, the V/ARTT applicability considerations described above also hold for ADS-B.

Like RADAR data, ADS-B information can be supplied to the V/ARTT in ASTERIX format (category 021).

[2] http://www.eurocontrol.int/services/asterix

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2.3.2.3 Visible/infrared camera

Infrared imaging provides a thermo-graphic representation of the focused area and is used as an additional view in darkness or in foggy conditions. Visible and infrared cameras have no operational application in the control tower from an ATC perspective. They are basically used for monitoring apron activities such as boarding, refuelling, aircraft loading, etc. The use of cameras becomes very important in the remote tower where the out of window's view is replaced by environmental video. In this case the air traffic control service is provided using cameras. Consequently, the use of data provided by the cameras will be useful for V/ARTT applications.

Visible/infrared camera information could be used as input for the V/ARTT, by integrating with other sources in order to create the augmented vision using a combination of synthetic technologies e.g. Head Mounted Display, Spatial Display, Volumetric Display. The use of these technologies has the following advantages:

- "Volumetric Display": It could generate true volumetric 3D image (360°) by using a visible/infrared video feed combined with other data sources. Combining Airport layout data and RADAR information (including 3D data of the obstacles) with visible/infrared camera data and visualizing them on a Volumetric Display could allow controllers to have a real and detailed picture of airport also in low visibility conditions.
- "Spatial Display": It could generate an additional transparent GRP to be integrated into the controller working position and it could be used as an additional layer in the controller vision line monitoring through the windows. Combining visible/infrared camera data with RADAR information and then visualizing it on a Spatial Display could allow controllers to have a complete situational awareness without losing any information coming from the singular data source. That could be obtained by visualizing on the Spatial display the supplementary data to the external view needed to perform the current controller task. Furthermore the displayed data could be configured online based on the current operational needs in order to avoid overcrowding the controllers view with too much information.
- "Head Mounted Displays": It could generate a detailed view of a specific flight using data combined with other data sources. Combining visible/infrared camera data with aircraft/vehicle data on a Head Mounted Display could allow controllers to have a magnified view of a selected aircraft or vehicle. Furthermore, image processing operations such as contrast enhancement or edge detection (particularly on an infrared image) could be useful to visually highlight objects of interest in a VR/AR display.

Technology for the streaming of live video to multiple clients is mature and commonplace. There are no specific technical caveats when providing video input to the V/ARTT.

2.3.2.4 Data supporting system (FDP/AOIS)

Data supporting systems provide the controller with information related to the scheduled times and the route. The most important scheduled times are:

- EOBT/TOBT: Estimated (Target in case of A-CDM, Airport collaborative decision making) off-block time.

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- ETOT/TTOT: Estimated (Target in case of A-CDM, Airport collaborative decision making) take off time.
- CTOT: Calculated take off time that is provided by the Network Manager Operations Centre (NMOC)

Data supporting system information is available via the Controller Working Position and typically requires controller head down operations. The integration of this information in the V/ARTT is very useful in order to reduce the head down operation and to improve the information accessibility. Operational application of data supporting system information combined with V/ARTT and others data sources could be as input of “Volumetric Displays”, “Spatial Display” and “Head Mounted Displays”. For example, the provision of the CTOT on the identification label of a flight makes it possible to reduce the mistake possibility and to clearly inform the controller about the time constraints. This represents an important means of support to the ground operations management. The main advantage is probably obtained in the Head Mounted Display: the provision of the scheduled times through an overlaid label of the flight could easily help the controller in the management of the task. In this context it will be very important to select the most appropriate scheduled times in order to avoid confusion or to overload the controller with unnecessary information.

FIXM[3] (Flight Information Exchange Model) is a cross-domain standard for the exchange of flight information. EUROCONTROL has defined an A-CDM extension[4] to the standard, which covers the scheduled times information described above. FIXM define a conceptual model as well as an XML-based physical representation of it, making it suitable for ingestion of the data into the V/ARTT.

2.3.2.5 Meteo sensing systems

The availability of meteo data is very important for ATC operational application. Depending on the weather conditions, different data types are important.

In VMC (Visual Meteorological Conditions), i.e. when VFR flights have no restrictions, the most important data types are wind and QNH. When visibility decreases below 5 km or the ceiling decreases below 1500 ft, only Special VFR flights and IFR flights are possible. In this situation two other data types become important for ATC operational use: visibility and ceiling. When the visibility decreases below 1500 m or the ceiling decreases under the 600 ft, only Special IFR flights are possible. In this context the most important meteo data types used by the Controller are: RVR, wind and QNH.

Currently meteo data is presented in the controller working position on a dedicated screen. They are used for each flight by the controller, i.e. it is frequently required by the Controller to look at this screen in order to access to meteo data. The provision of this data via V/ARTT will have many benefits; the most suitable application could be the HMD that presents meteo data as an overlay in an optical see-through.

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[3] https://www.fixm.aero/

[4] https://www.fixm.aero/eurocontrol_extension_10.pl

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Meteo data can be provisioned using WXXM[5] (Weather Information Exchange Model), a standard jointly developed by EUROCONTROL and the FAA. WXXM comprises both a conceptual model for aviation-related meteo data and an ISO standards-based physical representation.

2.3.3 User data

User input data is a valuable data resource for interactive augmented, virtual reality and conventional desktop applications. User input data is used for two purposes. First, it is used to let the user interact with the application, e.g. through mouse/keyboard input. Second, user input data could indicate positional information about the user. This information is essential for augmented and virtual reality application, as it is necessary to create a sense of immersion.

This section will give an overview of the types of user input data considered relevant for the RETINA project. This section only provides a general overview and possible application of the different types of user data.

- Location data: provides the location of the user;
- Head tracking: provides the orientation and location of the user's head;
- Input devices and gesture recognition: allows the user to interact with the application.

2.3.3.1 Location

The physical location of the user can be either a geospatial location, or a relative location in a room. For the RETINA project we consider the location to be the location of the user inside the control tower.

Location data can have multiple purposes. First, it can be used by the application to adapt itself to the changing context depending on where the user is currently positioned in the control tower. It might be necessary to present other data sources to the user. For instance, depending on which side of the control tower the user is located, other runway information might be required.

In virtual environments the location of the user can be used to position the camera at the same place as where the user is currently located in the real world. This is necessary if the user needs to physically walk around when using a VR device, which in most situations blocks the view of the user on the real world.

The location of users is also useful in a collaborative environment such as the control tower. In this case the location of multiple users could be used to present an embodiment of each user in the virtual world [1,2].

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[5] http://www.wxxm.aero/

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2.3.3.2 Head tracking

Head tracking provides information about the orientation and position of the user's head. Head tracking typically has six degrees of freedom (DOF), three for translation by the axis and one for each rotation around the different axis. The rotations are typically indicated as pitch, yaw and roll angles.

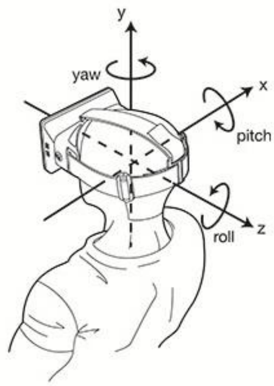

Fig 1. Head tracking six degrees of freedom

The head tracking input is fundamental for VR and AR environments, as it is crucial for the sense of immersion of the user in the simulated world. Therefore, it's important for the application to respect the orientation of the head, as suddenly changing it can disorient the user.

Two important properties that should be considered when selecting the head tracking technology are the latency and the accuracy. If there is a significant latency between an action of the user (e.g. looking to another direction) and the result of that action in the simulated environment, it will break the immersion in a virtual world and may impact the performance of the user [3].

On a technical level, most head tracking solutions provide direct access to the position of the head via either a transformation matrix or another mathematical representation. This data can be used directly by the rendering engine to position and orient the camera correctly. The position and orientation of the head can be combined with the location data described above.

In an operational application using a VR device, the head position/orientation is used to visualize the correct part of the virtual world based on the direction in which the user is looking. In case of an AR device, it is used together with depth sensing information to place simulated objects correctly in the real world.

Head tracking can also be relevant for stereoscopic displays, in that it may be used to prevent distortion of the image when not looking straight at the display.

2.3.3.3 Input devices and gesture recognition

Input devices and gesture recognition are used to let the user interact with the application. With traditional input devices, the user typically holds or touches the device (e.g. keyboard, mouse, …) and performs a simple action (e.g. mouse click). With gesture recognition the input device can recognize more complex input from the user (e.g. swipe gestures on a touch screen, gestures made with a hand). Many gesture recognition technologies use cameras to track the movements of the user, thereby allowing more mobility for the user.

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Input from the controller via either an input device or gesture recognition can give him the ability to switch between different data sources. Other possible use cases are to let the controller zoom in on specific data or change the layout of how the data is represented. Additionally this input could be used to let the controller create markers, labels, etc.

2.3.4 Auxiliary data

This section describes data which is not directly used by the controller in his or her decision making process, but which exists to provide context to the data sources mentioned above. The paragraphs that follow will present data sources which model the (mostly static) airport surroundings, and which may therefore improve the controller's situational awareness. Furthermore, the data can also help improve the accuracy of the V/ARTT itself.

Because the use cases for the auxiliary data sources are strongly intertwined, this section will discuss integration of the data into the V/ARTT in a separate paragraph at the end, rather than for each data source individually.

2.3.4.1 3D construction model

Many landmarks and public buildings have been modelled in 3D and are freely or commercially available from various online sources. Two popular examples of such sources are 3D Warehouse[6] and Turbosquid[7]. The quality of models obtained from these services is highly variable, however. Moreover, building models often lack the interior.

Some cities provide access to CityGML[8] data. CityGML is an OGC standard for the modelling of urban environments, and has a number of important benefits. First of all, CityGML models typically cover larger areas (i.e. many buildings) within a single data set. Moreover, CityGML supports models with multiple levels of detail (LOD). The highest detail level, if available, also includes building interiors. The main downside to CityGML is that public availability is still very limited.

Many file formats exist for the exchange of 3D models. Popular but dated formats include WaveFront OBJ[9] and 3DS[10]. At present, however, Collada[11] is widely perceived as the industry standard. It integrates with KML[12], allowing for precise geolocation of 3D models. KML was popularized by Google Earth, but has also been adopted as an OGC standard[13].

The glTF format[14] is essentially a JSON encoding of Collada, and is gaining popularity as a web-friendly exchange format for use in browser-based 3D applications. The Khronos Group (the

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[6] https://3dwarehouse.sketchup.com
[7] http://www.turbosquid.com
[8] http://www.citygml.org
[9] https://en.wikipedia.org/wiki/Wavefront_.obj_file
[10] https://en.wikipedia.org/wiki/.3ds
[11] https://www.khronos.org/collada
[12] https://developers.google.com/kml/
[13] http://www.opengeospatial.org/standards/kml
[14] https://www.khronos.org/gltf

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maintainer of both the Collada and glTF specifications) provides open source tools to convert between Collada and glTF[15].

The authoring of 3D models in any of the aforementioned formats can be done using a variety of different tools. Manual authoring of models is commonly done using one of the many free and commercial 3D modelling packages, such as SketchUp[16], Blender[17] or 3DS Max[18].

Larger-scale models such as CityGML are more commonly reconstructed from other data (e.g. LiDAR or aerial photography) using automated processes. 3DCityDB[19] is an open source tool which allows importing of CityGML data in a relational DBMS (Database Management Sytem). This is very valuable when working with large quantities of CityGML, since the raw GML files, by nature, prohibit random access and therefore limit the scalability of any system that consumes them.

2.3.4.2 Elevation model

Digital Elevation Models (DEM) are widely and freely available from various sources. Popular data sets with worldwide coverage include ETOPO[20] and SRTM[21]. Many national or local governments have GIS portal sites, through which they provide access to geospatial data for their region. Such portal sites will often carry DEM data that is more detailed than the aforementioned sources.

Popular file formats for elevation data include USGS DEM, DTED and GeoTIFF. In addition to file-based distribution, elevation data can be served using an OGC Web Coverage Service (WCS)[22].

2.3.4.3 Aerial/satellite imagery

Like elevation data, imagery is widely available from various sources. NASA publishes data from its various satellites missions such as LandSat[23]. Again, government GIS portals will often provide detailed regional data as well.

GeoTIFF, JPEG2000, ECW and many other formats can be used to store imagery. The OGC Web Map Service (WMS)[24], Web Map Tile Service (WMTS)[25] and Web Coverage Service (WCS) can all be used to distribute imagery to multiple clients.

Services such as Bing Maps[26] aggregate imagery from various sources and provide a unified access point.

[15] https://github.com/KhronosGroup/COLLADA2GLTF/
[16] http://www.sketchup.com/
[17] https://www.blender.org/
[18] http://www.autodesk.com/products/3ds-max/overview
[19] http://www.3dcitydb.org
[20] https://www.ngdc.noaa.gov/mgg/global/global.html
[21] http://www2.jpl.nasa.gov/srtm/
[22] http://www.opengeospatial.org/standards/wcs
[23] http://landsat.gsfc.nasa.gov
[24] http://www.opengeospatial.org/standards/wms
[25] http://www.opengeospatial.org/standards/wmts
[26] https://www.microsoft.com/maps/

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2.3.4.4 Airport layout

The aforementioned data sources can all contribute to a faithful 3D reproduction of the airport environment, but they do not provide any semantic information that may be valuable to the controller. A software system can not readily identify buildings described in a Collada 3D model, for instance, nor can it easily distinguish taxiways, runways, or other important airport features in an aerial photograph.

Therefore, a semantically rich model of the airport layout can add great value to the V/ARTT. The system could, for instance, visually highlight runways, taxiways or obstacles, and overlay important information on these features using text labels. In this way, irregular conditions such as runway closures can be clearly presented to the user.

The industry standard exchange format for this type of data is AIXM 5.1[27]. AIXM (short for Aeronautical Information eXchange Model) combines a conceptual model of the aeronautical information domain with a GML[28]-based storage format.

The AIXM conceptual model is organized into 15 main feature packages and supports obstacle modelling, aerodrome mapping, digital NOTAMs, and so on. All features described by AIXM are dynamic features, which use "time slices" to describe the changes of the AIXM feature over time (e.g. a temporary runway closure).

2.3.4.5 Integration

The V/ARTT could integrate the aforementioned auxiliary data sources in different ways, depending on the chosen display technology:

- **Volumetric display:** A 3D terrain model of the airport surroundings can be generated based on elevation data and imagery. Architectural models of structures on or near the airport can be superimposed on this 3D terrain. An airport layout schematic can be "draped" over the terrain surface. All operational data can be presented at the appropriate relative location within this environment model.
- **Spatial display:** The setup is similar, but a 3D model of the control tower is not needed because the observer is inside the tower looking out.
- **Head-mounted VR display:** Again, a similar setup as above is used to reflect reality as accurately as possible.
- **Head-mounted AR display:** In an AR display, elevation data serves only as a reference for the positioning of other objects - it is not visualized directly by itself. For the same reason, imagery is not required at all and 3D architectural models are equally superfluous, unless an application in low visibility conditions is considered.

It should be noted that AR could, in theory, be used in a similar way as a volumetric display, by presenting a full 3D environment rendered at a small scale inside the control room (e.g. on a

[27] http://aixm.aero/
[28] http://www.opengeospatial.org/standards/gml

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tabletop). The more powerful application of AR, however, would be to reduce the controller's head-down time by presenting information out in the physical environment.

Also note that for testing purposes, an AR display could be combined with spatial displays. In this case, the spatial displays are part of a simulated control tower and would mostly present the auxiliary data, whereas the head-mounted AR display would present the operational data.

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3 Selection of Virtual/Augmented Reality tools

The following chapter describes the selection of Virtual/Augmented Reality Tools for the provision of the Air Traffic Control (ATC) service by the airport control tower. The state of the art on existing synthetic vision and augmented reality technologies is described in [4]. Specifically the following technologies are considered (Fig.2):

- Head Mounted Displays
- Spatial Displays
- Hand Held Displays
- Object-Projected Displays
- Volumetric Displays

Fig 2. Augmented Reality Technologies identified for the airport control tower

Maturity level, benefits and drawbacks for each technology identified are summarized in Fig.3.

