ALMA MATER STUDIORUM
UNIVERSITA' DI BOLOGNA

SCHOOL OF ENGINEERING

-Forlì Campus-

SECOND CYCLE MASTER'S DEGREE in
INGEGNERIA AEROSPAZIALE/ AEROSPACE
ENGINEERING
Class LM-20

GRADUATION THESIS
In Aerospace Installations and Systems

DEVELOPMENT AND VALIDATION OF THE MULTIPLE REMOTE TOWER (MRT) FOR REMOTE AIR TRAFFIC CONTROL

CANDIDATE
Jacopo Scalbi

SUPERVISOR
Prof. Fabio Olivetti

Academic Year 2021/2022

------ This page was intentionally left blank ------

CONTENTS

ABBREVIATIONS & DEFINITIONS

- **A-SMGCS** *Advanced Surface Movement Guidance & Control System*. Is a system providing routing, guidance and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety.

- **A/G** *Air – Ground.*

- **ACC** *Area Control Center.* is a regional control center responsible for providing air traffic services to controlled flights in the airspace under its responsibility, generally an entire flight information region and the control areas contained therein.

- **ADS-B** *Automatic Dependent Surveillance – Broadcast.* It is an instrument used to determine the position of an aircraft. Consequently, it is not used for communication between pilots, but only between aviation systems. For example, with the help of an ADS-B, ATC can orient aircraft in the sky much more accurately. This system, coupled with a GPS, can determine the position of an aircraft with a high level of accuracy. In addition to location, it also provides various meteorological information.

- **AFIS** *Aerodrome Flight Information Service.*

- **AFISO** *Aerodrome Flight Information Service Officer.*

- **AIS** *Aeronautical Information Service.*

- **ANS** *Air Navigation Service.*

- **ANSP** *Air Navigation Service Provider.*

- **ATC** *Air Traffic Control.* Is the set of rules and organizations that contribute to the safe, expedited and ordered flow of aircraft traffic on the ground and in the skies around the world through the application of appropriate procedures and the use of communication and, when available, surveillance radar systems.

- **ATCO** *Air Traffic Control Officer*. People trained to maintain the safe, orderly, and expeditious flow of air traffic in the global air traffic control system.

- **ATFM** *Air Traffic Flow Management.* A function established to contribute to the safe, orderly and rapid flow of air traffic, ensuring the optimal use of air traffic control capacity, and to verify the compatibility of traffic volume with the capacities declared by the relevant air traffic service providers.

- **ATM** *Air Traffic Management*. The set of air and ground functions (air traffic services, airspace management and air traffic flow management) required to ensure the safe and efficient movement of aircraft during all phases of operations.

- **ATS** *Air traffic services***:** are services provided to air traffic by an air navigation service provider or ANSP for the safety and regularity of air traffic.

- **AWOS** *Automated airport weather station :* Airport weather stations are automated stations designed to serve aviation and meteorological operations, weather forecasting and climatology.

- **CHMIM** *Controller Human Machine Interaction Management*

- **CNS** *Communications, Navigation and Surveillance*

- **Common Project** A Commission Implementing Regulation which mandates the implementation of the most essential operational changes in the European ATM Master Plan by the Member States of the European Union and their operational stakeholders.

- **CWP** *Controller Working Position*

- **DLR** *Deutsches Zentrum für Luft- und Raumfahrt e.V.* Is the German space agency and is responsible for national research in the fields of aviation and space flight. The center also manages the research of the Helmholtz Association. Research programmes include complex national and international projects.

- **E-OCVM** *European Operational Concept Validation Methodology*

- **e.g.** *exampli gratia.*”e.g.”. Is an abbreviation of the Latin phrase exempli gratia , and means "for example".

- **EFS** *Electronic Flight Strip.*

- **G/G** *Ground – Ground.*

- **HMI** *Human Machine Interface.*

- **i.e.** *id est.* "i.e." is an abbreviation of the Latin id est , and means "that is".

- **MET** *Meteorological*

- **MRTM** *Multiple Remote Tower Module*

- **OTW** *Out The Window*

- **PCP** *Pilot Common Project.* PCP is the first Common Project and is defined by the Regulation (EU) N°716/2014.

- **PPP** *Public–Private Partnership*. PPP is a long-term arrangement between a government and private sector institutions. Typically, it involves private capital financing government projects and services up-front, and then drawing revenues from taxpayers and/or users over the course of the PPP contract.

- **PTZ Cameras** *PAN-TILT-ZOOM*

- **RTC** *Remote Tower Center*

• **SDM** *SESAR Deployment Manager.* SDM function consists of the synchronization and the coordination of the deployment of the Common Projects

• **SES** *Single European Sky*

• **SESAR Joint Undertaking** Set up to manage the activities of the development phase of the SESAR project. The aim of the SESAR Joint Undertaking is to modernise the European air traffic management system by coordinating and concentrating all relevant research and development (R&D) activities in the EU. It is responsible for the execution of the European ATM Master Plan.

• **SESAR** *Single European Sky ATM Research.* A project to improve ATM performance by modernising and harmonising ATM systems through the definition, development, validation and application of innovative technological and operational ATM solutions.

• **SHADOW MODE** A way to speed up the process of introducing new tools is to actively involve stakeholders in the validation process through the use of 'shadow mode' techniques. In these techniques, the proposed new system is brought into the operations room and exposed directly to the controllers. In this way, controllers can quickly identify limitations or opportunities in the system and provide timely feedback to the developers.

• **SLG** *Signal Light Gun.*

• **TAF** *Terminal Aerodrome Forecast.*

• **TMA** *Terminal Control Area.*

• **TRL** *Technology Readiness Levels.*

• **TWR** *Tower:* is the Air Traffic Services authority responsible for providing the air traffic control service at an airport, as well as being the name of the building that houses it.

- **VCS** *Voice Communications System.*

- **VP** *Visual Presentation.*

LIST OF FIGURES

ABSTRACT

The symbol in air traffic control (ATC), essentially unchanged since the beginning of commercial air traffic early last century, is the characteristic control tower with its large, tilted windows, situated at an exposed location, and rising high above the airport.

"Remote Tower" is changing the provision of Air Traffic Services (ATS) in a way that it is more service tailored, dynamically located and available when and where needed, enabled by digital solutions replacing the physical presence of controllers and control towers at aerodromes with a remotely provided Air Traffic Service for Multiple Aerodromes.

Thanks to Professor Fabio Olivetti and the availability of ENAV spa, I was able to study this phenomenon that will mark an epochal change, analysing the experiments and validations carried out in the last years.

1. INTRODUCTION

Air traffic controllers (ATCs), also improperly named “radar men”, are professionals involved in the provision of air traffic services in airspaces around the world, with the aim of maintaining a safe, expeditious and orderly flow of air traffic.

The main task that ATCs are called upon to perform is to constantly monitor the position, speed and altitude of aircraft, assisting, instructing and authorising the flight crew according to specific separation rules in order to keep aircraft at a safe distance from each other, both in the air and on the ground. Among other tasks, ATCs are also responsible for emergency management and the activation of the airport emergency plan in the event of an accident. The language normally used in communication between ATCs, and aircraft flight crew is English, for which all ATCs must be certified, irrespective of their geographical location and what their mother tongue is. The use of the local language or any other language known by both sides is only used when necessary for safety, to avoid misunderstandings.

The ATC profession is highly specialised, requires high levels of knowledge, skills, and competences; it can be notoriously stressful depending on numerous variables (traffic volumes, weather situation, breakdowns, etc.), and is globally regarded as one of the most mentally demanding professions due to high responsibilities and the need to make numerous real-time decisions in highly dynamic scenarios. Depending on their specific qualifications and the service they are called upon to provide, ATCs can be divided into three main types:

- Tower Controller (TWR) - works in airport control towers managing all traffic on the ground, on the runway, and in the immediate vicinity of the airport.
- Approach controller (APP) - works in special control tower rooms or at area control centers managing routing to and from the airfields, separating arrivals and departures, and setting arrival sequences with appropriate spacing between successive aircraft.
- Area controller (ACC) - works in area control centers managing en-route traffic along airways.

The Control Tower building, of a height appropriate to the size and surface area of the airport, is the workplace of the TWR controller. The control tower height must be such as to allow the best view of the runways, aprons and in the air in the landing directions; it is normally located at a safe distance from the runway, approximately halfway, or near their intersections if there is more than one runway. Having a good view of the airport is essential because the Aerodrome Control Service (ACS) is carried out mainly by observing what is happening on and around the airport. Over the years, technology has developed considerably to assist the controller in performing his tasks, trying to get closer and closer to ENAV's objective: the zero error.

"But what about the small airports that cannot afford this technology? And can we still in the 21st century base airport security on a limited number of controllers per zone? "
These questions may seem trivial, but they are not.

The Multiple Remote Tower (MRT) aims to answer these questions, giving to the airport world a high level of ATCS service independently of geographical location. For several years the German Aerospace Center (DLR) , SESAR and ENAV have been studying a new method of digitalising airport traffic to process this data and transfer it to a remote tower center which will provide the air traffic control service remotely. MRT is a very radical proposal and only in recent years is it clearly becoming possible at a reasonable cost. In **Chapter 2 –"***PROBLEM ANALYSIS AND PROJECT HISTORY***"**, we will introduce the history and issues that led to the adoption of this technology by SESAR.

In **Chapter 3** –**"***SESAR SOLUTIONS PROCESS & PROJECTS***"** we will analyse SESAR itself, its method of project development from the initial idea to the industrialisation of projects, passing through a large number of intermediate stages of review and approval, finishing with a general overview of the main projects currently carried out by SESAR.

In **Chapter 4** –**"***SESAR 2020 WAVE 1 -PJ 05 REMOTE TOWER FOR MULTIPLE* AIRPORTS*",* we will examine in detail the project of our interest, namely PJ05 - Remote Tower for Multiple Airports (MRT), identifying the various roles within the MRT, the way in which operators communicate each other and with the rest of the airport operators.
We will go through an ergonomic analysis for the choice of instrumentation to favor a high level of situational awareness of the controller, and we will study the various validation steps faced to make this technology became reality.

Lastly, the thesis concludes with **Chapter 5** –**"**SESAR 2020 WAVE 2 – PJ05-W2-DTT*",* where we report on the PJ05 validation experience at the ENAV Academy in Forlì, which I had the honor of attending in person and was able to get a taste of this now very close future.

2. PROBLEM ANALYSIS AND PROJECT HISTORY

2.1. IMPORTANCE OF LOOKING OUT FOR ATCO

The air traffic controller is largely dependant on visual information retrieved by direct observation of the real world scene. Studies on local controller's activity showed that they spend most of their time looking out of the window and at radar images.

The most complete study investigating the behavioural analysis of the tower controller activity, using video based eye/head tracking was conducted by Hilburn (Hilburn, 2004a). The observation was performed at Arlanda Airport (Sweden) on 27 April 2005 taking into account the working hour between 14.00 and 15.00.The study consider the position facing runway exclusively assigned for landing recording, during good visibility conditions, without traffic restriction.

The observation was based on the camera recordings and the audio of the controller; In order to describe controller's performance the following activities were distinguished:

- *Window:* When the controller was looking outside the window in front of his position.
- *Radar:* Describes the time when the controller was looking or manipulating with a radar or screen providing meteorological information.
- *Strips:* Describe the time when the controller was scanning, ordering or writing on the strips.
- *Strips delivery:* describe the time when the controller was out of the working position, allowing him to scan the window in order to provide strips to other positions.
- *Coordination:* activity of the controller to discuss and arrange traffic between the Ground control, Supervisors or Flight Data Assistant.
- *Clearance:* describes clearance issues. Main two kinds of instructions remarked:
    - *Landing Clearance (*instructions for aircraft that are still airborne -"clear to land" and "continue approach")
    - *Runway vacated* (instruction to aircraft that already landed - "contact ground").
- *Non active:* describes the time when a controller was not occupied with control activity due to low level of traffic, he was involved in other activities (chatting with others, resting) while remaining in his position.

Once the necessary data has been collected by Hilburn, we provided to print the relationship between the percentage of controller time occupied and duration as represented in *Figure 1*.

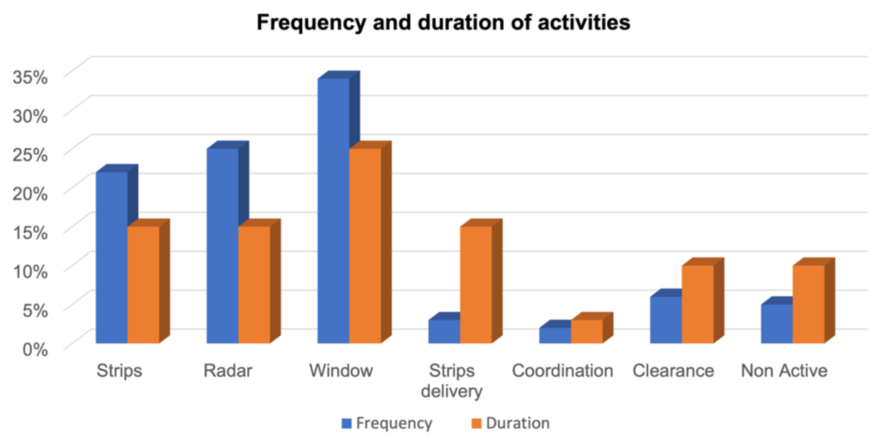

Figure 1 - Frequency and duration of activities

We get confirmation that the major occupancy of the controller, both for frequency and duration, was looking outside of the window (frequency at the level of 33% and duration 25%). Two other significant activities were "radar" (frequency 25% duration 17%) and "strips" (frequency 21%, duration 15%).

The high level of frequency within **window / radar / strips** activities showed that the controller is constantly switching attention between those three main sources of information. Looking outside of the window is the most frequent and longest activity of the tower controller, occupying him for roughly **30-40% of the time.**

2.2. MULTIPLE REMOTE TOWER CONCEPT

We have therefore shown how fundamental is for the controller to have a live view of the airport status, as a consequence of the fact that radar alone is not enough to have a clear perception of what is happening around. This study is the same as the one that led to the idea of the characteristic control tower with its large tilted windows, situated at an exposed location, and rising high above the airport with an impressive 360 panoramic far view out of windows.

But small and regional airports are challenged to reconcile the high cost of running a full capability air traffic control tower with the low revenue derived from landing and other flight-related charges when traffic is scarce and intermittent. Therefore, an innovative and more cost-efficient approach to providing control tower functionality at airports must be put into play.

The **remote tower concept** provides a solution to this problem. Remote tower works by deploying high-definition cameras complemented by a suite of supporting technologies and network links. A live video feed is securely relayed to an air traffic controller at a remote location. This live feed is combined with a panoramic array of high-definition screens, representing an ‘out of the window’-like view of a single or multiple airports.

Figure 2 - Multiple Remote Tower workstation

Remote towers offer several benefits comparable to conventional air traffic control towers at airports. Basically, it provides additional support tools for the controller, and this creates a safety enhancement. This system offers features of augmented reality, automatic object detection and virtual safety nets, features that cannot be implemented in a conventional tower.

To fully utilize the advantages of the remote tower concept, remote tower centers need to be connected to more than one airport combined into one Multiple Remote Tower Module and managed by one controller. This would allow for a much more efficient allocation of airports to controllers by allowing them to work flexibly at airports where and when the traffic occurs: During high traffic load or complex situations, one or two controllers can provide air traffic control to one airport, while a more efficient strategy will be implemented in low traffic situations.

2.3. SINGLE EUROPEAN SKY ATM RESEARCH – SESAR

In 1989, it was already estimated that 4.2 billion dollars were lost annually in air traffic control delays, excessive air traffic control costs and uneconomic flight paths.
National governments called for initiatives such as a central air traffic flow management (ATFM) unit to manage flows across the network and a European programme to harmonise and integrate air traffic control for technological compatibility.
During the same year the European Commission began to recognise the technological and institutional limitations of the air traffic control system, but it would have to wait until 2001 to have an action programme of the European Commission for the implementation of the SES (Single European Sky) and 2004 to have the first package of legislative regulations: *Regulations (EC) Nos. 549/2004, 550/2004, 551/2004 and 552/2004 of the European Parliament and of the Council*, that will be revised and extended in 2009 with the "SES II" package. These packages created the position of network manager (EUROCONTROL) as well as a performance evaluation body to support the development and management of the SES performance system and also various "technical" standards to ensure the inter-compatibility of the systems.
The major High-Level Goals of SES as stated in 2005 were:

- ✓ enable a three times increase in capacity while reducing delays both on the ground and in the air;
- ✓ improve safety by a factor of 10;
- ✓ enable a 10% reduction in the impact of flights on environmental pollution;
- ✓ a reduction of air traffic management (ATM) service costs to airspace users of at least 50%.

Remote Tower Service is one of the technological and operational solutions delivered for deployment by the Single European Sky Air Traffic Management Research Program. This new concept fundamentally changes how operators provide Air Traffic Services, as it becomes possible to control several airports from a single remote center.

SESAR 2020 partners performed four real-time simulations and one shadow mode trial using four different validation platforms in various airport environments.