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	Head Mounted Displays	*Spatial Displays*	*Hand Held Displays*	*Object-Projected Displays*	*Volumetric Displays*
Maturity Level	limited, although successful applications can be found in some fields, such as the military.	fairly high (without considering the need for additional equipment to be worn by the user allowing eye-tracked autostereoscopic displays).	fully mature devices, but are continuously being advanced with new technology.	fairly low, as it is difficult to set up a projection system which can handle at the same time different types of objects and AR contents. Therefore, the risk of having to set up a very customized configuration is very high.	under development: accessible only to academics, corporations, military.
Benefits	Customization of each device: it is a personal device that follows the user around and customized imagery can be shown to each user according to their tasks with a visual efficacy that is irrespective of the position, without impairing the view of other users, so that controllers are not distracted by irrelevant information, improving controllers' situational awareness.	overcome some of the shortcomings that are related to body-attached displays: an improved ergonomics, a theoretically unlimited field of view and a scalable resolution.	tablets and smartphones are relatively inexpensive and many AR applications are already being developed for these platforms, albeit not for the tower control environment.	high level of integration with the viewer's tasks within the working environment.	Allow more than one user to visualize the data at the same time.
Drawbacks	1)negative impact on teamwork, communications and information sharing with other interested colleagues. 2)reduction on peripheral vision. 3) increase of physical workload and a reduction of comfort for controllers due to weight. 4) physically or psychologically cumbersome to wear for extended periods of time. 5) Latency caused by communication between image processor, head movement tracker and display: a computer generated image is lagged behind the changes of background reality.	1) Since these are potentially large displays, to be used by multiple controllers simultaneously, it may be impossible for the application to adapt to the context of a specific user. Thus, there is a risk that too much irrelevant data is shown for some users, decreasing situational awareness. 2) The number of observers that can be supported simultaneously is restricted by the applied optics, which often translates to a single user scenario.	1) User has at least one hand occupied. For a tower controller, this can become an inconvenience and a limiting factor to the use of this type of technology. Also, physical fatigue must be considered. 2) The screen occupies a small part of the viewing space. This can become a problem with maintaining situational awareness.	1) The display area is constrained to the size, shape, and colour of the physical objects' surfaces (for example, no graphics can be displayed beside the objects' surfaces if no projection surface is present) and limited by the capabilities of the projection system. 2) Also, there is no standard procedure for the generation of the AR content.	1) visualization displayed in a fixed location, usually on a desktop or in a ball volume, drawing the controllers attention away from the out-the-window view. 2) require two to three orders of magnitude more CPU and/or GPU power beyond that necessary for 2D imagery of equivalent quality, due at least in part to the sheer amount of data that must be created and sent to the display hardware.

Fig 3. Augmented Reality Technologies identified for the airport control tower

The Augmented Reality Technology is intended to integrate the "out of the window" real images with a 3D digital model (concerning airport layout, precise positioning for both aerial and terrestrial objects and meteorological data), in order to provide controllers with:

1) Unlimited vision (neither by weather or distance),
2) Relevant information to be displayed on a single head-up view, as an alternative to the actual head-down displacement.

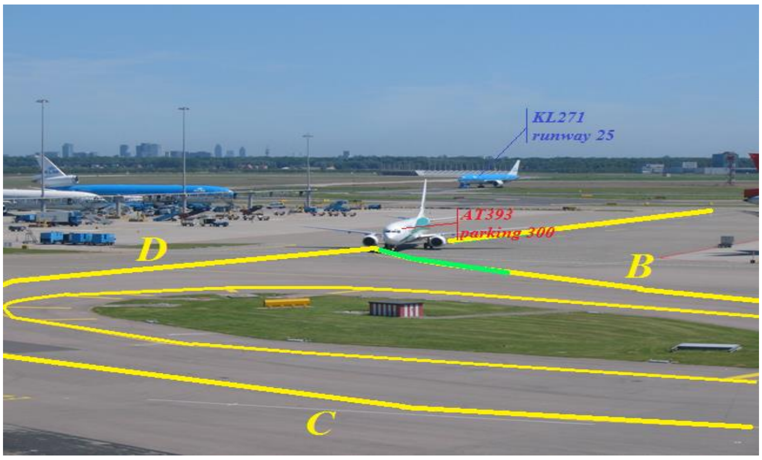

Fig 4. Augmented Reality Technology integrating real images and 3D digital model

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3.1 Methods and Tools

The selection process is based on an integrated approach, that combines Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) methods [5][6].

In particular, the approach considers only a part of the whole QFD process, namely the House of Quality (HOQ) method.

The HOQ model allows one to understand the features that the technology must have (HOWs) in order to meet certain requirements that the ATC stakeholders have established (WHATs) and then provides the importance weightings of the HOWs, which are derived by the importance ratings of stakeholder requirements (WHATs) together with the relationship weightings between stakeholder requirements and technology features. Finally, based on the ranked features, alternative technologies are evaluated and compared with each other (in pairs) using AHP, giving a more consistent and reliable result than the one based on an absolute score assignment.

In this framework the comparisons have been considered on the basis of the current average performance of the five generic classes of technology usable in control tower environment, as well as of predictions on possible improvements of such devices in the near future. This analysis could be subsequently updated, considering further development in technology.

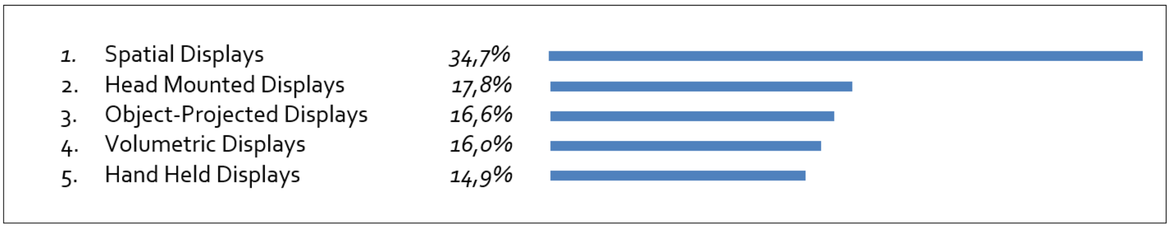

Fig 5. Final ranking of the Augmented Reality Technology

Figure 5 previews the results obtained in terms of final ranking of the Augmented Reality Technologies considered for the RETINA concept.
The methods and tools as well as the procedure adopted are described in the following paragraphs. Specifically, the QFD-AHP Model is reported in sections 3.1.1 and 3.1.2 and the selection process is described in section 3.1.3.

3.1.1 The House of Quality (HOQ) model

The House of Quality model can be summarized as a step by step process depicted in the figure below.

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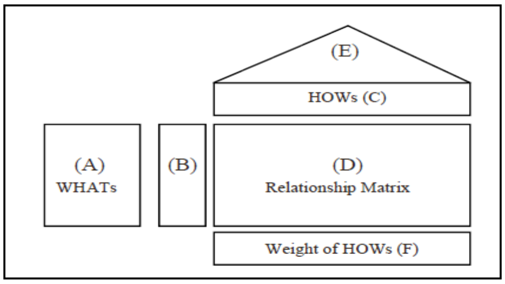

Fig 6. The House of Quality

According to the schema, five steps are considered:

1. Evaluate the WHATs (A), that represent customer needs, i.e. the expected benefits in a product or service in the customer's own words. Then the priorities to WHATs are assigned (B).
2. Identification of HOWs (C), the so called measurable requirements, i.e. the technical specifications the product or service might implement to fulfil benefits in a product or service in the customer's own words.
3. Determination of the relationship matrix (D), judging which HOWs impact which WHATs and to what degree.
4. Elaboration of the correlation matrix (E). The physical relationships among the technical requirements are specified on an array known as ''the roof matrix". The QFD-AHP integrated approach will replace this step, thus point 4 will no longer be considered in this framework.
5. The weights of the HOWs are computed and placed at the base of the quality matrix (F).

3.1.2 The Analytic Hierarchy Process (AHP)

The AHP model is a method for multi-criteria decision-making (MCDM).
Analytic Hierarchy Process (AHP), first developed by Prof. Saaty, derives alternatives ranking from paired comparisons of the alternatives. If the decision making problem is characterized by *n* criteria and *m* alternatives, there will be *n* comparison matrices of size *m* by *m*. In the following example, there are 3 alternatives to evaluate and 4 criteria, so that it should be considered 4 comparison matrices of size 3 by 3, i.e. one comparison matrix for each criteria.

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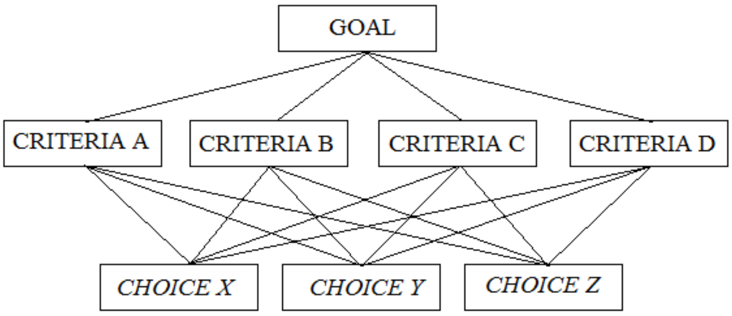

CRITERIA A			
	X	Y	Z
X			
Y			
Z			

CRITERIA B			
	X	Y	Z
X			
Y			
Z			

CRITERIA C			
	X	Y	Z
X			
Y			
Z			

CRITERIA D			
	X	Y	Z
X			
Y			
Z			

Fig 7. The Analytic Hierarchy Process (AHP)

Extremely less important	Very strongly less important	Strongly less important	Moderately less important	Equal important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important
-9	-7	-5	-3	1	3	5	7	9

Intermediate values of importance:

-8	-6	-4	-2	2	4	6	8

Fig 8. Saaty's 9 point scale

To fill the comparison matrix corresponding to each criteria, the decision maker postulates the degree of importance of the row element over the column one, considering the Saaty's 9 point scale to assess the priority of each alternative with respect to the others (Fig.8).

Note that the diagonal elements of the matrix are always 1 and we only need to fill up the upper triangular matrix (or the lower one). In fact, if we state that alternative X is *strongly more important (=5)* than alternative Y, then we need to put in the transposed cell of the matrix the value *-5 (=*alternative Y is *strongly less important* than alternative X.

Once the comparison matrix has been assigned, AHP calculates the *consistency ratio* to reflect the consistency of decision maker's judgments. In mathematical terms, Saaty proved that the judgment is consistent if the largest eigenvalue of the comparison reciprocal matrix (the comparison matrix where the negative values (-a) are replaced by the positive reciprocal ones (1/a)) is equal to the size of comparison matrix:

$$\lambda_{max} = n$$

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Then the measure of consistency, the so called *Consistency Index*, can be derived as deviation of consistency:

$$CI = (\lambda_{max} - n) / (n - 1)$$

The next question is how do we use this index? Again, Saaty proposed that we have to compare it with the appropriate one, the *Random Consistency Index* (RI). He randomly generated reciprocal matrices using scale 1/9 , 1/8,…, 1, …, 8, 9 and get the random consistency index to see if it is about 10% or less. The average random consistency index on a sample of 500 matrices is reported in the following table:

Random Index (source: Saaty 1977)														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Fig 9. Random Consistency Index

Then, he considered the *Consistency Ratio*, the comparison between CI and RI:

$$CR = CI/RI$$

If CR <= 10%, the inconsistency is acceptable. Otherwise, it is necessary to revise the subjective judgment. This way, AHP allows some small inconsistency in judgment because humans are not always consistent.

Once all comparison matrices has been assigned and are consistent, the principal Eigen vector of each comparison reciprocal matrix is considered (the Eigen vector that corresponds to the highest Eigen value) and then normalized (the sum of all elements is made 1), in order to compute the priority vector, i.e. the alternatives rankings for each criteria. Finally, the scores of each alternative are weighted (according to the criteria importance) and added, obtaining the final ranking of the alternatives.

3.1.3 The Integrated QFD-AHP model applied to Control Tower Augmented Reality Technology Selection

According to Rajesha et al. [5] a QFD-AHP Integrated model has been considered to select *Control Tower Augmented Reality Technology*. The QFD model allows the identification of the needs of the intended users (WHAT the technology has to do and HOW the technology might be implemented to fulfil the needs). AHP instead, offers a method based on pairs comparison to compute the weights of WHATs and to rank technologies. The AHP integration makes the HOQ more acceptable than an ordinary “guideline" when it deals with the problem of choosing priorities of the alternatives (i.e. the problem of selecting the best suitable *Control Tower Augmented Reality Technologies*), as it appears

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more consistent and reliable to make pairs comparison than make an absolute score assignment. The integrated model is represented below.

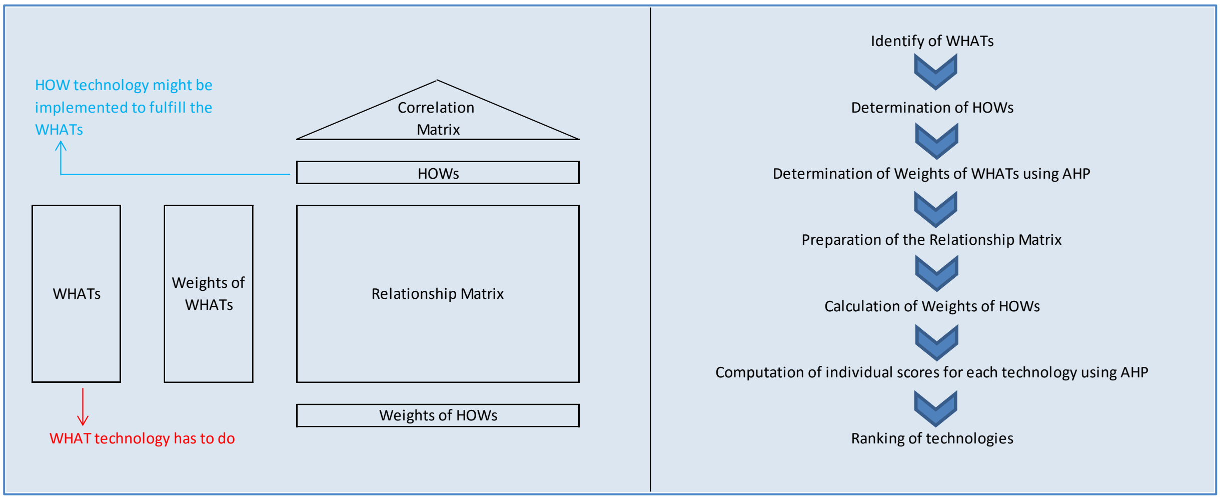

Fig 10. The Integrated QFD-AHP model

3.1.3.1 Requirements

WHATs are largely independent of any particular technology we might develop: a team should be able to identify customer needs without knowing how those needs will be addressed.
From a questionnaire survey to ATCOs, the following requirements have been identified:

Requirements	Meanings
Precision	The augmented reality overlay should be seen where expected
Reactivity	No delay of the augmented reality overlay with respect to the real world
Clear vision	The augmented reality overlay should be clearly visible in every working condition
Comfortable (physical comfort)	Wearable with low intrusiveness and weight
Flexible	Any change to the airport layout and procedures should be easily implemented
Scalable	The system ca be easily improved and grown large
Customizable	The system can be easily adapted to any controller's ergonomics needs
Easy to setup at each use	Setup time and effort at each use should be as little as possible
Close to current working practice (i.e. intuitive)	No need for extensive training
No cluttering	The interface should avoid high information density
No overlapping images for controllers performing different tasks	Augmented reality overlays should be filtered by person

Fig 11. The WHATs

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3.1.3.2 Determination of HOWs

The Technical Measures (HOWs) to fulfil the requirements (WHATs), as represented in Fig. 12:

Technical measures	Meanings
Resolution	The ability of an imaging system to resolve detail in the object that is being imaged
FOV	Field of view
FOV aspect ratio	Ratio between vertical FOV and horizontal one
Display transmissivity	Display opacity. If transmissivity increases, opacity decreases.
Brightness, contrast and light compensation	Compensation for tower lighting conditions. They could change from window to window
Perfomance in depth cue provision	monocular, binocular, biocular
Latency	Virtual image delay with respect to real image (including refresh rate, tracking system latency, pixel latency). Very strict hard real-time constraint in digital image processing is mandatory!
Wearability	Intrusiveness
Weight	Weight
Layout adaptability	adaptability to airport layout changes
Overlay separation	The system is able to provide separated overlays for different users (each user has its own overlays)
Configuration time	configuration time at the beginning of each task

Fig 12. The HOWs

3.1.3.3 Determination of Weights of WHATs using AHP

Based on the assumption that weight determination is more reliable when using pairwise comparisons than obtaining them by an absolute assignment, the comparison matrix of requirements has been filled in by means of a survey performed on ten ATCOs[29] to assess the priority of each *requirement* with respect to the others. The assessment is based on Saaty's nine point scale and the degree of importance of the requirement is derived.

The survey has been conducted by the online questionnaire available on the RETINA Project website.

[29]The subjects involved in the survey are volunteers and the survey was conducted anonymously.

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WHATs Comparison Matrix	Precision	Reactivity	Clear Vision	Comfortable (physical comfort)	Flexible	Scalable	Customizable	Easy to setup at each use	Close to current working practice (i.e. intuitive)	No cluttering	No overlapping images for controllers performing different tasks
Precision		1	1	5	9	9	7	5	8	7	7
Reactivity			1	5	9	9	7	5	8	7	7
Clear Vision				5	9	9	7	5	8	7	7
Comfortable (physical comfort)					5	5	3	3	5	5	5
Flexible						1	-3	-5	-3	-3	-3
Scalable							-3	-5	-3	-3	-3
Customizable								-3	-3	-2	-2
Easy to setup at each use									5	3	3
Close to current working practice (i.e. intuitive)										-3	-3
No cluttering											1
No overlapping images for controllers performing different tasks	Incon: 0.07%										

Legenda:

Extremely less important	Very strongly less important	Strongly less important	Moderately less important	Equal important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important
-9	-7	-5	-3	1	3	5	7	9

Intermediate values of importance:

-8	-6	-4	-2	2	4	6	8

WHATs Relative Weights sorted by priority:

Precision	21,95%
Reactivity	21,95%
Clear Vision	21,95%
Comfortable (physical comfort)	9,57%
Easy to setup at each use	7,23%
No cluttering	3,97%
No overlapping images for controllers performing different tasks	3,97%
Close to current working practice (i.e. intuitive)	3,24%
Customizable	2,93%
Flexible	1,62%
Scalable	1,62%
Sum	100%

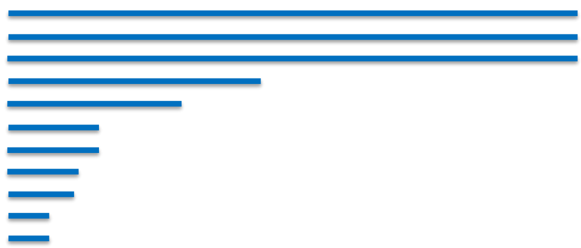

Fig 13. Weights of WHATs using AHP

The obtained relative weights are characterized by an high consistency of decision makers' judgments, as the *consistency ratio* (6,70%) is well within the acceptable limit of 10%. Results highlight that *precision*, *reactivity* and *clear vision* are the most important *WHATs* evaluated with the same score (≈ 22%) and followed by *physical comfort* and *set up complexity at each use* requirements, cut by 50% and 60% with respect to the first ones. The other six requirements have very low weights (from 1% to 4%) and together represent less than 20% of the total weight (100%), showing that ATCO stakeholders have not attributed much importance to them.

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3.1.3.4 The relationship matrix and calculation of Weights of HOWs

The impact of each ''HOW'' on each ''WHAT'' has been assessed in a focus group, recording it by means of linguistic variables, namely High, Medium and Low. Then the numerical values of 9, 3 and 1 have been assigned to High, Medium and Low impact, respectively. The unbalanced gap between 9 and 3 (with respect to 3 and 1) is to assign more importance to the best impacts. Finally, each literal value of the relationship matrix has been replaced by the product (see last matrix below):

$$weight \ \ x \ \ numerical\ value\ of\ the\ impact$$

The resulting matrices are showed below:

	HOWs											
	Resolution	FOV	FOV aspect ratio	Display transmissivity	Brightness, contrast and light compensation	Perfomance in depth cue provision	Latency	Wearability	Weight	Layout adaptability	Overlay Separation	Configuration time
Precision	H	L	L	L	L	H	H	L	L	L	L	L
Reactivity	M	M	M	L	L	M	H	H	H	L	L	L
Clear vision	H	H	M	H	H	H	L	L	L	L	H	L
Comfortable (physical comfort)	L	L	L	L	L	L	L	H	H	L	L	L
Flexible	L	L	L	L	L	L	L	L	L	H	H	H
Scalable	L	L	L	L	L	H	M	M	M	H	H	M
Customizable	L	M	L	L	L	L	L	M	M	M	H	H
Easy to setup at each use	L	L	L	L	L	L	L	H	H	M	L	H
Close to current working practice (i.e. intuitive)	M	H	H	M	M	H	M	H	M	H	H	L
No cluttering	M	H	L	L	M	H	L	L	L	M	H	L
No overlapping images for controllers performing different tasks	L	H	M	L	L	M	L	L	L	L	H	L

How does an high resolution impact precision? → Strong influence

How does a low weight impact clear vision? → No influence

		HOWs												
WHATs	WEIGHTS	Resolution	FOV	FOV aspect ratio	Display transmissivity	Brightness, contrast and light compensation	Perfomance in depth cue provision	Latency	Wearability	Weight	Layout adaptability	Overlay Separation	Configuration time	SUM
Precision	0,18	1,66	0,18	0,18	0,18	0,18	1,66	1,66	0,18	0,18	0,18	0,18	0,18	6,62
Reactivity	0,17	0,50	0,50	0,50	0,17	0,17	0,50	1,50	1,50	1,50	0,17	0,17	0,17	7,32
Clear vision	0,18	1,58	1,58	0,53	1,58	1,58	1,58	0,18	0,18	0,18	0,18	1,58	0,18	10,87
Comfortable (physical comfort)	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,83	0,83	0,09	0,09	0,09	2,58
Flexible	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,25	0,25	0,25	1,02
Scalable	0,03	0,03	0,03	0,03	0,03	0,03	0,27	0,09	0,09	0,09	0,27	0,27	0,09	1,31
Customizable	0,05	0,05	0,15	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,45	0,45	1,78
Easy to setup at each use	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,61	0,61	0,20	0,07	0,61	2,56
Close to current working practice (i.e. intuitive)	0,06	0,17	0,50	0,50	0,17	0,17	0,50	0,17	0,50	0,17	0,50	0,50	0,06	3,87
No cluttering	0,07	0,20	0,60	0,07	0,07	0,20	0,60	0,07	0,07	0,07	0,20	0,60	0,07	2,80
No overlapping images for controllers performing different tasks	0,09	0,09	0,77	0,26	0,09	0,09	0,26	0,09	0,09	0,09	0,09	0,77	0,09	2,73
SUM	1,00	4,45	4,49	2,30	2,51	2,65	5,59	3,97	4,21	3,88	2,27	4,92	2,22	43,46
RELATIVE WEIGHTS		10%	10%	5%	6%	6%	13%	9%	10%	9%	5%	11%	5%	100%

Ratio of *Resolution values sum* (4,45) to *total values sum* (43,46)

Fig 14. The relationship matrix and calculation of Weights of HOWs

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The relative weights of each HOW are summarized as follows:

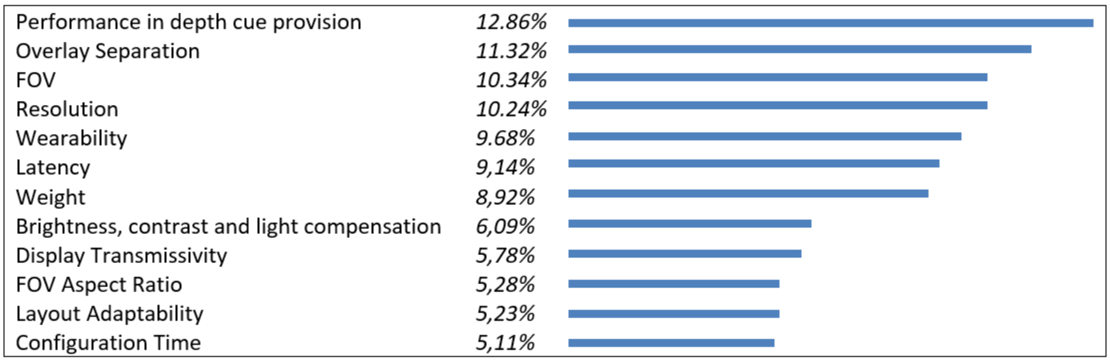

Fig 15. The relative weights of each HOW

Scores reveal a ranking divided in three main areas:

1. *stereoscopic* capabilities and *overlay separation* are the major criteria;
2. then the ranking highlights *FOV, resolution, wearability, latency and weight*, very close to each other, as the difference between the higher (*FOV*) and the lower (*weight*) is less than 1,5%.
3. finally, the less important criteria are *Brightness, contrast and light compensation, display transmissivity, FOV aspect ratio, layout adaptability* and *configuration time*, which are very far from the ranking middle area (point 2).

3.2 Results

As the final step of the process, the five technologies have been compared with respect to every single HOW using the AHP model and considering the aforementioned 9-point scale (see figure below). The comparisons have been focused on the current average performance of the five generic classes of technology usable in a control tower environment and on predictions on possible improvements of such devices in the near future. This analysis, mainly based on the RETINA Project Deliverable D1.1 Chapter 3 and on its references [1], could be subsequently updated, considering further development in technology.

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Resolution	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-7	-4	-5	5
Spatial Displays			3	6	9
Hend Held Displays				2	8
Object-Projected Displays					6
Volumetric Displays	Incon: 0.10				
FOV	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-7	3	-5	5
Spatial Displays			9	5	9
Hend Held Displays				-5	2
Object-Projected Displays					5
Volumetric Displays	Incon: 0.10				
FOV Aspect Ratio	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-7	3	6	7
Spatial Displays			7	9	9
Hend Held Displays				4	4
Object-Projected Displays					2
Volumetric Displays	Incon: 0.10				
Display Transmissivity	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-5	3	-6	-7
Spatial Displays			8	-2	-3
Hend Held Displays				-7	-8
Object-Projected Displays					-2
Volumetric Displays	Incon: 0.05				
Brightness, contrast and light compensation	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-7	-3	4	3
Spatial Displays			5	6	7
Hend Held Displays				2	3
Object-Projected Displays					2
Volumetric Displays	Incon: 0.10				
Performances in depth cue provision	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-3	5	5	6
Spatial Displays			7	7	9
Hend Held Displays				1	2
Object-Projected Displays					2
Volumetric Displays	Incon: 0.02				
Latency	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		1	1	4	3
Spatial Displays			1	4	3
Hend Held Displays				4	3
Object-Projected Displays					-2
Volumetric Displays	Incon: 0.00				
Wearability	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-9	-2	-9	-9
Spatial Displays			7	1	1
Hend Held Displays				-7	-7
Object-Projected Displays					1
Volumetric Displays	Incon: 0.01				
Weight	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-9	1	-9	-9
Spatial Displays			7	1	1
Hend Held Displays				-7	-7
Object-Projected Displays					1
Volumetric Displays	Incon: 0.00				
Layout Adaptability	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		4	1	8	5
Spatial Displays			-4	4	2
Hend Held Displays				8	5
Object-Projected Displays					-3
Volumetric Displays	Incon: 0.02				
Overlay Separation	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		7	3	9	5
Spatial Displays			-3	3	-2
Hend Held Displays				7	3
Object-Projected Displays					-4
Volumetric Displays	Incon: 0.03				
Configuration Time	Head Mounted Displays	Spatial Displays	Hend Held Displays	Object-Projected Displays	Volumetric Displays
Head Mounted Displays		-3	-2	-3	-3
Spatial Displays			2	1	1
Hend Held Displays				1	1
Object-Projected Displays					1
Volumetric Displays	Incon: 0.01				

Fig 16. Technologies comparison matrices for each HOW using AHP model

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With respect to *stereoscopic* capabilities, spatial displays perform better than any other candidate.
HMDs have been evaluated strongly more efficient than hand-held and object-projected displays, as Tablet PCs, PDAs (personal digital assistant), smartphones and video-projectors are characterized by a very rare capability to display images in 3D. On the other hand, spatial displays have been considered slightly better than HMDs, since the first ones are generally characterized by a longer working distance, so that they suffer from vergence-accommodation conflict less than HMDs.
Volumetric displays have been evaluated as the least efficient technology since in those systems the visualization is displayed in a fixed location, usually on a desktop or in a ball like volume, drawing the controllers attention away from the out-the-window view. This way, volumetric displays have been considered extremely less efficient than spatial ones.
The other comparison values considered in the *performance in depth cue provision* matrix have been derived with consistency according to the assumptions just mentioned.

According to the *overlay separation*, HMDs strongly beat their competitors.
In fact, their very powerful benefit is represented by the customization of each device: it is a personal device that follows the user around and customized imagery can be shown to each user according to their tasks with a visual efficacy that is irrespective of the position. It also does not impair the view of other users, so that controllers are not distracted by irrelevant information, improving controllers' situational awareness.
Hand held displays show a very similar behaviour by pointing the device towards the interest area of the task, but they have been evaluated moderately less efficient as they are less immersive than HMDs.
Volumetric and spatial displays have been evaluated as strongly and very strongly less efficient than HMDs respectively, since volumetric and spatial technologies are generally large displays (especially spatial ones), to be used by multiple controllers simultaneously, so that it may be impossible to adapt them to the context of a specific user.
Finally, object-projected technology adds many more variables to the *overlay separation* problem: the display area is constrained to the size, shape and colour of the physical objects' surfaces. This characteristic makes them extremely less efficient than HMD technology.
It is significant to highlight that the efficiency of the *overlay separation* decreases when the distance between eyes and display area increases.

In contrast, HMDs are affected by the *FOV* limitations, as no existing HMD achieves the wide FOV of the human visual system, which is about 150°-160° in the horizontal direction and about 110°-120° in the vertical direction for the single eye. Although very strongly and strongly less efficient then spatial displays (characterized by a theoretically unlimited FOV) and object-projected ones (where display area is limited by the capabilities of the projection system) respectively, HMDs have been evaluated as better performing than hand held and volumetric displays (the screen occupies small part of the viewing space).

The *resolution matrix* shows spatial displays as the best technology, followed by hand held displays (50 – 100 pixels/°), object-projected ones and HMDs (these last typically offer 10 to 20 pixels/°, though advances in micro-displays may help increase this number). The worst technology in this field is volumetric displays, where the creation of a device that can display photorealistic 3D content at high resolution may be considered a holy grail problem.

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The *wearability* and *weight* matrices are self-explanatory, since only HMDs and hand held displays are penalized (at the same level in *weight* and HMDs mostly than HHDs in *wearability*, as the first ones may be physically and psychologically cumbersome to wear for extended periods of time).

From the *latency* point of view, object-projected and volumetric displays have been penalized with respect to the others.
The reason of this choice lies in the fact that, the latency being equal for all 5 technologies, object-projected and volumetric displays requires much more powerful hardware since:

- Object-projected displays can be thought of as a very wide system made of many projectors disseminated on the airport ground, it is necessary to send information very far from a central processing unit, causing delays due to the distance.
- Volumetric displays requires a huge amount of bandwidth, as they would need to send about three orders of magnitude more information/second to the display hardware to sustain the image. Furthermore, a 3D volumetric display would require two to three orders of magnitude more CPU (Central Processing Unit) and/or GPU (Graphic Processing Unit) power beyond that necessary for 2D imagery of equivalent quality, due at least in part to the sheer amount of data that must be created and sent to the display hardware.

Although current HMDs typically suffer from info delays in communication between image processor, head movement tracker and display (computer generated image is lagged behind the changes of background reality), it is expected that advances in software and hardware solutions may help to overcome this problem in the near future. This way, HMDs have been evaluated at the same level of efficiency as spatial and hand held displays.

Finally, moving to the less important criteria, *Brightness, contrast and light compensation* HOW is guided by spatial displays, followed by hand held displays and HMDs, as their luminance and contrast capabilities are, in general, compatible with the ambient backgrounds brightness that could be found in a control tower.