The exercises tested human performance, visual information display, advanced voice services, technical support systems, and safety performance. Results showed that the Multiple remote tower module (MRTM) could handle the same traffic volume as the single remote tower with up to 25 per cent fewer controllers. In addition, different types of aerodromes could be coupled together in the MRT module, and in case of traffic overload, aerodromes could be split between modules.

They also notice that for very small airports, it is a safety enhancement because they are often providing only aerodrome flight information service (AFIS). The AFIS officer typically doesn't have a tower, only radio communications with the pilot. It is the pilot's responsibility to check if the runway is free because the officer can't see. Remote tower technology solves this issue by giving the AFIS officer a clear view of the runway and the arrival and departure sector.

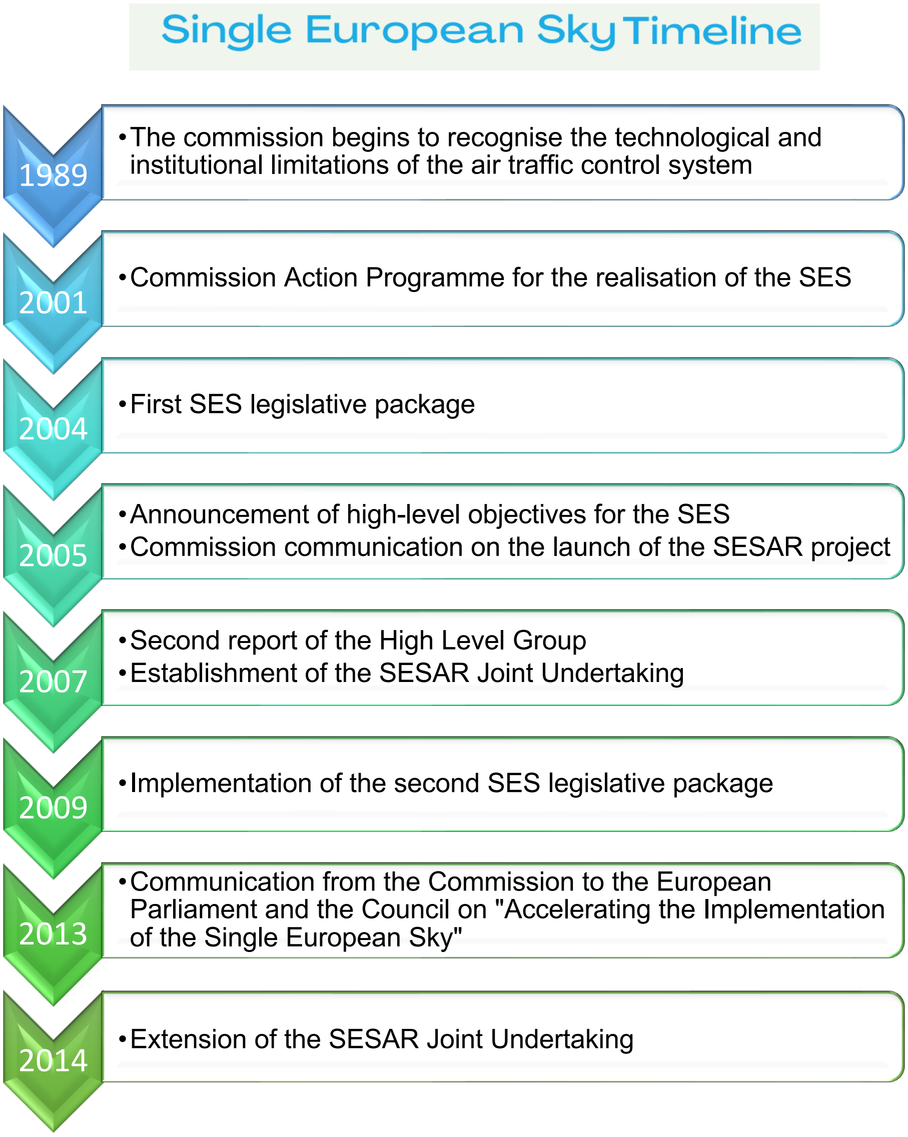

Figure 3 - Single European Sky Timeline

3. SESAR SOLUTIONS PROCESS & PROJECTS

The SESAR Programme is generally divided into three phases

- The *definition phase* aimed at defining the way forward and resulted in the "European Air Traffic Management Master Plan" (ATM Master plan).

- The *development phase* is going to develop, validate and demonstrate the required solutions. The programme is managed by the SESAR Joint Undertaking (SJU) and is divided into SESAR (2009-2016) and SESAR 2020 (Split into Wave 1 and the current Wave 2). The SESAR Joint Undertaking was set up to manage the research and development phases of the project, it consists of the founding members: European Union and EUROCONTROL, as well as 19 members representing Airport, Air Navigation Service Providers, Manufacturing Industry and the Scientific Community.

- The *deployment phase* is conducted by the SESAR Deployment Manager (SDM) who coordinates the implementation of the EU's Pilot Common Project (PCP) to ensure that the solutions derived from the ATM Master Plan are deployed in a timely, coordinated and synchronised way in Europe.

3.1. SESAR 2020 PROGRAMME

The SESAR 2020 programme is structured into three main research phases, including Exploratory Research, Industrial Research & Validation and Very Large Scale Demonstrations.

Figure 4 – The three SESAR Research phases

Exploratory Research (**ER** or Phase 1)

Exploratory Research is powered via open Horizon 2020 calls and is further divided into two areas.

- ✓ One research the fundamental science.
- ✓ The other studies the application of this science for ATM.

Industrial Research & Validation (**IR** or Phase 2)

Industrial Research & Validation represents the wider part and includes *Applied Research as well as Pre-Industrial Development and Validation*.
This part is covered by the SJU public-private partnership (PPP), a long-term arrangement between the government and SJU.

Very Large Scale Demonstrations (**VLD** or Phase 3)

The third phase consists of the Very Large Scale Demonstrations (VLD) of concepts and technologies. This part is powered in two ways

- ✓ Partially covered by the PPP and its members
- ✓ Partially covered via open Horizon 2020 calls securing the involvement of Airspace Users (AU) in the Programme.

3.1.1. NASA TECHNOLOGY MATURITY LEVELS

These phases have been designed to bring projects from the idea to a tangible solution for industrialization and subsequent deployment.
The structure is also needed to try and create consistency and an organized, transparent and repeatable approach to concept development and validation. It also ensures traceability and helps understand how the Solutions fit together and to create the global picture and help to achieve SESAR's high level goals.

The three research phases cover a **technology maturity level** ranging from 1 to 7 in the NASA scale of the Technology Readiness Levels (TRL). TRLs are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress.

There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

a) TRL 1 is when exist just the idea of the technology, so scientific research is performing, and those results are being translated into future development.

b) TRL 2 occurs once the basic principles have been studied and practical applications can be applied to those initial idea. It has no experimental proof of concept for the technology.

c) TRL 3 consist in active research and design. Generally, both analytical and laboratory studies are required at this level to see if a technology is viable and ready to proceed further through the development process. During TRL 3, a *proof-of-concept model* is constructed.

d) TRL 4 is reached when the proof-of-concept technology is ready; At this level multiple component pieces are tested together.

e) TRL 5 is a continuation of TRL 4, however, technology at 5 must undergo more rigorous testing than technology that is only at TRL 4.
For Simulations should be run in environments that are as close to realistic as possible to move to TRL 6.

f) A TRL 6 technology has a fully functional prototype or model.

g) TRL 7 technology requires that the working model or prototype be demonstrated in the final environment.

h) TRL 8 technology has been tested and it's ready for implementation into an already existing technology or system.

i) TRL 9 qualification is obtained when a technology has been "flight proven" during a successful mission.