On the basis of a review of technologies specifications, it results that *Display transmissivity* and *FOV aspect ratio* criteria are led by volumetric and spatial displays respectively.

With regard to *layout adaptability*, it is simpler to update HMDs and HHDs, as it is sufficient to modify software behaviour. Moreover, the high level of integration capabilities of such technologies (many AR applications are already being developed for their platforms with the aim to make them usable in different environments) makes them very powerful and unrivalled tools in this area.

Instead, object-projected displays show the worst *layout adaptability,* as they require more complex modifications in case of airport configuration changings, since it is necessary to implement hardware extensions, adding projectors and their connections in the worst case.
Spatial and volumetric displays lies in the middle of the ranking with a slight preference for the former, as they are more mature devices.

Finally, in relation to *configuration time* at the beginning of each task, HMDs are classified at the bottom of the ranking, since in most cases they may need to be customized and calibrated on each

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user. Moreover, controllers generally require a reasonable start-up time to approach the immersive reality characterizing such devices.

3.2.1 Final Ranking of Technologies

The scores gained by technologies in each HOW matrix above have been multiplied by the relative weight of each HOW and added, deriving the following final ranking of technologies:

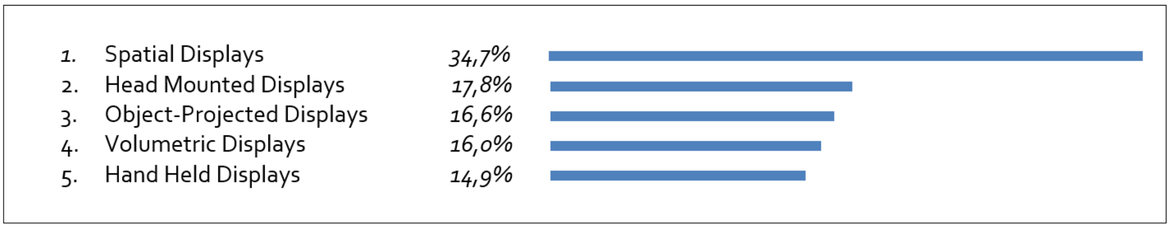

Fig 17. Final ranking of the Augmented Reality Technology

The Integrated QFD-AHP model has evaluated the spatial displays as the preferred technology solution, since they have been considered more efficient than competitors in almost every HOW examined in the analysis, especially in the most weighted ones, as illustrated in the following graph, which shows a graphical analysis of the above obtained results, reporting technology scores (y-axis) for each HOW (x-axis) represented over the abscissa by a white rectangle with height directly proportional to the corresponding HOW's weight (degree of importance).

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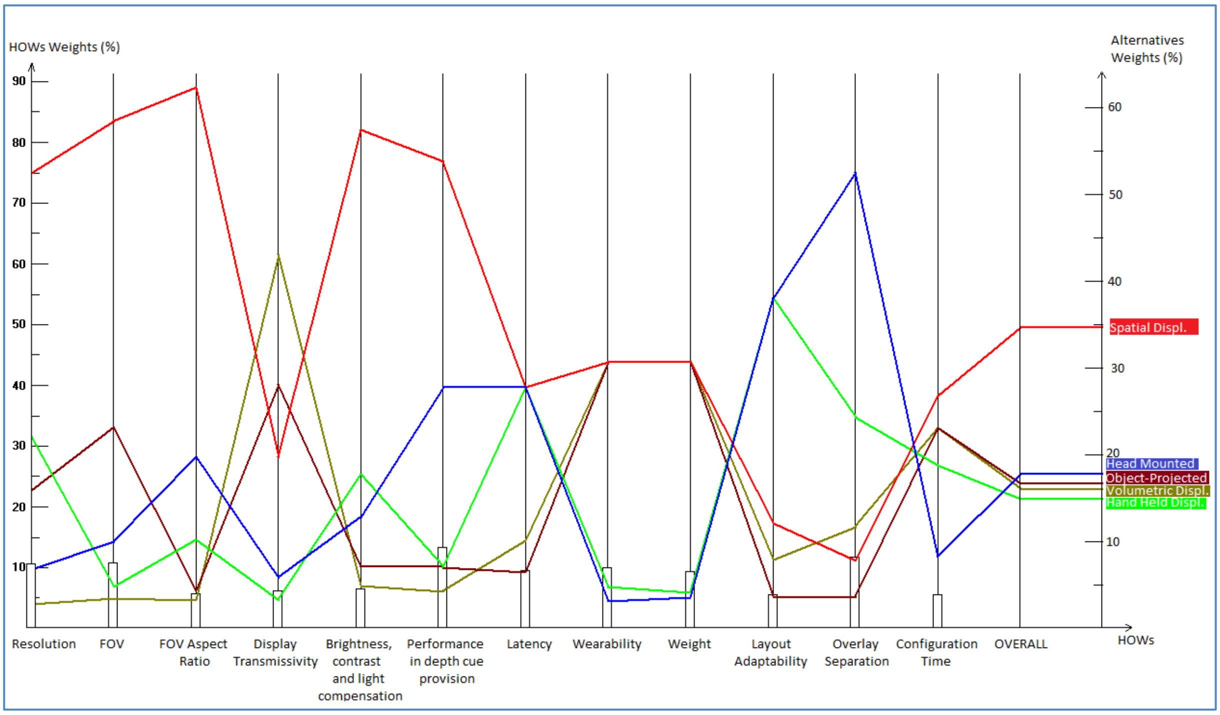

Fig 18. Technology scores for each HOW

3.3 Conclusion

The target of the analysis reported above is to select the more efficient Augmented Reality Technologies integrating the "out of the window" real images with a 3D digital model (concerning airport layout, precise positioning for both aerial and terrestrial objects and meteorological data).

The selection process has been based on an integrated approach combining the House of Quality (HOQ) method and the Analytic Hierarchy Process (AHP), in order to make the HOQ technique more consistent and reliable to decision makers. This way, HOQ has allowed us to hear the “voice” of ATCOs stakeholders (WHAT technology has to do and HOW technology might be implemented to fulfil the WHATs), while AHP has offered a method based on pairs comparison to compute the priorities of WHATs and the level at which each technology fits the HOWs.

The output of the integrated model has generated the following technology ranking: Spatial Displays, Head Mounted Displays, Object-Projected Displays, Volumetric Displays and Hand Held Displays. Spatial displays strongly beat the competitors, as other technologies have obtained about half score or less than spatial one and their results are very close.

It should be noted that the selection process has been based on current average performance of the five generic class of technology usable in control tower environment, as well as on predictions on possible improvements of such devices in the near future.

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4 Virtual/Augmented Reality Overlays and Control Tower Procedures

4.1 Ecological Interface Design

4.1.1 Introduction

Ecological Interface Design is a theoretical framework for designing human-machine interfaces in complex, real-time and dynamic environments. EID differs from User-Centred Design (UCD) insofar it focuses on the work domain rather than on the end user requests, “ecological” is referred to an interface that has been designed to reflect the constraints of the work environment in a way that is perceptually available to the people who use it. Simply put, the users are able to take effective actions with the interface, understanding how those actions will move them towards their interface.

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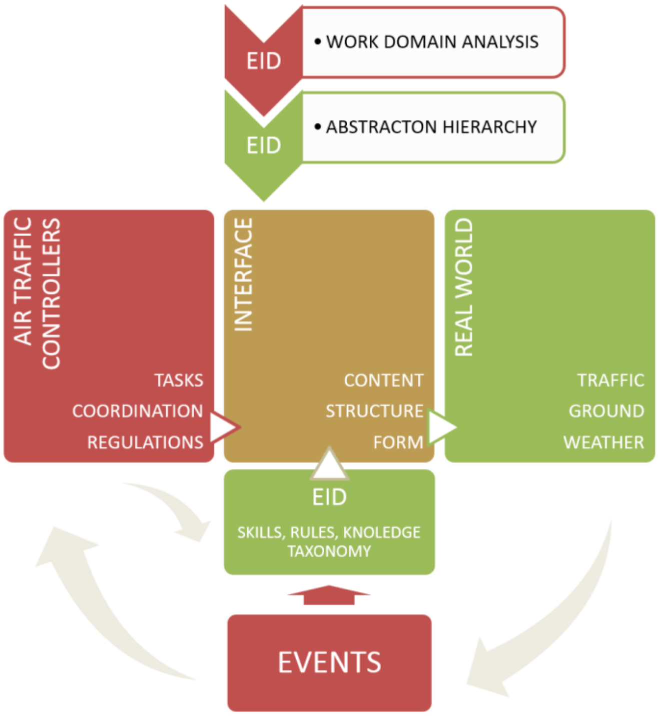

Fig 19. EID framework

The goal of EID is to make constraints and complex relationships in the work environment perceptually evident (e.g. visible, audible) to the user. This allows more of users' cognitive resources to be devoted to higher cognitive processes such as problem solving and decision making. EID is based on three key concepts from cognitive engineering research:

- the Work Domain Analysis,
- the Abstraction Hierarchy (AH) and
- the Skills, Rules, Knowledge (SRK) framework.

By reducing mental workload and supporting knowledge-based reasoning, EID aims to improve user performance and overall system reliability for both anticipated and unanticipated events in a complex system.

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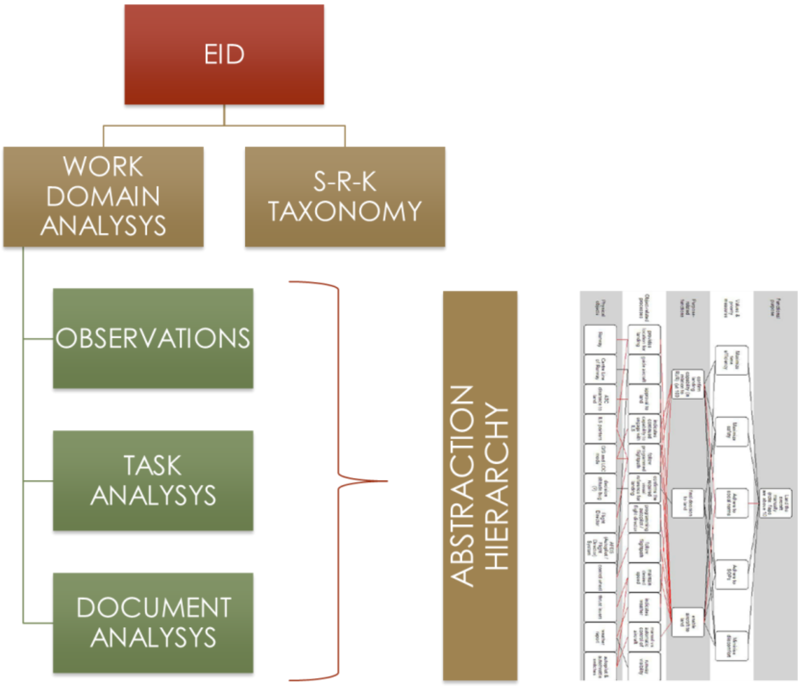

Fig 20. EID structure

4.1.2 The Abstraction Hierarchy

The Abstraction Hierarchy (AH) is a 5-level functional decomposition used for modelling the work environment, or more commonly referred to as the work domain, for complex sociotechnical systems [12] . In the EID framework, the AH is used to determine what kinds of information should be displayed on the system interface and how the information should be arranged. The AH describes a system at different levels of abstraction using how and why relationships. Moving down the model levels answers how certain elements in the system are achieved, whereas moving up reveals why certain elements exist. Elements at highest level of the model define the purposes and goals of the system. Elements at the lowest levels of the model indicate and describe the physical components (i.e. equipment) of the system. The how and why relationships are shown on the AH as means-ends links. An AH is typically developed following a systematic approach known as a Work Domain Analysis [13]. It is not uncommon for a Work Domain Analysis to yield multiple AH models; each examining the system at a different level of physical detail defined using another model called the Part-Whole Hierarchy [14].

Each level in the AH is a complete but unique description of the work domain.

4.1.2.1 Functional Purpose

The Functional Purpose (FP) level describes the goals and purposes of the system. An AH typically includes more than one system goal such that the goals conflict or complement each other [14]. The relationships between the goals indicate potential trade-offs and constraints within the work domain

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of the system. For example, the goals of a refrigerator might be to cool food to a certain temperature while using a minimal amount of electricity.

4.1.2.2 Abstract Function

The Abstract Function (AF) level describes the underlying laws and principles that govern the goals of the system. These may be empirical laws in a physical system, judicial laws in a social system, or even economic principles in a commercial system. In general, the laws and principles focus on things that need to be conserved or that flow through the system such as mass [14]. The operation of the refrigerator (as a heat pump) is governed by the second law of thermodynamics.

4.1.2.3 Generalised Function

The Generalised Function (GF) level explains the processes involved in the laws and principles found at the AF level, i.e. how each abstract function is achieved. Causal relationships exist between the elements found at the GF level. The refrigeration cycle in a refrigerator involves pumping heat from an area of low temperature (source) into an area of higher temperature (sink).

4.1.2.4 Physical Function

The Physical Function (PFn) level reveals the physical components or equipment associated with the processes identified at the GF level. The capabilities and limitations of the components such as maximum capacity are also usually noted in the AH [14]. A refrigerator may consist of heat exchange pipes and a gas compressor that can exert a certain maximum pressure on the cooling medium.

4.1.2.5 Physical Form

The Physical Form (PFo) level describes the condition, location, and physical appearance of the components shown at the PFn level. In the refrigerator example, the heat exchange pipes and the gas compressor are arranged in a specific manner, basically illustrating the location of the components. Physical characteristics may include things as colour, dimensions, and shape.

4.1.3 The Skill, Rule And Knowledge Based Taxonomy

The Skills, Rules, Knowledge (SRK) framework or SRK taxonomy defines three types of behaviour or psychological processes present in operator information processing [13]. The SRK framework was developed by Rasmussen [15] to help designers combine information requirements for a system and aspects of human cognition. In EID, the SRK framework is used to determine how information should be displayed to take advantage of human perception and psychomotor abilities [16]. By supporting skill- and rule-based behaviours in familiar tasks, more cognitive resources may be devoted to knowledge-based behaviours, which are important for managing unanticipated events. The three categories essentially describe the possible ways in which information, for example, from a human-machine interface is extracted and understood:

4.1.3.1 Skill-based level

A skill-based behaviour represents a type of behaviour that requires very little or no conscious control to perform or execute an action once an intention is formed; also known as a sensorimotor

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behaviour. Performance is smooth, automated, and consists of highly integrated patterns of behaviour in most skill-based control [17]. For example, bicycle riding is considered a skill-based behaviour in which very little attention is required for control once the skill is acquired. This automaticity allows operators to free up cognitive resources, which can then be used for higher cognitive functions like problem solving [18].

4.1.3.2 Rule-based level

A rule-based behaviour is characterised by the use of rules and procedures to select a course of action in a familiar work situation [17]. The rules can be a set of instructions acquired by the operator through experience or given by supervisors and former operators.

Operators are not required to know the underlying principles of a system, to perform a rule-based control.

4.1.3.3 Knowledge-based level

A knowledge-based behaviour represents a more advanced level of reasoning [19]. This type of control must be employed when the situation is novel and unexpected. Operators are required to know the fundamental principles and laws by which the system is governed. Since operators need to form explicit goals based on their current analysis of the system, cognitive workload is typically greater than when using skill- or rule-based behaviours.

4.1.3.4 Skill-Based Behaviour

At the skill-based level, the behaviour is regulated by the lowest level of conscious involvement and is characterized by highly routinized and automated activities. In fact, skill-based mode refers to "the smooth execution of highly practiced, largely physical actions in which there is virtually no conscious monitoring".

- High Automated processes involving long term memory (procedural)
- Low Executive control (i.e. low attention and working memory)
- No Decision-making (resolution of conflicts and error detection)
- No Problem solving

4.1.3.5 Rule-Based Behaviour

Rule-based behaviour is also activated in familiar work situations, but it is distinguished from skill-based behaviour, as "it requires some degrees of conscious involvement and attention. Situation assessment leads to recognition of which procedures apply to particular familiar situations".