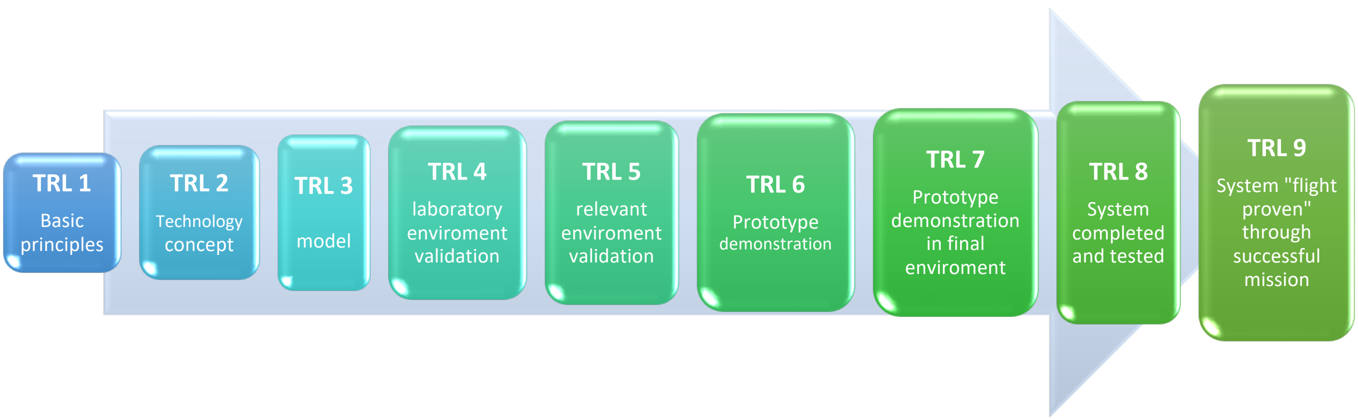

Figure 5 - Technology Readiness Levels (TRL) goals

Note that:

A TRL number is reached once the description in the diagram has been achieved.

For example, successfully achieving TRL 4 (laboratory environment validation) does not move the technology to TRL 5. TRL 5 is achieved once is performed validation in a relevant environment. The technology remains TRL 4 until the relevant environmental validation is complete.

3.1.2. SESAR SOLUTION LIFECYCLE: THE 7V PHASES

The SESAR Solution lifecycle is a process executed at Project level which includes a standard sequence of activities to develop, validate and progressively increase SESAR Solution maturity. It doesn't follow the NASA Technology Readiness Levels, but have an his own levels nomenclature called E-OCVM (European Operational Concept Validation Methodology) or "V" phases.

The final purpose is to deliver a SESAR Solution package for Industrialization and Deployment.

E-OCVM and validation are mainly concerned with lifecycle phases V1, V2 and V3 but are also concerned with V0 to ensure that the correct initial conditions have been met.

- **V1 Scope:** Definition of the operational concept and technical solution. Identification of potential costs and benefits for meeting the target performance identified in the pre-R&D needs phase (V0).
- **V2 Feasibility:** It develops and explores the development of the concept and its feasibility, mainly through simulation, until it can be considered operationally feasible, or it can be determined that further development is no longer justified.
- **V3 Pre-industrial development & integration**: It develops and refines the operational concepts and support tools to prepare the transition from research to the operational environment. Done via implementation of industrial prototypes in realistic environments.

In the main phases we can also consider V4, cause the validation activities in V3 must have sufficient understanding of V4 to ensure that the correct information is available to manage the V3 to V4 transition.

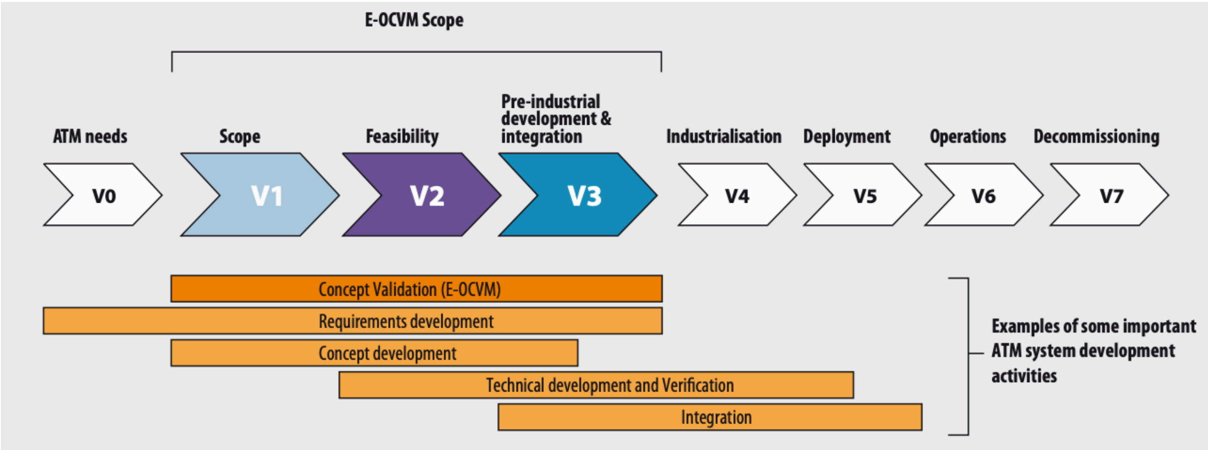

Figure 6 - The 7V Phases
[E-OCVM Volume I - Version 3.0]

The remaining phases V5, V6 and V7 are not within the scope of validation; they talk about integrating the technology into an existing infrastructure.

3.1.3. NASA TRL Vs. 7V PHASES

Focusing on the research and validation part the lifecycle consists of five phases (V0-V4) in which, following the TRL path, before any new concept is developed further towards higher TRL in SESAR 2020, it has to successfully pass several reviews that are named "**GATE**".

The SESAR Solution lifecycle includes five Maturity Gates, these are decision points assessing achieved results and authorizing continuation of development and validation activities along the lifecycle. Each Gate is based on a set of success criteria. The Gates are:

- **Gate ER/IR:** This Gate verifies the achievement of V1 maturity as a condition required for transition from Exploratory Research to Industrial Research and Validation. The Gate may authorize the transition to phase V2 or to a complement/extension of V1 validation taking place in the Industrial Research and Validation domain.

- **Gate V1:** This Gate verifies the achievement of full V1 maturity and authorizes transition to phase V2. In case the Gate ER/IR has concluded to a full V1 maturity, this Gate V1 can be skipped.

- **Gate V2:** The Gate may authorize transition to phase V3. This Gate has two objectives
  - verifying the achievement of full V2 maturity
  - accepting the plan for future V3 validation activities.

- **Gate V3:** This Gate verifies the achievement of full V3 maturity. The Gate may authorize transition to the Industrialization and Deployment phase
- **Gate DEMO:** This Gate, based on a set of criteria confirming readiness for wide scale Deployment, verifies successful achievement of Demonstration objectives. The Gate may confirm transition to the Industrialization and Deployment phase.

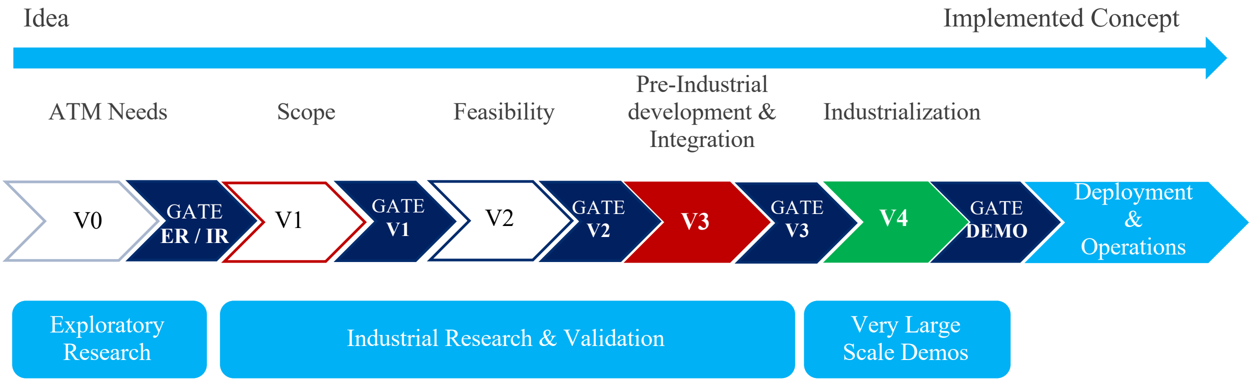

Figure 7 - SESAR 2020 phases & gates

The first three phases develop and validate the SESAR Solution up to, respectively, the E-OCVM maturity levels V1, V2 and V3. These levels correspond to the Technology Readiness Levels TRL2, TRL4 and TRL6.

Demonstration activities, executed by Projects in the VLD domain, are in some cases justified to bridge the gap between Pre-Industrial Development & Validation and Industrialization & Deployment. When they take place, these activities ensure a step beyond V3 maturity, up to TRL7.

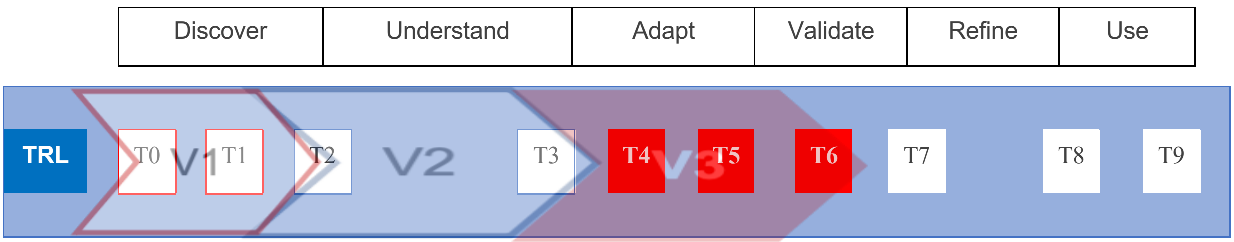

Figure 8 - NASA TRL Vs. 7V Phases

Within each project, you will find a variety of Solutions. These are new or improved operational concepts, procedures or technologies that aim to contribute to the modernization of the European ATM system. The range from quick win options to more complex solutions therefore can be at differing states of maturity.

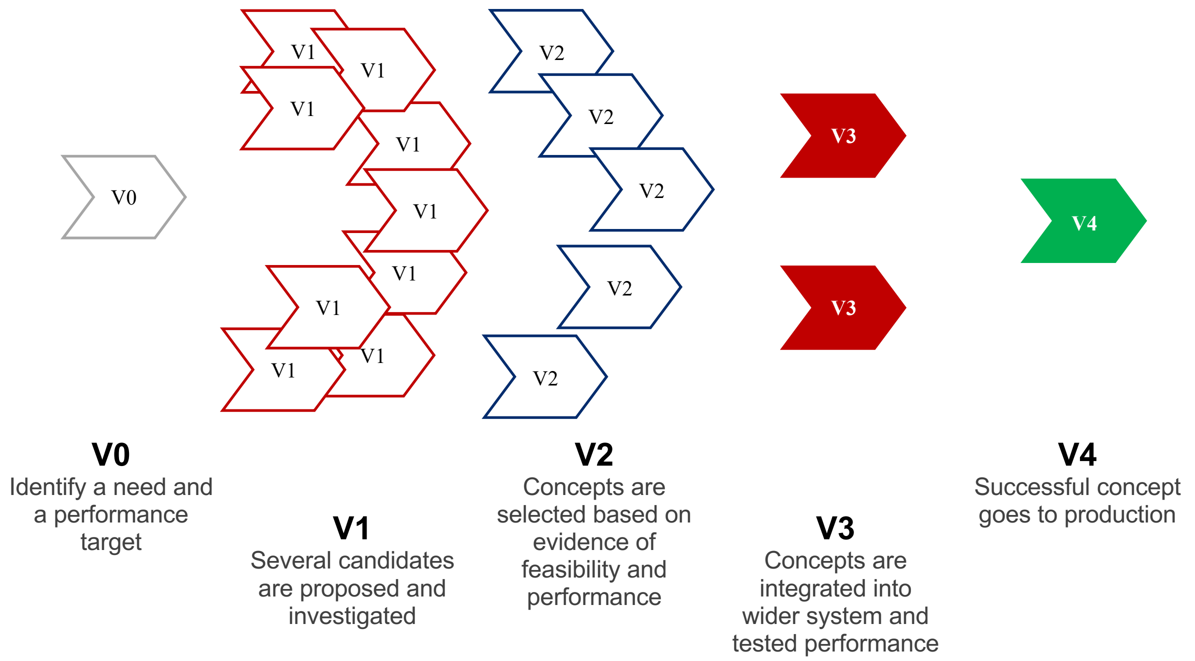

Figure 9 - Maturity and Selection Concept

Each Solution is performance driven and assessed according to Key Performance Areas such as Safety, Cost Efficiency, Capacity or the Environment at specific stages of flight, and in specific operational environments, with benefits applicable to particular stakeholders.

When working on a recent solution whereby a validation exercise addressed multiple variants of a concept, some of these elements worked while others needed more development. It's normal that some Solutions need a bit more tweaking along the way before performance benefits are realized while others may get stopped during work in progress and may not complete their journey. This is the whole point of validation and research that ensure us we are going to invest our future money and efforts in the right concepts and projects that will provide value.

3.2. SESAR 2020 MAJOR PROJECTS

Projects that majorly contributes in the Industrial Research phase are here mentioned:

EXPLORATORY RESEARCH

MINIMA	MItigating Negative Impacts of Monitoring high levels of Automation
MALORCA	Machine Learning of Speech Recognition Models for Controller Assistance
OptiFrame	An Optimization Framework for Trajectory Based Operations
BEST	Achieving the benefits of SWIM by making smart use of semantic technologies.
PACAS	Participatory Architectural Change Management in ATM Systems.
SALSA	Satellite-based ADS-B for Lower Separation Minima Application
CORUS	Concept of Operations for the EuRopean UTM System
AIRPASS	Advanced Integrated RPAS Avionics Safety Suite
SECOPS	An integrated SECurity concept for drone OPerationS
TERRA	Technological European Research for RPAS in ATM

INDUSTRIAL RESEARCH

PJ 01	Enhanced Arrivals and Departures
PJ 02	EARTH Enhanced RWY Throughput
PJ 03a	SUMO Integrated Surface Management
PJ 03b	Airport Safety Nets
PJ 04	Total Airport Management (TAM)
PJ 05	Remote Tower for Multiple Airports (MRT)
PJ 08	AAM Advanced Airspace Management
PJ 09	DCB Advance Demand and Capacity Balancing
PJ 10	Separation Management en-route & TMA
PJ 14	Essential and Efficient Communication Navigation and Surveillance Integrated System
PJ 16	Controller Working Position Human Machine Interface (CWP HMI)
PJ 18	4D Trajectory Management
PJ 19	CI Content Integration

VERY LARGE SCALE DEMONSTRATIONS

PJ 25	Arrival Management extended to en-route Airspace
PJ 28	Integrated Airport Ops

Figure 10 - SESAR Projects

The research covers an extremely wider conceptual area, but to mention all the projects would be beyond the scope of this thesis.

4. SESAR 2020 WAVE 1 -PJ 05 REMOTE TOWER FOR MULTIPLE AIRPORTS

PJ 05 is the focus of our study, and we will analyse it in detail in this chapter.
To help everyone understand the complexity of each project and to leave a trace of the research already carried out and that which will be carried out, SESAR provides the ATM Master Plan through its portal (*https://www.atmmasterplan.eu/data/projects*). On their website, we can find tree diagrams with hyperlinks to each project that gave us an immediate understanding of the scope of each project, how it relates to other research, the V phase it has already reach and his deadline. The steady decrease in the real cost of air travel, the accessibility of it has significantly increased with consequently led to the increase in the demand for air transportation. One of the components of the cost of the air travel is air navigation service (ANS) costs for the provision of ATM services by an air navigation service provider (ANSP). That's why ANSPs has faced with a challenge for optimisation and reduction of operational costs, especially for small and medium airports with low and/or irregular traffic to cover these costs.

The remote tower concept is the basis of a series of SESAR solutions that all aim to increase the cost efficiency of air traffic service provision, thus offering the possibility of improving efficiency and safety at airports where it is too costly to build and/or maintain a conventional ATS tower. Another purpose of the remote tower is to improve safety. Various technologies have been developed with this in mind:

- **Virtual stop bars**, to support controllers in low visibility conditions (SESAR Solution #48)

A line of red lights, known as a stop bar, is currently in place to prevent aircraft from entering the runway without controller clearance. In addition to these physical safety nets, SESAR is developing a new technology known as virtual stop bar solution to support the ground controller in providing guidance to surface movement by displaying red stop lights on his display. Once this technology is operational, the ATCO will be able to activate this tool in low visibility conditions to introduce procedural control and maintain safety separation by requesting permission for aircraft to enter different areas; these virtual stop bars can be used by the controller to reduce the size of areas according to conditions. When the airport surface surveillance system identifies an infraction, the controller's display receives an alert.

Real-time simulations tested the solution, including the use of datalink communications with aircraft and vehicles at the airport.

- Electronic flight strips (SESAR Solution #02)

E-Strips makes the instructions given by a controller available electronically and integrated with other data, allowing the system to monitor the information and alert the controller when inconsistencies are detected. Using airport surface surveillance sensors and ground security networks, controllers can warn pilots of potential conflicts.

- Digital anti-collision system (PJ - 03b - 05)

Runway incursion is one of the biggest causes of collisions in the airport world. This solution is designed to provide pilots with a final warning of impending runway and taxiway collisions, based on the software on board the aircraft. Specifically, the system analyses aircraft position data and calculates factors, such as collision time, using specialized algorithms before alerting pilots of surrounding aircraft. Sufficient ADS-B performance is a key factor, which is why work was undertaken in SESAR 1 and then followed up in SESAR 2020 (PJ.28, large-scale) to evaluate ADS-B performance, including data quality.