- Less automated processes and long term memory (procedural) than Skill level
- More executive control (i.e. more attention and working memory) than Skill level
- No Decision-making (resolution of conflicts and error detection)
- No Problem solving

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4.1.3.6 Knowledge-Based Behaviour

When faced with unfamiliar situations, where no solutions are already available, it is necessary to move to the knowledge-based level of behaviour. At this level, the User "carries out a task in an almost completely conscious manner. This would occur in a situation where a beginner is performing the task (e.g. a trainee at the beginning of its training) or where an expert is facing with a completely novel situation. In either such cases, the User would have to exert considerable mental effort to assess the situation, and his or her responses are likely to be slow. Also, after each control action, the User would need to review its effect before taking further action, which would probably further slow-down the responses to the situation”.

- No automated processes and long term (procedural) memory
- Executive control (high attention and working memory)
- Decision-making (resolution of conflicts and error detection)
- Problem solving

4.1.4 The use of Constraints

EID is also about exposing “constraints” in order to facilitate the operator job and move complex cognitive behaviours toward simpler cognitive behaviours (K –> R –> S)

4.1.5 EID application in RETINA domain project

4.1.5.1 Assumption

Using the S-R-K taxonomy we should:

- Expose/move relevant information onto the outside of the window view
- Make constraints visually perceivable
- Increase controllers’ situation awareness

This should result in:

- Fewer limitations, therefore:
    - Increased capacity
    - Increased efficiency
- Increased safety

4.1.5.2 RETINA EID – Workflow

The S-R-K taxonomy applied to the control tower tasks should provide different results according to the current working condition (visibility, traffic), tower equipment (SMR, A-SMGCS, PSR/SSR) and procedures.

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Fig 21. S-R-K to Control Tower Task

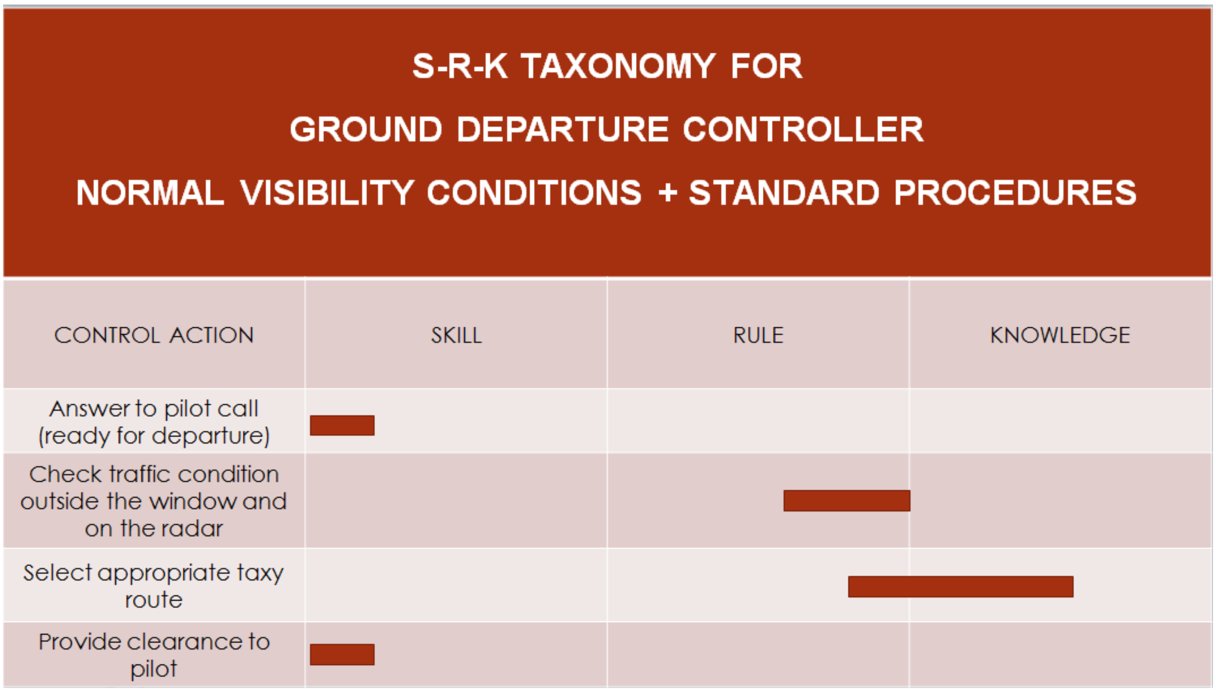

Fig 22. Example of S-R-K taxonomy

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The workflow for SRK taxonomy applied to RETINA is described below.

- Identify Case Studies

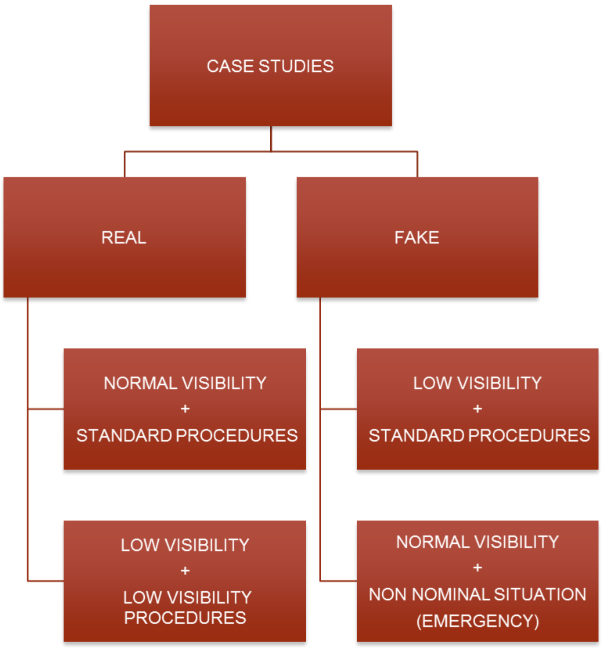

Fig 23. Case studies criteria

- Perform S-R-K Taxonomy for each selected case study.
- Identify shifts in cognitive behaviour.
- "Improve" cognitive behaviour by exposing constraints, moving information
- Design overlays
- Remove limitations.

4.2 Operational Context

4.2.1 Operational Context Analysis

In order to be eligible for the implementation phase, an airport shall meet some basic requirements useful for a first applications of V/ARTT. These requirements are related to the equipment, to the airport layout, to the traffic and to the ATC procedures.

In order to provide V/ARTT with the position and identification of aircraft on the manoeuvring area and in the Aerodrome Traffic Zone, the airport shall be equipped by Primary and Secondary Surveillance RADAR (PSR/SSR) and by Surface Movement RADAR (SMR). PSR/SSR provide position and identification of aircraft in the Aerodrome Traffic Zone, i.e. a specific traffic volume around the airport that includes final segments of instrumental procedures and visual circuit patter. The SMR

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provides the position of all the traffic (aircraft and vehicles) in the manoeuvring area that includes runway and taxiway.

Airports with moderate complexity in term of layout have some strong benefits for a first implementation of V/ARTT. First of all the manoeuvring area is easy to model and the restrictions of the Low Visibility Procedures prove more effective. Moreover, as a first implementation step, an overly large manoeuvring area could be confusing and dispersive.

The airport shall be able to support low visibility conditions and ATC Low Visibility Procedure shall be implemented. This is very important in order to show the benefits provided by the V/ARTT when the visibility conditions are critical. CAT II/III approach and LVTO (Low Visibility Take Off Operations) shall be available; in terms of equipment, this means that the airport shall be ILS CAT 3B equipped.

Finally, it is important that specific procedures for the apron management are available and implemented. Typically, such procedures are based on slots and times displayed on video and often implicate ATCO head down operations. The integration of such information in the V/ARTT has several benefits.

Resuming, in order to be eligible for the implementation phase, an airport shall have at least the following features:

- Primary Surveillance RADAR and Secondary Surveillance RADAR (PSR/SSR) equipped;
- Surface Movement RADAR (SMR) equipped;
- Low Visibility Procedures able to manage more than one aircraft at the same time implemented;
- ILS CAT 3B equipped;
- Moderate complexity (one runway, several taxiway, more than one apron)
- Moderate traffic: volume of 200/300 movement per day;
- Apron Management Procedures available;

Guglielmo Marconi International Airport in Bologna (LIPE) has been chosen as a reference scenario for the implementation phase. Bologna Airport meets all the requirements mentioned above. Moreover, the Control Tower is quite large in order to easily host future real time experiments.

4.2.1.1 Aerodrome Layout

Bologna is a single Runway (12 and 30) airport with a main taxiway T and several taxiway and aircraft stand taxilanes. The runway has a 12/30 orientation with an asphalt strip of 2803x45 m. In the table below the declared distances are reported for both runways.

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13 DISTANZE DICHIARATE		DECLARED DISTANCES		
Designazione RWY RWY designator	TORA (M)	TODA (M)	ASDA (M)	LDA (M)
1	2	3	4	5
12 INT TAKE-OFF B INT TAKE-OFF C INT TAKE-OFF D	2803 2400 2100 1900	2923 2520 2220 2020	2803 2400 2100 1900	2493 - - -
30 INT TAKE-OFF J INT TAKE-OFF H	2803 2630 2395	2863 2690 2455	2803 2630 2395	2442 - -

Table 2. Declared distances for both runways

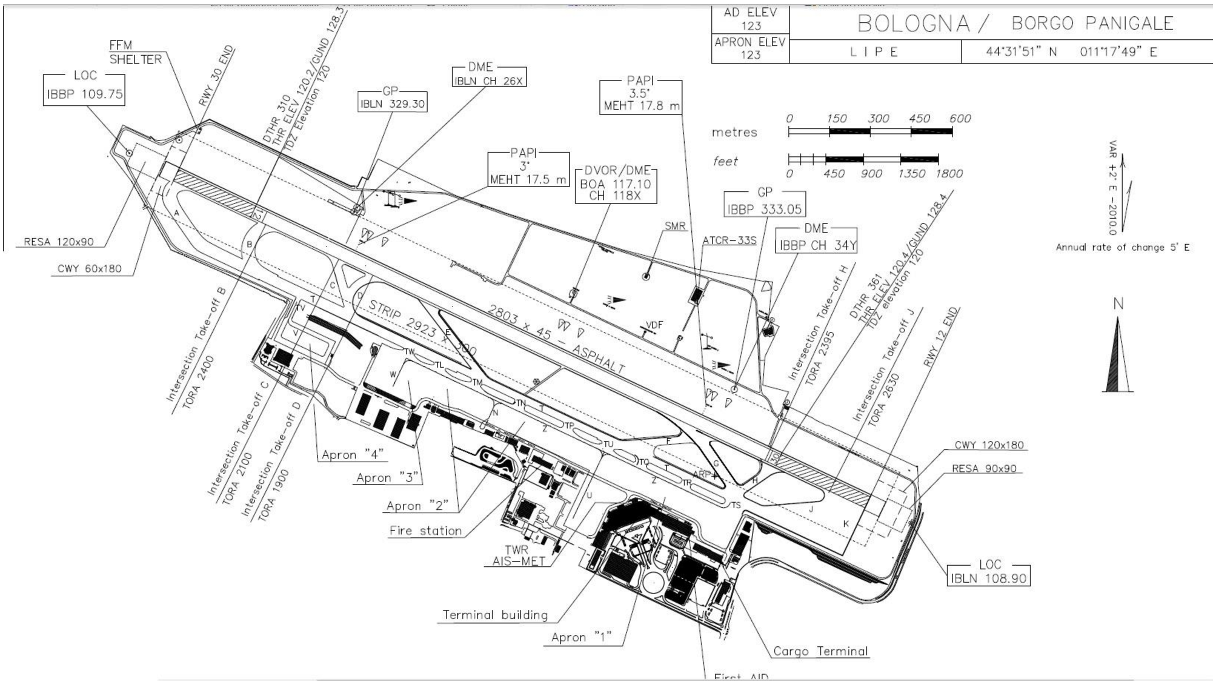

Fig 24. Bologna airport layout

Figure 24 reports Bologna Airport layout. The main taxiway T is parallel to the runway and it links all the aprons with the runway. Four aprons are available; Apron 1 in front of the terminal and the Control Tower, Apron 2 on left in front of the fire fighting area and hangars, Apron 3 is the cargo area and Apron 4 for general aviation. Aprons 1, 2 and 3 are linked to taxiway T with a short taxiway TW, TL, TN, TM,TP, TU, TQ, TR, and TS; Apron 4 is separated from the other aprons and is linked to the main taxiway T with taxiway TV.

The Runway and the main taxiway T are linked via the taxiways A, B, C, D, E, F, G, H, J and K.

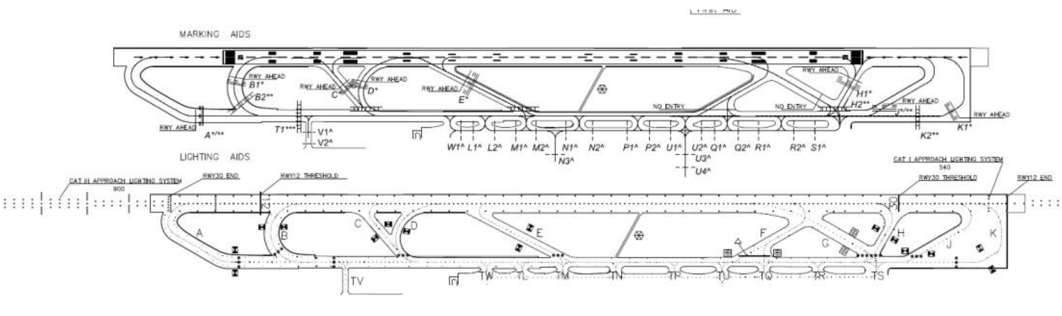

Fig 25. Bologna airport layout, runway, taxiways

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Taxiway characteristics including width, surface and strength are reported in the following table.

2	Larghezza, superficie e resistenza delle TWY	TWY width, surface and strength
	A Larghezza: 23 M Superficie: ASPH Resistenza: PCN 50 F/B/X/T	A Width: 23 M Surface: ASPH Strength: PCN 50 F/B/X/T
	B Larghezza: 23 M Superficie: ASPH Resistenza: PCN 70 F/B/X/T	B Width: 23 M Surface: ASPH Strength: PCN 70 F/B/X/T
	C Larghezza: 23 M Superficie: ASPH Resistenza: PCN 50 F/A/X/T	C Width: 23 M Surface: ASPH Strength: PCN 50 F/A/X/T
	D Larghezza: 23 M Superficie: ASPH Resistenza: PCN 46 F/A/X/T	D Width: 23 M Surface: ASPH Strength: PCN 46 F/A/X/T
	E Larghezza: 23 M Superficie: ASPH Resistenza: PCN 42 F/A/X/T	E Width: 23 M Surface: ASPH Strength: PCN 42 F/A/X/T
	F Larghezza: 23 M Superficie: ASPH Resistenza: PCN 52 F/B/X/T	F Width: 23 M Surface: ASPH Strength: PCN 52 F/B/X/T
	G Larghezza: 23 M Superficie: ASPH Resistenza: PCN 85 F/B/X/T	G Width: 23 M Surface: ASPH Strength: PCN 85 F/B/X/T
	H Larghezza: 23 M Superficie: ASPH Resistenza: PCN 57 F/B/X/T	H Width: 23 M Surface: ASPH Strength: PCN 57 F/B/X/T
	J Larghezza: 23 M Superficie: ASPH Resistenza: PCN 60 F/A/X/T	J Width: 23 M Surface: ASPH Strength: PCN 60 F/A/X/T
	K Larghezza: 23 M Superficie: ASPH Resistenza: PCN 60 F/A/X/T	K Width: 23 M Surface: ASPH Strength: PCN 60 F/A/X/T
	T Larghezza: 23 M Superficie: ASPH Resistenza: PCN 70 F/A/X/T	T Width: 23 M Surface: ASPH Strength: PCN 70 F/A/X/T
	TL Larghezza: 45 M Superficie: ASPH Resistenza: PCN 120 F/A/W/T	TL Width: 45 M Surface: ASPH Strength: PCN 120 F/A/W/T
	TM Larghezza: 38 M Superficie: ASPH Resistenza: PCN 120 F/A/W/T	TM Width: 38 M Surface: ASPH Strength: PCN 120 F/A/W/T
	TN Larghezza: 41 M Superficie: ASPH Resistenza: PCN 14 F/C/W/T	TN Width: 41 M Surface: ASPH Strength: PCN 14 F/C/W/T
	TP Larghezza: 38 M Superficie: ASPH Resistenza: PCN 56 F/B/W/T	TP Width: 38 M Surface: ASPH Strength: PCN 56 F/B/W/T
	TQ Larghezza: 38 M Superficie: ASPH Resistenza: PCN 79 F/A/W/T	TQ Width: 38 M Surface: ASPH Strength: PCN 79 F/A/W/T
	TR Larghezza: 38 M Superficie: ASPH Resistenza: PCN 113 F/A/W/T	TR Width: 38 M Surface: ASPH Strength: PCN 113 F/A/W/T
	TS Larghezza: 75 M Superficie: ASPH Resistenza: PCN 111 F/A/W/T	TS Width: 75 M Surface: ASPH Strength: PCN 111 F/A/W/T
	TU Larghezza: 51 M Superficie: ASPH Resistenza: PCN 120 F/A/W/T	TU Width: 51 M Surface: ASPH Strength: PCN 120 F/A/W/T
	TV Larghezza: 19 M Superficie: ASPH Resistenza: PCN 87 F/A/W/T	TV Width: 19 M Surface: ASPH Strength: PCN 87 F/A/W/T
	TW Larghezza: 44 M Superficie: ASPH Resistenza: PCN 120 F/A/W/T	TW Width: 44 M Surface: ASPH Strength: PCN 120 F/A/W/T

Table 3. Bologna airport taxiway features

The stands are grouped in blocks: all the stands belonging to a block have the same Apron Holding Position, i.e. a position where the aircraft are pushed back and where they start up the engines.

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4.2.1.2 Radio aids and surveillance systems

Bologna Airport is equipped with Primary and Secondary Surveillance RADAR and with Surface Movement RADAR (SMR). The PSR/SSR version is ATCR 33/S and it is Mode-S equipped. The range of the PSR covers about 65NM and the range of the SSR is about 110NM; the antennas are located together with a rotation every 4 seconds. Mode S information is displayed in a specific window of the CWP (controller working position) and includes several pieces of information such as aircraft call-sign, Indicated Air Speed, Heading, Level, etc. The SMR provides aircraft and vehicle positions on the manoeuvring area. Specific labelling is available on the CWP for identification. The SMR has a range of 3.5NM and also provides raw video information. The SMR is also able to detect foreign objects and flocks of birds on the runway.

Both runways are equipped with ILS; runway 12 until CAT IIIB and runway 30 until CAT1. The table below reports the main characteristics of the ILS for both runways.

Tipo di radioassistenza Type of aid CAT di/of ILS (VAR ILS/VOR)	ID	FREQ	Orario Operational hours	Coordinate antenna Antenna site coordinates (WGS84)	Elevazione antenna DME Elevation of DME antenna	Copertura operativa nominale Limitazioni Designated operational coverage Limitations	Note Remarks
1	2	3	4	5	6	7	8
GP	-	333.05 MHZ	H24	44°32'00.9"N 011°17'52.3"E	NIL	NIL	Slope 3.5° RDH:16.60 M
ILS RWY 12 LOC CAT IIIB (2° E-2010.0)	IBLN	108.90 MHZ	H24	44°31'45.2"N 011°18'21.4"E	NIL	NIL	1) Fascio posteriore non utilizzabile/ back beam not usable
DME	IBLN	CH 26X	H24	44°32'24.2"N 011°16'50.8"E	40 M AMSL	25 NM/10000 FT limitazioni a/limitations at 25 NM 120°/270° MRA 5000 FT 270°/120° MRA 2500 FT	NIL
GP	-	329.30 MHZ	H24	44°32'23.7"N 011°16'50.3"E	NIL	NIL	Slope 3° RDH:16.50 M
ILS RWY 30 LOC CAT I (1° E-2005.0)	IBBP	109.75 MHZ	H24	44°32'31.3"N 011°16'13.2"E	NIL	limitazioni oltre/limitations beyond 17 NM MRA 3000 FT	NIL

Table 4. Bologna airport ILS features

4.2.1.3 Local traffic rules and Low Visibility Procedures

The use of the taxiways is regulated via some restrictions:

1) TWY F and G shall be used only as an exit taxiway
2) TWY B and D shall not be used to enter the runway 12and perform backtrack
3) TWY G is a rapid exit taxiway: max speed 93km/h
4) Minimum thrust requested to pilots on all taxiways/taxilanes.
5) RWY 30 shall be used only if RVR (TDZ, MID and STOP/END) is equal or greater than 550m.

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Moreover some restrictions applies depending on the ICAO code of the aircraft:

1) Aircraft with ICAO Code F shall use only taxiway A, J and K to enter the runway: A to enter runway 12, J as preferential to vacate runway 12 and K to enter runway 30.
2) Taxilane Z shall be used by aircraft up to ICAO code C between TQ and TS
3) aircraft with ICAO code letter “D” are allowed to taxi on TWY T and on aircraft stand taxilane Z only simultaneously with aircraft with ICAO code letter “A”
4) aircraft with ICAO code letter “E” shall not taxi on aircraft stand taxilane Z. Taxiing on TWY T and aircraft stand taxilane Z simultaneously with any other aircraft is forbidden
5) aircraft with ICAO code letter “F” shall not taxi on aircraft stand taxilane Z. Taxiing on TWY T and aircraft stand taxilane Z simultaneously with any other aircraft is forbidden
6) aircraft with ICAO code D, E, F parked on stand 114 or 115 shall be pushed-back on TWY T through TWY TS
7) aircraft with ICAO code E, F parked on apron 3 shall be pushed-back on TWY T through TWY TW
8) Use of taxilane N allowed only for aircraft up to ICAO code B included
9) aircraft with ICAO code letter “D” shall not taxi on the aircraft stand taxilane Z between apron holding points Q2 and S1
10) aircraft with ICAO code letter “E” shall use TWY TU/TS/ TW as exit/entry TWY from/to aprons
11) aircraft with ICAO code letter “F” shall use TWY “TS” as exit/entry TWY from/to stands 114 and TWY “TW” as exit/entry from/to Apron 3.

Low visibility Procedures will be applied CATII/III approaches and to departure operations at following conditions:

a) RVR TDZ is 550 m or below.
b) Cloud base height/ceiling is below 200ft according to the meteorological local report.
c) When the rapid deterioration of weather conditions recommends so.

Pilots will be informed by ATIS (Airline Travel Information System) and/or frequencies when LVP are in force. In case of poor visibility conditions a reduced airport capacity can be expected due to the requirement of increased spacing between arriving aircraft and/or restrictions applied to ground movements.

The ground movements and the separation between arriving aircraft (arrival vs arrival) and between arriving and departing aircraft (arrival vs departure) depends on the prevailing visibility conditions (CONDI VIS). As such, three visibility conditions are possible:

1) CONDI VIS1: Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

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2) CONDI VIS2: Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

3) CONDI VIS3: Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on taxiways and at intersections by visual reference, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing, this is normally taken as visibilities equivalent to an RVR of less than 400 m but more than 75 m.

4.2.1.3.1 Local traffic regulation in CONDI VIS 2

Runway 12 is used preferentially and it is mandatory if RVR is less than 550m. Arriving aircraft vacate runway 12 only via taxiway G,H and J and runway 30 only via B. Departing aircraft enter runway 12 only via A and runway 30 via J. The stopbar at the Runway Holding point CAT II and III are activated. Minimum spacing between arriving aircraft is 10NM if LVP are not in force, 12NM in case LVP in force, 15NM to permit departure between arrivals and LVP in force. In case of LVP, in order to ensure that the radio path of the ILS is free, the TWR controller will clear for take off a departure only if it will overfly the LOC antenna before the arriving aircraft is 4NM on final.

4.2.1.3.2 Local traffic regulation in CONDI VIS 3

Only runway 12 is used. Intermediate holding point (IHP) T1 on main taxiway is activated, the follow-me is positioned on the taxiway T abeam TS on TWR request in case of arrival. Departing aircraft taxi to IHP T1 initially and then to RHP A. Further departures start taxi only once the previous one is between T1 and A RHP. Arriving aircraft vacate the runway only via J and follow the follow-me until the parking. Push back operations are allowed only from stand belonging to not contiguous blocks. Minimum spacing between arriving aircraft is 15NM in case of no departure and 16NM in case of departure. In order to ensure that the radio path of the ILS is free, the TWR controller will clear for take off a departure only if it will overfly the LOC antenna before the arriving aircraft is 4NM on final.

4.2.1.4 Controller Working Position

The TWR controller is responsible to provide the Aerodrome Control Service, the Flight Information Service and the Alert Service to all traffic in the Aerodrome Traffic Zone (portion of airspace with radius of 5NM and 2000ft) and on the Runway. Image below reports the TWR CWP:

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Fig 26.   Bologna Airport TWR CWP

The most important systems used by the ATCO in his tasks are the RADAR (air and ground), the Compunction system, the Light Control and the Strips.

The Air RADAR screen is in front of the ATCO and provide position and identification information of all traffic in the area of responsibility, i.e. ATZ (Aerodrome Traffic Zone) in particular information of the traffic on final. The SMR (Ground RADAR) screen is positioned in higher position (not visible in this picture) linked to the room ceiling in front of the ATCO. This position support the ATCO in the RWY check operations performed before providing all the take off and landing clearances.

The screen on the right is used by the ATCO to control the aerodrome lights, stopbar (RWY and intermediate) included. Specific buttons are available to set the light in accordance to the visibility conditions and to the approach category (CATII and III) in low visibility conditions. On this screen is also displayed to the ATCO a warning system that inform the ATCO of the aerodrome decategorization in case of system failure. Between the RADAR and the light screen the communication control panel is available. Via this panel, the ATCO manages the frequencies and the telephones. On the right strip printer prints the arrival strips 20 minutes before estimated landing time (departure strip are provided by GND ATCO to the TWR ATCO).

Fig 27.   Bologna airport COO working positions

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The picture above shows the COO position where two screen are available. The screen on the right is the approach RADAR providing information of all inbound and outbound flight position within an area of about 100NM. The screen on the right provide the ATCO with the access to all the supporting systems (FDP, AOIS, ADM, see next section). A Communication panel is also available to manage frequencies and telephone.

Picture below reports the GND position (that includes also DEL function).

Fig 28. Bologna airport GND working positions

The GND controller is responsible to provide the Aerodrome Control Service and the Flight Information Service on the manoeuvring area except the runway. Information from supporting systems are displayed in the screens on the left and on the right. The screen on the right displays AOIS (Aeronautical Operational Information system) information and the screen on the left displays ADM and FDP (see Supporting system section). The central screen is the SMR (ground RADAR) and provide the ATCO with the position information of all the traffic on the manoeuvring area.

4.2.1.5 Meteo systems

In Bologna Airport all the sensors required for CATIIIB operations are available. The meteo data available are:

- Wind (direction and intensity, both average and instant value)
- Pressure (QNH,QFE)
- Temperature, Dew Point
- Visibility general and RVR (in 3 points, i.e. TDZ, MID and STOP/END)
- Cloud base

The meteo info are provided to aircraft via the ATIS.

4.2.1.6 Supporting systems

Data supporting systems provide the controller with a set of information related to the scheduled times and to the route. The most important scheduled times are:

- EOBT/TOBT: Estimated (Target in case of A-CDM, Airport collaborative decision making) off-block time.

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- ETOT/TTOT: Estimated (Target in case of A-CDM, Airport collaborative decision making) take off time.
- CTOT: Calculated take off time that is provided by the Network Manager Operations Centre *(*NMOC*)*

In Bologna airport the data supporting system available are FDP (Flight Data Processing) and AOIS (Aeronautical Operational Information system). The FDP provides the Controller with route and clearance information for all IFR flights. The AOIS provides the Controller with a set of information, among them the scheduled time and the actual time, i.e. ALT (Actual Landing Time) and ATOT (Actual Take Off Time), and the NOTAM (NOTice to Air Man).

In Bologna airport the most used scheduled time are the EOBT and the CTOT.

4.2.2 Scenario definition

The information needed by the controller considering the following 4 scenarios are analysed:

1. VMC scenario: visibility equal or greater than 5km and ceiling equal or greater than 1500ft (VFR flights available).
2. IMC visibility CONDITION 1: there are no condition for the visual flights (only Special VFR) but visibility condition 1 still hold. Visibility condition 1 (CONDI VIS 1) is considered whereas the visibility is sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
3. IMC visibility CONDITION 2: Visibility condition 2 (CONDI VIS 2) is considered whereas the visibility is sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
4. IMC visibility CONDITION 3: Visibility condition 3 (CONDI VIS 3) is considered whereas the visibility is sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on taxiways and at intersections by visual reference, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing, this is normally taken as visibilities equivalent to an RVR of less than 400 m but more than 75 m.

It is important to note that scenario 1 and 4 are defined by measured value while the shift from CONDI VIS 1 and 2 is defined by the controller.

4.2.2.1 VMC scenario

4.2.2.1.1 Task analysis and Flight Phases in VMC scenario

- GND/DEL: issue ATC clearance, Issue Start Up clearance, Approve Push Back, Issue taxi clearance, monitor taxi route;

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- TWR: issue Landing clearance (in case go around), issue take off clearance, monitor take off and landing operations, issue clearance to vehicle for runway inspections/operations.

4.2.2.1.2 ATCO information in VMC scenario

- Information related to Aircraft: Identification, Altitude, Speed, Type/WCAT, CTOT, Taxi Route assigned, Distance from Touch Down (only arrival), Ready message (only departure at stand), "Animated Bounding Box" to highlight far aircraft position, Landing/take-off clearance;
- Information related to Ground Vehicles: Identification, speed, taxi route assigned;
- Information related to Airport static features: RWY status (Occupied, closed), Restricted areas (Taxiway closed);
- Environmental Information: Wind, QNH, RWY surface condition, NAVAIDS status;
- Safety Net: Warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

4.2.2.2 IMC Visibility CONDITION 1

4.2.2.2.1 Task analysis and Flight Phases in CONDI VIS 1

- GND/DEL: issue ATC clearance, Issue Start Up clearance, Approve Push Back, Issue taxi clearance, monitor taxi route;
- TWR: issue Landing clearance (in case go around), issue take off clearance, monitor take off and landing operations, issue clearance to vehicle for runway inspections/operations.

4.2.2.2.2 ATCO information in CONDI VIS 1

- Information related to Aircraft: Identification, Altitude, Speed, Type/WCAT, CTOT, Taxi Route assigned, Distance from Touch Down (only arrival), Ready message (only departure at stand), "Animated Bounding Box" to highlight far aircraft position, Landing/take-off clearance;
- Information related to Ground Vehicles: Identification, speed, taxi route assigned;
- Information related to Airport static features: RWY status (Occupied, closed), Restricted areas (Taxiway closed);
- Environmental Information: Wind, Visibility, Ceiling, QNH, RWY surface condition, NAVAIDS status;
- Safety Net: Warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

4.2.2.3 IMC Visibility CONDITION 2

4.2.2.3.1 Task analysis and Flight Phases in CONDI VIS 2

- GND/DEL: issue ATC clearance, Issue Start Up clearance, Approve Push Back, Issue taxi clearance, monitor taxi route;
- TWR: issue Landing clearance (in case go around), issue take off clearance, monitor take off and landing operations, issue clearance to vehicle for runway inspections/operations.

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4.2.2.3.2 ATCO information in CONDI VIS 2

- Information related to Aircraft: (position and attitude) for close aircraft, “Animated Bounding Box” to highlight far aircraft position, Identification, Altitude, Speed, Type/WCAT, CTOT, Taxi Route assigned, Distance from Touch Down (only arrival), Ready message (only departure at stand), Landing/take-off clearance;
- Information related to Ground Vehicles: Identification, speed taxi route assigned;
- Information related to Airport static features: Aerodrome layout (apron and manoeuvring area), RWY status (Occupied, closed), Restricted areas (Taxiway closed: F), stopbar;
- Environmental Information: Wind, Visibility (RVR), Ceiling, QNH, RWY surface condition, NAVAIDS status;
- Safety Net: Warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

4.2.2.4 IMC Visibility CONDI VIS 3

4.2.2.4.1 Task analysis and Flight Phases in CONDI VIS 3

- GND/DEL: issue ATC clearance, Issue Start Up clearance, Approve Push Back, Issue taxi clearance, monitor taxi route;
- TWR: issue Landing clearance (in case go around), issue take off clearance, monitor take off and landing operations, issue clearance to vehicle for runway inspections/operations.