While Single Remote Tower has already been implemented in several locations, PJ05 dealt with Remote Supplied Air Traffic Service for Multiple Aerodromes, where an ATCO provides ATS for two or three aerodromes simultaneously from a Multiple Remote Tower Module. The goal of PJ05 was to expand the scope of multiple remote tower solutions to allow "multiple" control in more complex traffic and environmental situations, for two or three simultaneously controlled aerodromes, to further increase cost efficiency and job satisfaction.

Special attention was paid to improving HMI design, planning support and workload balancing through the flexible allocation of aerodromes to a multiple remote tower module (MRTM). The project consists of 3 main work packages (two operational and one technological), also called "Solutions":

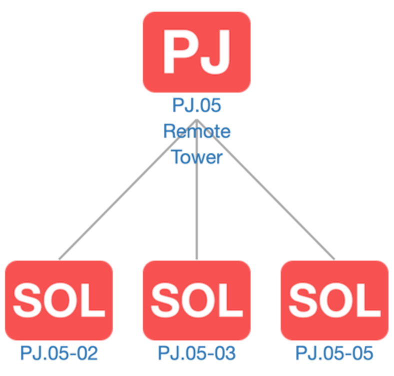

Figure 11 - PJ05 Solutions
[SESAR eATM Portal]

Solution PJ.05-02

Multiple Remote Tower Module (V1 → V3)

Solution PJ.05-03

Remote Tower Center (RTC) with Flexible Allocation of Aerodromes to MRTMs (V1 → V2)

Solution PJ.05-05

Advanced Automated MET System (TRL2 → TRL4)

The two operational solutions describe sequential steps to extend the reach of multiple remote tower services. The PJ.05-02 solution aims to reach the V3 maturity level at the end of this project, the PJ.05-03 solution the V2 maturity level, and the V3 level will be reached at the end of the next R&D phase. The PJ.05-05 technology solution, on the other hand, was to reach TRL4 maturity level.

At the base of all these solutions there is an Essential Operational Changes, the **Virtualization of Service Provision**. It is the ability to provide air traffic services from a remote location in all operating environments either it is airport, TMA, or en-route.
In TMA, and enroute environments, the virtual center concept allows a geographical sector to be managed from anyplace subject to the availability of services crucial for the provision of ATS:

- CNS Communications, navigation and surveillance
- MET Meteorological
- AIS Aeronautical information service
- All data related to the flight plan

To make the Virtualization became reality a certain number of projects and Deployment Scenarios need to be completed.

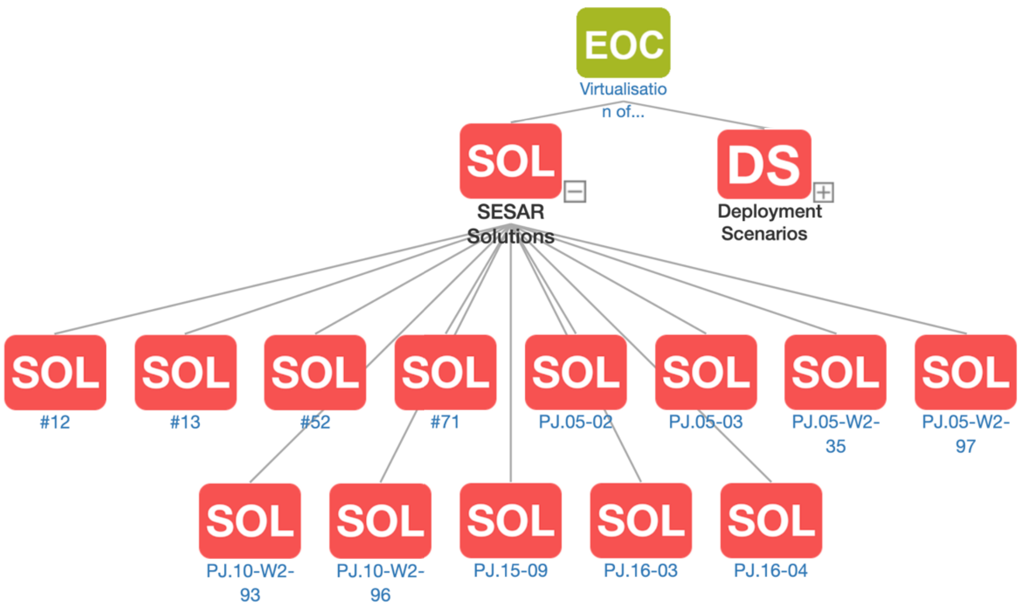

Figure 12 - Projects for virtualization

Here we can also find the PJ16 - CWP HMI, that take care of Controller Working Position (CWP) Human Machine Interface, already analysed by us in the Bachelor Thesis "Nextower Technology and Implementation".

4.1. MRTM CONNECTIONS, INSTRUMENTATIONS & SERVICES

The following diagram represents the high-level interactions between the CCs involved. The Resource Connectivity for Solution PJ.05-02 & PJ.05-03.

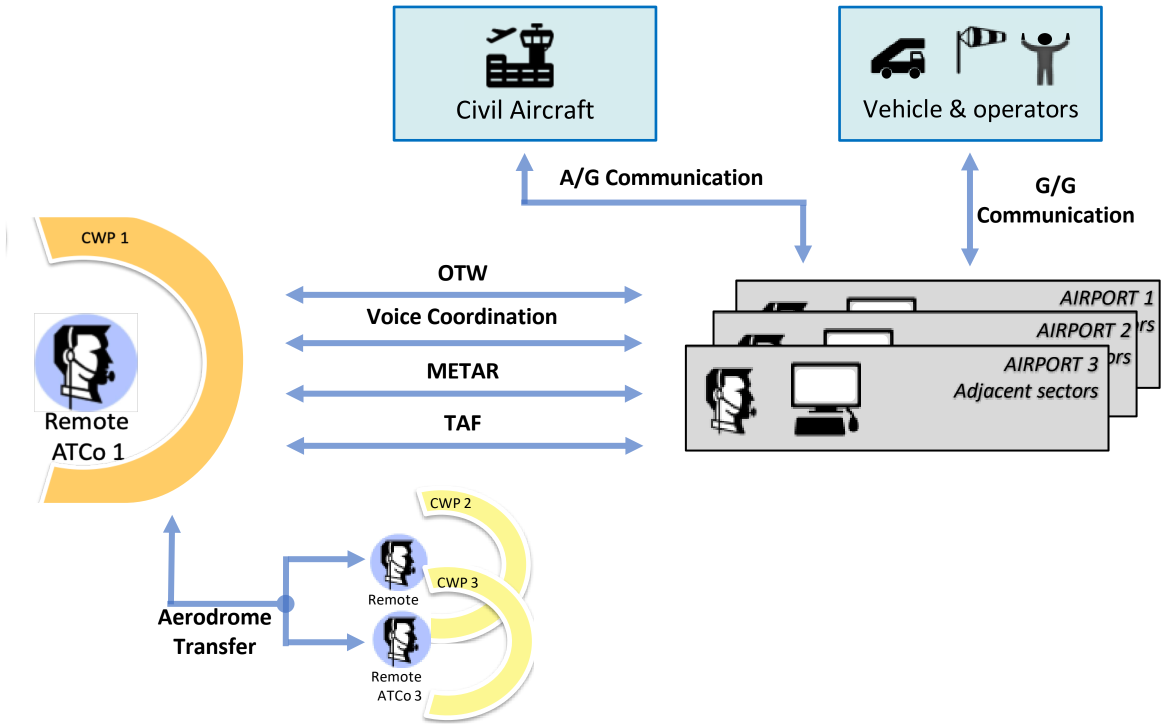

Figure 13 - MRT Connnnections

4.1.1. OTW (OUT THE WINDOW)

The OTW (Out The Window) functional block allows ATCOs to have a representation of what they would see from the window of one or more conventional control towers under normal operating conditions, in order to support ATCOs in managing air traffic. The OTW provides remote tower controllers with a clear view of what is happening at the aerodrome and all air traffic present, through a visual presentation.

OTW can also help the ATCO identify targets in low visibility conditions with the support of aerodrome surveillance data. This functionality is possible thanks to the fusion of surveillance information from different sources and provides a unique picture of the actual traffic situation.

Inside the OTW functional block, different functions are included:

- OTW includes several functions:
- Visual presentation PTZ cameras
- Additional views, e.g. IR cameras
- Tracking function

4.1.1.1. VISUAL PRESENTATION

In the Remote Tower, together with the CWP, an appropriate OTW visualisation function will provide ATCOs a view of the aerodrome to assist them in air traffic management.