4.2.2.4.2 ATCO information in CONDI VIS 3

- Information related to Aircraft: (position and attitude), “Animated Bounding Box” to highlight far aircraft position, Identification, Altitude, Speed, Type/WCAT, CTOT, Taxi Route assigned, Distance from Touch Down (only arrival), Ready message (only departure at stand), Landing/take-off clearance;
- Information related to Ground Vehicles: Identification, speed, taxi route assigned;
- Information related to Airport static features: Aerodrome layout (apron and manoeuvring area), RWY status (Occupied, closed), Restricted areas (Taxiway closed: B,C,D,E,F,G,H), stopbar (including intermediate);
- Environmental Information: Wind, Visibility (RVR), Ceiling, QNH, RWY surface conditions, NAVAIDS status;
- Safety Net: Warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

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4.3 EID Analysis

4.3.1 Working condition and environment

The S-R-K analysis is focused on the following working conditions applied to Bologna airport as defined in section 4.2.2:

1. VMC scenario
2. IMC visibility CONDITION 1
3. IMC visibility CONDITION 2
4. IMC visibility CONDITION 3

4.3.2 S-R-K Analysis

This section reports a SRK analysis of the controller tasks for each selected use cases. This analysis is performed in 3 steps:

1. categorization of controller tasks in each visibility condition;
2. categorization of controller tasks by excluding the limitation based on visibility condition;
3. categorization of controller tasks by excluding the limitation based on visibility condition and using RETINA technologies.

For each behaviour, four main dimensions have been considered:

SKILL-BASED BEHAVIOUR:

- High Automated processes involving long term memory (procedural)
- Low Executive control (i.e. low attention and working memory)
- No Decision-making (resolution of conflicts and error detection)
- No Problem solving

RULE-BASED BEHAVIOUR:

- Less automated processes and long term memory (procedural) than Skill level
- More executive control (i.e. more attention and working memory) than Skill level
- No Decision-making (resolution of conflicts and error detection)
- No Problem solving

KNOWLEDGE-BASED BEHAVIOUR:

- No automated processes and long term (procedural) memory
- Executive control (high attention and working memory)

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- Decision-making (resolution of conflicts and error detection)
- Problem solving

In order to perform the analysis, each controller task is split in the related subtasks. For each of them, all the dimensions (automation, executive control, decision-making and problem solving) of the controller cognitive process is evaluated assigning a qualitative value (high, medium, low and no).

For example:

	Automation	Executive control	Decision-making	Problem solving
TASK GND 1 – Issue ATC clearance:				
1. Active electronic strip on FDP	high	low	No	No
2. check SID: ATC have to check if SID is congruent to RWY in use and other restrictions (if present)	medium	medium	No	No
3. assign initial level: Local procedure request to assign 5000ft to every flight (rules)	high	low	No	No
4. ATC clearance: Transmit ATC clearance – hear-back – confirmation of the correct receipt of the authorization (standard phraseology)	high	medium	No	No

Table 5. Sample of subtask analysis

The table reads as follow: the task "issue ATC clearance" is split in four subtasks. Based on the analysis of those subtasks, the task "issue ATC clearance" has a high level of automation and requires to apply rules increasing attention and the use of working memory.
The task GND 1 is evaluated between the categories **skill based behaviour, rule based behaviour**.

A colour coding is used to show the differences from the VMC conditions (in yellow) and the potential improvements obtained using RETINA information (highlighted in green). For each subtask, the impacting restrictions are reported in red.

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TASK DESCRIPTION: Red = limitation (condi vis 2-3) Yellow = different from VMC Green = Using RETINA	VMC				CONDI VIS 1				CONDI VIS 2				CONDI VIS 3			
	Automation	*Executive control*	*Decision-making*	*Problem solving*	*Automation*	*Executive control*	*Decision-making*	*Problem solving*	*Automation*	*Executive control*	*Decision-making*	*Problem solving*	*Automation*	*Executive control*	*Decision-making*	*Problem solving*
TASK GND 1 – Issue ATC clearance:																
1. Active electronic strip on FDP	high	low	No	No	hi	low	No	No	hi	low	No	No	hi	low	No	No
2. check SID: ATC have to check if SID is congruent to RWY in use (rules)	medium	medium	No	No	med	med	No	No	med	med	No	No	med	med	No	No
3. assign initial level: Local procedure request to assign 5000ft to every flight (rules)	high	low	No	No	hi	low	No	No	hi	low	No	No	hi	low	No	No
4. ATC clearance: Transmit ATC clearance – hear-back – confirmation of the correct receipt of the authorization (standard phraseology)	high	medium	No	No	hi	med	No	No	hi	med	No	No	hi	med	No	No
TASK GND 2 – Issue START UP clearance:																
1. Check EOBT and if any CTOT (rules)	high	low	No	No	hi	low	No	No	hi	low	No	No	hi	low	No	No
2. Check traffic condition (SMR and RADAR) ATC can not see the manoeuvring area There are more regulation ATC can see aircraft ("bounding box") position	medium	medium	No	No	med	med	No	No	med	Hi med	No	No	no	hi	Yes no	No
3. If necessary ask for start up approval to approach unit	High	low	no	No	Hi	low	no	No	Med	Med	no	No	no	hi	no	No
4. Estimate any delay There are more traffic rules ATC can see aircraft ("bounding box") position and attitude	Medium	Medium	no	No	Med	Med	no	No	Med	Hi med	yes	No	Med	Hi med	yes	No
5. Transmit clearance (standard phraseology)	high	low	No	No	hi	low	No	No	hi	low	No	No	hi	low	No	No
TASK GND 3 – Approve push back																
1. Identify aircraft on apron (SMR) ATC can not see the manoeuvring area ATC can see aircraft ("bounding box") position and attitude	high	low	No	No	hi	low	No	No	no	Hi med	No	No	no	Hi med	No	No
2. Assess the push back conflict between stand and apply local regulation	No	medium	yes	yes	No	med	yes	yes	No	hi	yes	yes	No	hi	yes	yes
3. Estimate any delay There are more traffic rules Allowed from stand belonging to not contiguous blocks	No	medium	yes	yes	No	med	yes	yes	No	Hi med	yes	yes	No	hi	yes	yes
4. Transmit pushback clearance (standard phraseology)	high	low	No	No	hi	low	No	No	hi	low	No	No	hi	low	No	No
TASK GND 4 – Issue taxi clearance																
1. Identify aircraft on apron (SMR) ATC can not see the manoeuvring area	high	low	No	No	hi	low	No	No	no	Hi med	No	No	no	Hi med	No	No

ATC can see aircraft ("bounding box") position																
2. Choose the correct taxiway according to local regulation (rules) ATC can not see the manoeuvring area There are more traffic regulation ATC can see aerodrome layout, taxiway closed, stop-bar	medium	high	No	No	med	hi	No	No	no	hi	No	No	no	hi	No	No
3. Identify taxiway closed or not allowed, choose correct holding point according runway in use (rules) (airport layout, stopbar) ATC can not see the manoeuvring area There are more traffic rules (B, C, D, E, F, G, H closed, STOPBAR cat II/III ON, intermediate holding point on) Followme for arriving aircraft ATC can see aerodrome layout, taxiway closed, stop-bar ATC can see vehicles ("follow-me")	Medium	Medium	yes	no	Med	Med	yes	no	no	Hi med	no	no	no	Hi med	yes	no
4. Assess aircraft/vehicle conflict already moving (SMR) ATC could not see air traffic STOPBAR cat II/III ON, intermediate holding point ON Further departures start taxi only once the previous one is between T1 and A RHP ATC can see aircraft ("bounding box") position and attitude ATC can see aerodrome layout, taxiway closed, stop-bar	No	medium	Yes	yes	No	med	Yes	yes	No	Hi med	Yes	yes	No	Hi med	Yes	yes
5. Choose best path ATC can not see the manoeuvring area ATC could not see air traffic There are more traffic regulation ATC can see aerodrome layout, taxiway closed, stop-bar ATC can see aircraft ("bounding box") position and attitude	Medium	High	Yes	Yes	Med	Hi	Yes	Yes	no	Hi med	Yes	Yes	No med	Hi	Yes	Yes
6. Transmit taxi clearance (standard phraseology)	Medium	low	No	No	Med	low	No	No	no	med	No	No	No	Hi	No	No

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ATC has to issue regulation and instruction (limit of clearance, which holding point)																
TASK GND 5 – Monitor taxi route																
1. Identify aircraft on manoeuvring area (SMR) ATC can not see the manoeuvring area 7. ATC can see aircraft (“bounding box”)	high	low	No	No	hi	low	No	No	no	Hi	No	No	No med	Hi med	No	No
2. Monitor if aircraft is following the path assigned (SMR) ATC could not see the traffic path 8. ATC can see aircraft (“bounding box”) position and taxi route assigned	medium	medium	No	No	med	Med low	No	No	No	Hi med	No	No	No	hi	No	No
3. Identify aircraft/vehicle conflict (SMR) ATC could not see all the traffic 9. ATC can see aircraft (“bounding box”) position and taxi route assigned	No	medium	Yes	Yes	No	med	Yes	Yes	No	Hi med	Yes	Yes	No	Hi med	Yes	Yes
1. Be sure that aircraft stop at holding point assigned (runway incursion) (SMR) ATC could not see the traffic 10. ATC can use safety net warning for runway incursion	No	High	Yes	Yes	No	Hi med	Yes No	No	No	Hi med	Yes	Yes	No	Hi med	Yes	No
Choose appropriate action to be taken	No	High	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes
TASK TWR 1 – Issue landing clearance																
1. Identify aircraft position (RADAR) ATC can not see traffic on final ATC can see aircraft (“bounding box”) on final, also distance from touch down	high	low	No	No	Med	Med low	No	No	no	Hi med	No	No	no	Hi med	No	No
2. Check runway status free/occupied (SMR) ATC can not see the runway should use SMR ATC could not see all the traffic at holding point There are more traffic regulation (overfly LOC and 4 NM) ATC can use safety net warning ATC can see runway status (occupied) ATC can see all aircraft (“bounding box”) position and attitude	No	medium	Yes	Yes	No	med	Yes	Yes	No	Hi med	Yes	Yes	No	Hi med	Yes	Yes
3. Check wind, runway surface and NAVAIDS status, visibility RVR, ceiling ATC has to check more data, mostly RVR ATC can see all weather data	medium	medium	No	No	Med	med	No	No	med	Hi med	No	No	no	Hi med	No	No
4. Check traffic condition and choose the right taxiway to be used for vacating the runway according local regulation (SMR)	No	High	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes

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ATC can not see all the manoeuvring area ATC could not see all the traffic There are more traffic regulation ATC can see all aircraft ("bounding box") position and attitude ATC can see aerodrome layout																
5. Transmit landing clearance and required information (standard phraseology) ATC has to issue regulation and instruction (which taxiway for vacate, report on the ground)	high	low	No	No	hi	low	No	No	No	med	No	No	No	hi	No	No
TASK TWR 2 – Issue take off clearance																
1. Identify aircraft position (SMR) ATC could not see the traffic ATC can see aircraft ("bounding box") position and attitude	high	low	No	No	hi	low	No	No	No	Hi med	No	No	No	Hi med	No	No
2. Check runway status free/occupied (SMR) ATC can not see the runway ATC can not see air traffic at holding point There are more traffic rules (overfly LOC and 4 NM) ATC can see aerodrome layout ATC can use safety net warning for runway incursion ATC can see runway status (occupied)	No	medium	Yes	Yes	No	med	Yes	Yes	No	Hi med	Yes	Yes	No	Hi med	Yes	Yes
3. Check wind, runway surface and NAVAIDS status, visibility, ceiling ATC has to check more data, mostly RVR ATC can see all weather data	Medium	medium	No	No	med	med	No	No	Med	Hi med	No	No	No	Hi med	No	No
4. Check runway availability and if departure route is free of traffic if departure route is free of traffic (RADAR) ATC can see aircraft ("bounding box") on final, also distance from touch down	No	medium	Yes	yes	No	med	Yes	yes	No	Hi med	Yes	yes	No	Hi med	Yes	yes
5. Transmit take off clearance and required information (standard phraseology) ATC has to had instruction (report airborn)	high	low	No	No	hi	low	No	No	no	med	No	No	no	med	No	No

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TASK TWR 3 – Monitor take off and landing operation																
1. Identify aircraft position (SMR e RADAR) ATC could not see air traffic on the runway ATC can see all aircraft ("bounding box")	high	low	No	No	Med	Med low	No	No	no	Hi med	No	No	no	hi med	No	No
Check if land o take off occurred (SMR e RADAR)	No	High	No	No	No	Hi	No	No	No	Hi	No	No	No	Hi	No	No
2. Identify any unexpected (abort take off, go around, runway incursion) (SMR e RADAR) ATC could not see all the traffic	No	High	Yes	yes	No	Hi med	Yes	yes	No	Hi med	Yes	yes	No	Hi	Yes	yes
Choose appropriate action to be taken	No	high	Yes	yes	No	hi	Yes	yes	No	hi	Yes	yes	No	hi	Yes	yes
3. Transmit new instruction to avoid conflict ATC should promptly issue instruction	Medium	Medium	No	No	Med	Med	No	No	Med	Med	No	No	no	hi	No	No
TASK TWR 4 – Issue clearance to vehicle for runway inspection/operations																
1. Identify vehicle position (SMR) ATC can not see vehicle ATC can see vehicle, taxi route assigned	high	low	No	No	hi	low	No	No	no	Hi med	No	No	no	Hi med	No	No
2. Check runway status free/occupied (SMR) ATC can not see the runway ATC can not see all the manoeuvring area ATC can see runway status (occupied)	No	High	Yes	Yes	No	Hi	Yes	Yes	No	Hi	Yes	Yes	No	Hi	Yes	Yes
3. Check traffic condition and estimate any delay (SMR e RADAR) ATC can not see air traffic ATC can not see manoeuvring area ATC can see all aircraft ("bounding box") ATC can see aerodrome layout	No	High	Yes	No	No	Hi	Yes	No	No	Hi	Yes	yes	No	Hi	Yes	yes
4. Choose any restriction to apply ATC can not see manoeuvring area	No	High	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes	No	Hi	Yes	yes
5. Transmit clearance and required information ATC has to had regulation and instruction (which taxiway can be used)	high	low	No	No	hi	low	No	No	no	Hi med	No	No	no	Hi med	No	No

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The use of the RETINA information described above impacts the controller task by shifting the behaviour in the skill-rules-knowledge paradigm. This is analysed in the following three tables (Tables 6,7,8). Table 6 reports the S-R-K analysis of the controller tasks for each scenario: a dedicated colour coding is used to identify each scenario in order to perform a comparison of the S-R-K categorization of the used scenarios. Table 7 reports a qualitative analysis of the controller tasks using RETINA overlays which are able to provide the controller with all the data previously described.

Table 8 shows the analysis assuming the use of RETINA overlays with no LVP limitation or regulations (as operating in VMC).

This requires further considerations:

- Task GND 2, ISSUE START UP CLEARANCE:

Workload decreases because there are no more restrictions (as CTOT) due to airport capacity.

- Task GND 4, ISSUE TAXI CLEARANCE:

It is assumed that there are no restrictions, no closed taxiway, there is no obligation to use the stopbar, the controller's workload in conditions of visibility 3 can be considered the same as in VMC.

- Task TWR 2, ISSUE TAKE OFF CLEARANCE:

It is assumed that there are no controller's visual limits: this simplifies the observation of aerial overflights of LOC. This limit remains necessary for operation in Class II / III, in order to protect the ILS sensitive areas.

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CONDI:	ATC INFORMATION
VMC VIS 1 VIS 2 VIS 3	• MOVING OBJECTS: ○ AIRCRAFT: identification, altitude, speed, type/WCAT, CTOT, taxi route assigned, distance from touch down (only arrival), ready message (only departure at stand), animated 'bounding box" to highlight far aircraft position, landing/take-off clearance. ○ VEHICLES: Identification, speed, assigned Taxi Route. • FIXED OBJECTS: RWY status (occupied, closed), restricted areas (e.g. taxiway closed). • UNREGISTRED: wind, QNH, RWY surface condition, NAVAIDS status. • SAFETY NET: warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

TASK CODE	TASK DESCRIPTION	S	R	K
GND 1	ISSUE ATC CLEARANCE			
GND 2	ISSUE START UP CLEARANCE			
GND 3	APPROVE PUSH BACK			
GND 4	ISSUE TAXI CLEARANCE			
GND 5	MONITOR TAXI ROUTE			
TWR 1	ISSUE LANDING CLEARANCE			
TWR 2	ISSUE TAKE OFF CLEARANCE			
TWR 3	MONITOR TAKE OFF AND LANDING OPERATIONS			
TWR 4	ISSUE CLEARANCE TO VEHICLE FOR RUNWAY INSPECTIONS / OPERATIONS			

Table 6. S-R-K analysis of the controller tasks for each scenario (baseline equipment)

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RETINA

CONDI:

- VMC
- VIS 1
- VIS 2
- VIS 3

ATC INFORMATION

- MOVING OBJECTS:
  - AIRCRAFT: identification, altitude, speed, type/WCAT, CTOT, taxi route assigned, distance from touch down (only arrival), ready message (only departure at stand), "animated bounding box" to highlight far aircraft position, landing/take-off clearance, position and attitude for close aircraft, "animated bounding box" to highlight far aircraft position.
  - VEHICLES: identification, speed, taxi route assigned;
- FIXED OBJECTS: RWY status (occupied, closed), restricted areas (taxiway closed: B, C, D, E, F, G, H), aerodrome layout (apron and manoeuvring area), stop-bar.
- UNREGISTRED: wind, QNH, RWY surface conditions, NAVAIDS status, status, visibility (RVR), ceiling.
- SAFETY NET: warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

TASK CODE	TASK DESCRIPTION	S	R	K
GND 1	ISSUE ATC CLEARANCE			
GND 2	ISSUE START UP CLEARANCE			
GND 3	APPROVE PUSH BACK			
GND 4	ISSUE TAXI CLEARANCE			
GND 5	MONITOR TAXI ROUTE			
TWR 1	ISSUE LANDING CLEARANCE			
TWR 2	ISSUE TAKE OFF CLEARANCE			
TWR 3	MONITOR TAKE OFF AND LANDING OPERATIONS			
TWR 4	ISSUE CLEARANCE TO VEHICLE FOR RUNWAY INSPECTIONS/OPS			

Table 7. S-R-K analysis of the controller tasks for each scenario (RETINA equipment)

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RETINA "no limitation" CONDI: VMC VIS 1 VIS 2 VIS 3	ATC INFORMATION
	• MOVING OBJECTS: ○ AIRCRAFT: identification, altitude, speed, type/WCAT, CTOT, taxi route assigned, distance from touch down (only arrival), ready message (only departure at stand), "animated bounding box" to highlight far aircraft position, landing/take-off clearance, position and attitude for close aircraft, "animated bounding box" to highlight far aircraft position. ○ VEHICLES: identification, speed, taxi route assigned; • FIXED OBJECTS: RWY status (occupied, closed), restricted areas (taxiway closed: B, C, D, E, F, G, H), aerodrome layout (apron and manoeuvring area), stop-bar. • UNREGISTRED: wind, QNH, RWY surface conditions, NAVAIDS status, status, visibility (RVR), ceiling. • SAFETY NET: warning for some RWY incursion (RWY closed, vehicle and aircraft on RWY).

TASK CODE	TASK DESCRIPTION	S			R			K		
GND 1	ISSUE ATC CLEARANCE									
GND 2	ISSUE START UP CLEARANCE									
GND 3	APPROVE PUSH BACK									
GND 4	ISSUE TAXI CLEARANCE									
GND 5	MONITOR TAXI ROUTE									
TWR 1	ISSUE LANDING CLEARANCE									
TWR 2	ISSUE TAKE OFF CLEARANCE									
TWR 3	MONITOR TAKE OFF AND LANDING OPERATIONS									
TWR 4	ISSUE CLEARANCE TO VEHICLE FOR RUNWAY INSPECTIONS / OPERATIONS									

Table 8. S-R-K analysis of the controller tasks for each scenario (RETINA equipment + NO limitations)

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4.4 Conclusion

The S-R-K analysis has been used to evaluate the controller tasks and the possible impact that the use of the Retina tools could have. Each controller task has been divided into subtasks and, for each of them, the S-R-K "dimensions" (i.e. automation, executive control, problem solving and decision making) have been evaluated in each scenario. The knowledge-based behaviour is the most "consuming" in terms of resources for a controller performing the assigned tasks: low visibility scenarios require a greater use of the "knowledge" compared to the VMC scenario. This is typically mitigated via the application of restrictions (number of taxiways available in low visibility, aerodrome capacity, etc.) which shift the behaviour to the "rules" field. Considering the tables reported above, it is easy to see that the use of the RETINA tools potentially mitigates the "shift" to the knowledge behaviour due to low visibility condition (No RETINA VS RETINA tables). The last table (RETINA No limits) makes it possible to comment on this behaviour by proposing a hypothetical theory: the suppression of all restrictions in low visibility conditions as a what-if analysis, i.e. what happens hypothetically if we remove all retractions applicable in low visibility. Also in this context it is possible to see that the RETINA tools make it possible to balance the shift to the "knowledge" behaviour.

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5 4D Model and Concept Integration

5.1 RETINA solutions

This section will describe the solutions proposed by RETINA based on the results of WP1 and WP2 T-2.1, 2.2 and 2.3.

Each solution describes the exploitation of one or more datasets, integrated into the 4D airport model, and presented to air traffic controllers by means of selected AR tools.

The information to be displayed is categorized as follows:

INFORMATION	REGISTERED TO MOVING OBJECTS	REGISTERED TO FIXED OBJECTS	UNREGISTERED	CONDI VIS
Aircraft/Ground Vehicle position and attitude (close vehicles)	X			IMC 2, 3
Aircraft Bounding Box (far aircraft)	X			VMC; IMC 1, 2, 3
Aircraft Label: Identification, Altitude, Speed, Type/WCAT, CTOT, Distance from Touch Down (only arrival), Ready Message (only departure at stand)	X			VMC; IMC 1, 2, 3
Assigned Taxi Route		X		VMC; IMC 1, 2, 3
Landing/take-off clearance	X			VMC; IMC 1, 2, 3
Ground Vehicle: Identification and speed.	X			VMC; IMC 1, 2, 3

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Aerodrome layout (apron and manoeuvring area)		X		IMC, 2, 3
RWY status (free, occupied, closed)		X		VMC; IMC 1, 2, 3
Restricted areas		X		VMC; IMC 1, 2, 3
Stop-bars (including intermediate)		X		IMC 2, 3
Wind			X	VMC; IMC 1, 2, 3
Visibility (RVR)			X	IMC 2, 3
Ceiling			X	IMC 1
QNH			X	VMC; IMC 1, 2, 3
RWY surface conditions,			X	VMC; IMC 1, 2, 3
NAVAIDS status			X	VMC; IMC 1, 2, 3
Warning for some RWY incursion		X		VMC; IMC 1, 2, 3

Table 9. Classification of information according to the RETINA concept

Each solution also describes how the AR tools will impact the controllers' behaviour in the control tower and how controllers should react in case of failure of the AR systems.

5.1.1 Solution 1: See-Through Head Mounted Display

In this solution, both Ground/Delivery and Tower controllers will be provided with a HMD to be used as a personal device. The device will show ad-hoc generated images based on the controllers' role, position and gaze orientation.

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5.1.1.1 Data sources

- Aircraft position, identification, altitude, speed, type/WCAT, CTOT, distance from touch down and ready message.
- RWY in use, wind, QNH, RWY surface condition, NAVAIDS status, RVR (TDZ/MID/END).
- Controllers' head tracking (position and orientation)

5.1.1.2 AR overlays

The HMD will show a semi-transparent display that provides ATCOs with the most relevant environmental information based on the current visibility condition. Hereafter, this concept will be referred to as the 'transparent HUD' or simply the HUD. The information displayed by the HUD is summarized as follows:

- CONDIVIS VMC: RWY in use, Wind, QNH, RWY surface condition, NAVAIDS status.
- CONDIVIS IMC 1: RWY in use, Wind, QNH, RWY surface condition, NAVAIDS status, ceiling.
- CONDIVIS IMC 2: RWY in use, wind, QNH, RWY surface condition, NAVAIDS status, RVR (if visibility < 2000 m).
- CONDIVIS IMC 3: RWY in use, wind, QNH, RWY surface condition, NAVAIDS status, RVR.

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INFORMATION	EXAMPLE
RWY in use	RWY 12
WIND (direction and speed)	60° - 04 Kts
QNH	1024 hPa
RWY surface condition (colour coding)	
CEILING (only if BKN or OVC)	050 BKN
NAVAIDS status (ILS,...)	--
RVR TDZ (MID, END only if <TDZ)	TDZ 1200

Table 10. Sample Information displayed over semi-transparent display in the HMD

The display will be positioned on the outside view, preferably within the line of sight of strategic points, such as the runway end point, the Apron mid point and the manoeuvring area left and right edges. At any time, the controller will be able to adjust the HMD position according to his or her preference or remove the ones that are not deemed useful.

When looking at far aircraft (>1,5 NM from the control tower) the HMD will show a bounding box that will draw controllers' attention toward the aircraft. Hereafter, this concept will be referred to as the "animated bounding box" concept. The animated bounding box will be visible only to the tower controller and will help him or her retrieving the aircraft position and heading.

Alphanumeric text labels (billboards) will be displayed near aircraft that are inside the HMD FOV. Hereafter, this concept will be referred to as the "billboard" concept. The billboards will provide controllers with aircraft identification, altitude, speed, type/WCAT, CTOT/EOBT, distance from touch down (only arrival) and ready message (only departure at stand). The displayed information will depend on the aircraft flight phase (departure or arrival). The selected colour coding is depicted in Fig. 29.

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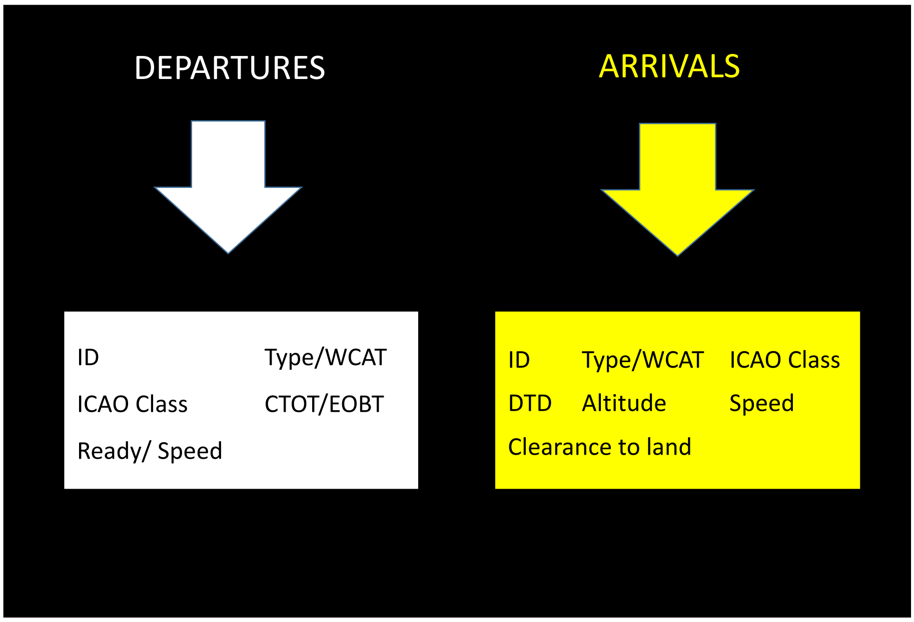

Fig 29. Colour coding for billboards

5.1.1.3 Impact

With the transparent HMD concept the controller will be able to retrieve basic environmental information such as wind direction and speed, QNH, RWY surface condition, NAVAIDS status and the RVR, by simply looking thought the control tower windows. This is expected to limit the time the controller will spend looking at the head down equipment and will reduce the number of head movements and attentional shifts between the outside and inside view.

Billboards will provide controllers with vehicles related information that was previously available only via the integration of many sources, such as radio communication, flight strips and RADARs. This will simplify controllers' cognitive behaviour when dealing with aircraft or ground vehicles.

Bounding boxes will draw controller's attention toward aircraft that are still far from the tower's view and thus can be barely seen by the naked eye. This will increase controllers' situation awareness without forcing them to look at the RADAR to confirm the position of such aircraft.

5.1.1.4 Recovery procedures

In case of failure or noticeable error by the AR equipment the controller will remove the device and find all the necessary information in the "head-down" equipment just like he or she would do nowadays.

5.1.1.5 Recommendations for implementation

Based on the analysis performed on solution 1, the following aspects should be considered in the implementation phase:

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- Registration of aircraft and ground vehicles overlays: data frequency, precision and reliability.
- Head tracking precision.
- Sight occlusion due to AR overlays and brightness reduction.

5.1.2 Solution 2: See-Through Spatial Display

In this solution, both Ground/Delivery and Tower controllers will be provided with a see-through spatial display placed between their working position and the outside view. The device will show ad-hoc generated imagery based on controllers' role, eyes position and outside visibility condition.

5.1.2.1 4D model and data sources

- Aircraft position, identification, altitude, speed, type/WCAT, CTOT/EOBT, distance from touch down and ready message.
- Controllers' eyes tracking

5.1.2.2 AR overlays

The Ground/Delivery controller will be provided with a see-through spatial display that will overlap most of the airport's apron and taxiways. Depending on the visibility condition, overlaid static features will include taxiways borderlines, parking stands, stop-bars and restricted areas. Colour-coding will be used to distinguish between accessible areas and inaccessible areas (e.g. closed taxiways), as further detailed in Table 11. Alphanumeric text labels will provide controllers with aircraft identification, type/WCAT, CTOT/ EOBT and ready message (only departure at stand). Assigned taxi routes will be shown on the airport layout with a green colour. In IMC 2 and 3 the aircraft position will be shown on the ground. Keeping track of the historical position and showing it to controllers will provide directional information.

The Tower controller will be provided with a see-through spatial display that will overlap the runway and the entrance/exit taxiways. Colour-coding will be used to highlight runway occupancy and restricted areas, as further detailed in Table X. The ILS glide-path will be displayed to detect discrepancies between theoretical landing trajectory and real aircraft landing trajectories.

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	COLOUR CODING	
FEATURE	RED	GREEN
RWY	Occupied	Free
TWY	Closed	Open

Table 11. Semantic meaning of RETINA colour coding

5.1.2.3 Impact

The spatial display concept will impact controllers' working practice by providing them with easy to understand updated information on the runway and taxiways status. Thus, controllers' will rely less on working memory and look outside the tower windows to easily retrieve such information.

Alphanumeric labels will identify aircraft by call sign, type/WCAT and provide controllers with CTOT/EOBT/DTD and ready message. This feature will reduce the visual scanning needed to locate specific aircraft on the apron and manoeuvring area. Also, the time spent looking down at the RADAR and flight strips to retrieve aircraft related information should decrease.

Showing the aircraft taxi route will allow controllers' to easily double-check the cleared path against taxi blocs that might be closed or restricted to specific aircraft categories. This is expected to simplify controller's cognitive behaviour when performing this task.

5.1.2.4 Recovery procedures

In case of failure or noticeable error by the AR equipment it will be turned off and the controller will operate just like he or she would do nowadays. Depending on the visibility condition, all the necessary information will be retrieved from the outside view, the RADAR, the flight strips and by radio communicating with pilots.

5.1.2.5 Recommendations for implementation

Based on the analysis performed on solution 2, the following aspects should be considered in the implementation phase:

- Registration of static airport features overlays
- Registration of ground vehicles' overlays: data frequency, precision and reliability
- Eye tracking precision
- Sight occlusion and brightness reduction.

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