Data acquired from the remote aerodrome (e.g. video) are sent to the Multiple Remote Tower module, where the system's OTW will display the data on the visual presentation to allow the ATCO to see the actual view of the multiple control towers.

4.1.1.2. PAN-TILT-ZOOM (PTZ) CAMERAS

Remote towers make extensive use of cameras that collect and send images of the airport to the MRTM to give remote ATCOs the same view as conventional ATCOs. The remote tower environment is equipped with PTZ (Pan Tilt Zoom) cameras that the ATCO can remotely manage to focus the image on a specific area of the airport with the correct zoom. The PTZ cameras also provide the system with additional functionality, such as automatic tracking, anomaly detection, etc.

4.1.1.3. ADDITIONAL VIEW

In addition to cameras, conventional or PTZ, the remote tower system can be equipped with additional sensors to support the operators; their main role is to support viewing of critical, dark areas where visibility is reduced or absent. The system can be supported by infrared (IR) cameras, A-SMGCS or laser systems that provide additional information on the position of the aircraft and/or vehicle on the runway.

4.1.1.4. TRACKING

This component performs automatic object tracking functions based on the available video streams. The output of this component is the position information of the identified object, or its marking superimposed on its image in the video stream. Tracking can be performed using only video data or by exploiting a combination of position information from different sensors.

Data fusion combines different inputs from surveillance sensors and generates the trace of the specific object.

The data used as input could come either from conventional surveillance sensors (such as radar, Mode S, A-SMGCS, etc.) or from dedicated remote tower sensors (such as cameras, IR, etc.) to provide the remote ATCO a common image, for normal and low visibility, in a dedicated or separate OTW display. The anomaly detection function could provide alerts to the ATCO and the AFISO (aerodrome flight information service officer) when anomalies are detected in the airport area to help him in preventing collisions.

4.1.2. CONTROLLER HUMAN MACHINE INTERACTION MANAGEMENT (CHMIM)

The CHMIM functional block provides ATCOs with a graphical user interface and the means to provide ATC services at different aerodromes in parallel.

Its main responsibility is to provide the most relevant communication information, to support flight data management and to provide a friendly user interface to the ATCO. All the information is well organised to provide an efficient and safe working environment and additional functions support the controller in maintaining situational awareness at multiple airports. In addition to what ATCO usually needs for ATCS services, in the remote tower environment, the CHMIM must provide additional data related to the environment, such as video from external cameras, real-time weather information, etc.

4.1.3. A/G VOICE COMMUNICATION

This block provides the functions performed by a radio VCS. In the remote tower operation scenario, the air-to-ground communication is not directly interconnected to the local radio, but it needs a dedicated connection to the local radio to access the air-to-ground communication. Therefore, an additional infrastructure and access gateway for the radio will be required.

It must be considered that a backup or emergency radio system will require a dedicated backup connection between the local tower and the remote tower center. Standard fall-back solutions, such as portable radios used directly in the tower, are not applicable to the remote tower scenario.

In a scenario with several remote towers, the VCS system must combine and manage all frequencies of the relevant airports. Based on a role concept, an assigned frequency function or frequency pairing must be provided to an ATCO.

4.1.3.1. AERONAUTICAL MOBILE SERVICE

The aeronautical mobile service allows the ATCO to make direct contact with the pilot of the aircraft, as with conventional ATCOs. An appropriate data link for air-to-ground communication must be considered.

4.1.3.2. SIGNAL LIGHT GUN (SLG)

In the event of radio failure, air traffic control can use a signal lamp to direct the aircraft. The signal lamp or Signal Light Gun (SLG) has a focused beam and can emit three different colours: red, white and green. The remote ATCO, in this case, needs a link to control the SLG remotely.

4.1.4. G/G VOICE COMMUNICATION

This functional block provides the function that allows the ATCO to use the communication infrastructure to communicate with remote airports, in particular aviation services and surface vehicles. This connection can be made using the traditional voice system or the innovative Ground Datalink.

4.1.5. WEATHER INFORMATION

4.1.5.1. METAR

The METAR (acronym for METeorological Aerodrome Report) is a coded message containing meteorological information, The frequency of emission may be 'hourly' or 'half-hourly' depending on the type of traffic supporting the airport.

4.1.5.2. TAF

A Terminal Aerodrome Forecast or TAF is a weather forecast valid from 6 to 30 hours for an aerodrome and using a coding equivalent to the METAR format. TAFs also contain additional information, such as the percentage probability of the occurrence of a phenomenon

4.1.6. CONTROL WORKING POSITION (CWP)

The following picture shows the HMI used for 2 airports, where each one was presented side by side. For the validations of 3 other environmental airports, two different layouts were used: one on top of the other or a mix of one on top and one next to the other.

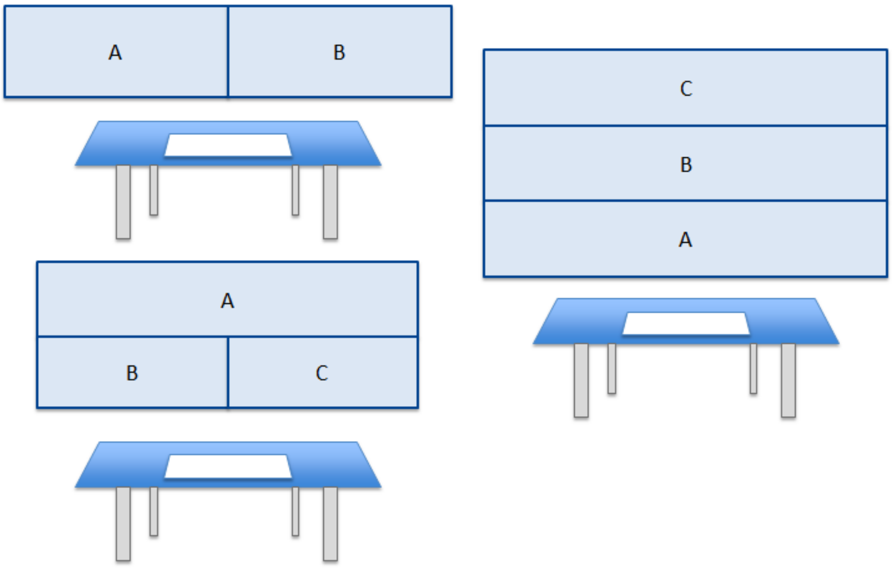

Figure 14 - CWP HMI configurations

4.2. PJ 05 - 02 MULTIPLE REMOTE TOWER MODULE (MRTM)

The objective of PJ.05-02 is to develop and validate a multiple remote tower module (MRTM) that allows the ATCO to maintain situational awareness for 2 or 3 airports simultaneously, with the goal of bringing this technology to V3 maturity. PJ05-Solution 03 is a closely related solution that develops and validates the Remote Tower Center (RTC) functionality.

Since the main objective of the solution is, in addition to maintaining safety, to increase cost efficiency, which cannot be verified directly in exercises, the validations focused on safety and human performance.

4.2.1. VALIDATION OF PJ05-02: REACH V3 PHASE

The validations were carried out with real-time simulations, performed at different locations based on different prototypes.

First of all, in order to complete the project, an operational improvement, consisting of 4 enablers, must be implemented, i.e. new or modified technical system, procedure, standard or regulation necessary to make (or enhance) an operational improvement.

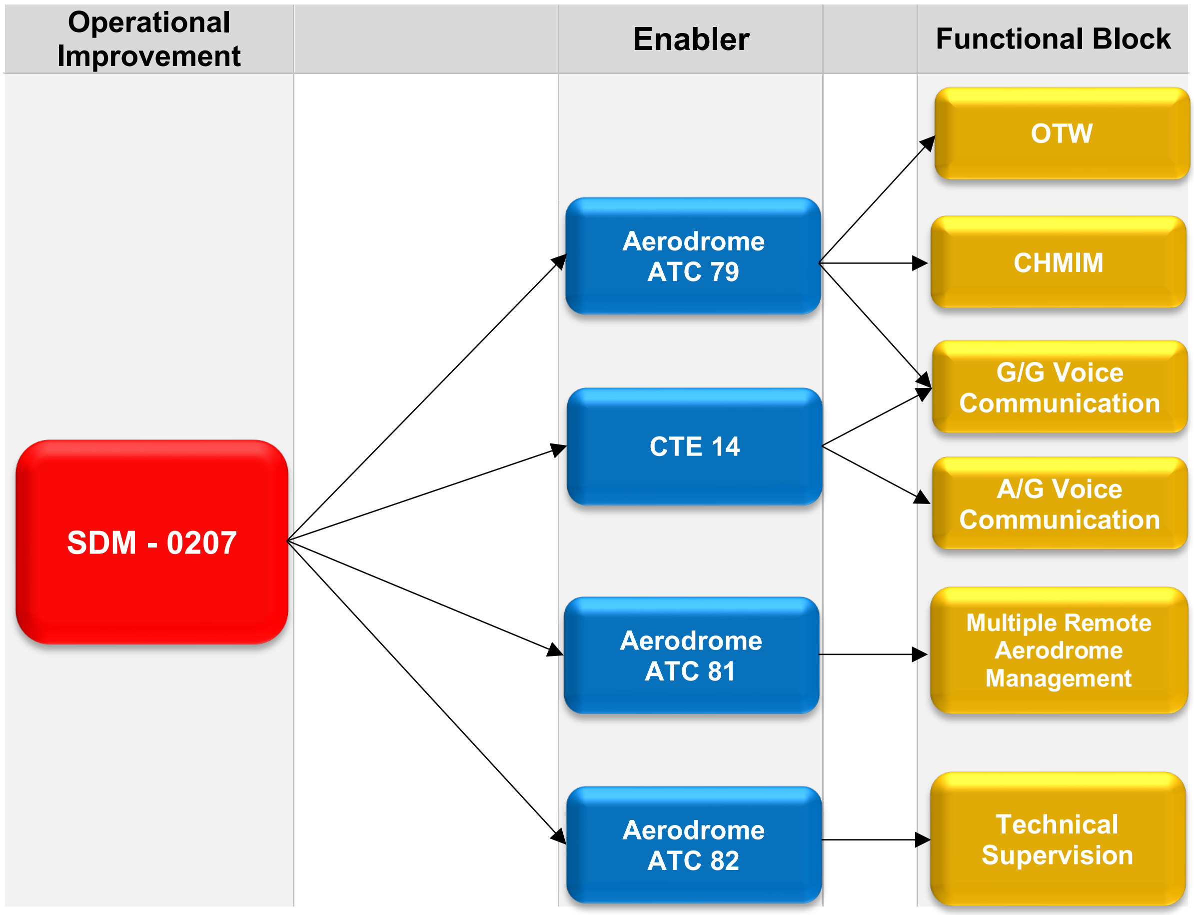

Figure 15 - SDM 0207 Scheme

The objective of all validation exercises was to validate two or three aerodromes simultaneously controlled by an ATCO with a total traffic level of 20 movements per hour.

The main conclusions of the validations are:

- ✓ A multiple remote tower, with an ATCO controlling more than one aerodrome simultaneously, can be safe if operator workload and situational awareness (SA) are kept at reasonable levels. where:
  - The workload and situational awareness of the ATCO are related to complexity. Factors contributing to complexity are, for example, traffic load, VFR/IFR mix, airport layout. Multiple remote control is a factor affecting workload and safety and must be considered (like all other factors contributing to complexity) when using MRTM.
  - Short-term planning tools helped the ATCO monitor and predicted traffic loads. Validations showed that safety could be maintained, both for ATCOs participating in the test as subjects and for experienced observers.
- ✓ The complexity of the airport layout has an impact on capacity
- ✓ Several HMIs could be used, one next to the other, and a combination was tested.

- ✓ The use of the airport name in the communication adds situational awareness and it was not necessary to add a phrase indicating Remote Control.
- ✓ The angle of the VP (Visual Presentation) presenting the airports is important for situational awareness and must be considered.

Validations, conceived as real-time simulations, allow various hazards and technical degradations to be stressed without any risk compared to testing in active mode. A shadow mode test was performed. These situations focus on ATCO situational awareness. The tests were carried out in different locations based on different prototypes.

An ATCO planning tool, improved voice communication and an improved HMI design served as technical enablers that bring the maturity level increased from V1 to V3.

To reach V3 maturity of Solution 02, the following four validations with the following properties were performed:

	COOPANS	INDRA	FSP	ENAV
Airports				
Number of simultaneous Airports	2	3	3	2
Traffic Volumes – amount per hour	20 (a/c + vehicles)	20-25	20 - 30	10-20 (a/c + vehicles)
VFR Traffic	~ 50%	~13%	10-20%	NIL
Panorama				
Monitor alignment	Side by side	Side by side and above	Above each other	Side by side
Viewing Angle (panning)	330° / 45°	180° / 40°		160° / 180°
PTZ				
Displayed	In Panorama	N/A	Next to panorama	In Panorama
Hot Spots (Pre-set positions)	Pre fixed locations	N/A	N/A	Pre-fixed locations
Automatic Tracking	Yes	N/A	N/A	N/A
Manoeuvring	Mouse steering	N/A	Separate input device	Separate input device
EFS				
Integrated into one Screen	Columns	Columns	Columns	Columns
VFR Flight plans available	Yes	Yes	Yes	N/A
Radar				
Air situation Display	Yes	Yes	Yes	Yes
MRTM				
Colour coding for each airport	Yes	No	Yes	N/A
Merge / Split	Yes	Yes	N/A	Yes - optional
Voice communication				
Phraseology with Airport ID	Yes	Partly	Yes	Yes
Frequencies	Coupled	Coupled	Coupled	Coupled

Figure 16 - Properties of Validation test

EXE-05.02-V3-002 - COOPAN

Objective: Verify the situational awareness of ATCOs when providing ATS to multiple aerodromes simultaneously.

Conclusion: The experience with the CWP's user-friendliness exceeded the ATCOs' expeATCtions. After each test, the ATCOs were asked how representative the scenario was of the real environment. The answers were given on a five-point scale, with an average of more than four points.

EXE-05.02-V3-003 - INDRA

Objective: Evaluate the ATCO's ability to provide ATS to three airports at a time from an integrated controller position. The ATCO simultaneously performed the roles of permit delivery, ground controller and tower runway controller for the three airports.
Validation covered situational awareness, the maximum amount of total traffic per hour in a multiple remote tower module (MRTM) and the maximum simultaneous movements handled by the ATCO.

Conclusions: The results show that one controller can handle up to 25 movements for three aerodromes in an MRTM. Safety was not compromised during validation. It was seen that with a high workload, efficiency decreases slightly in some situations as the controller has to hold traffic while dealing with other situations.

Recommendations:

- ✓ The use of electronic flight strip systems (EFS) should be recommended in a multiple environment.
- ✓ The complexity of airports and traffic determines the workload and must be carefully considered when combining airports. A short-term planning tool for multiple operations is recommended.
- ✓ An integrated HMI with a harmonised user interface and as few input devices as possible is recommended.

EXE-05.02-V3-004 - FSP

Objective: Ability to provide ATS to three airports simultaneously, with emphasis on situational awareness and workload. The traffic distribution was varied between scenarios.
In addition, two scenarios included wind shear warnings and wind changes that resulted in a change of direction of the RWY. Two other scenarios included an unscheduled shutdown of RWY due to an oil leak and the fifth scenario introduced an emergency landing. The responsibilities of the ATCOs included the delivery of clearances, the ground controller and the tower runway controller for all three aerodromes simultaneously. As another objective, the usability of the HMI design (planning tool, wind display) was evaluated.

Conclusions:

- ✓ Although this is not a problem solely related to the MRTM, ideal camera positions (for fixed and Pan tilt Zoom - PTZ cameras) are sometimes not available and further mitigation actions should be implemented.
- ✓ During night hours, image quality may decrease; this issue should be further investigated in V4 and V5.
- ✓ The PTZ is intuitive to use and is an efficient tool; moreover, controlling the three PTZs with one mouse is a good concept. On the other hand, some automatic functions could be added (e.g. object tracking) and the PTZ control should be as simple as possible to support the provision of ATS in high workload situations.
- ✓ The overlay information (labels, MET information, RWY and TWY contours) is accurate and useful.
- ✓ The short-term planning tool is useful and important, but a long-term planning tool with limited content may be needed to predict traffic volumes and complexity.

EXE-05.02-V3-005 - ENAV

Objective: To evaluate the ability of the ATCO to provide ATS to two aerodromes from an ad-hoc developed MRTM and under different conditions of traffic volume and complexity.

Conclusions: From the analysis of the ATCOs' feedback, the implementation of the "Remotely Provided Air Traffic Service for Multiple Aerodromes" has an impact on their operational activities in terms of working methods, timeliness and accuracy of tasks and communication.

They did not report any specific problems either in terms of mental workload or situational awareness, but underlined that the effective implementation of this new operational method requires careful case-by-case evaluation according to the scenarios considered.
They reported a positive expectation regarding the level of service provided, thanks to which the overall management of two aerodromes simultaneously will potentially be improved.

4.2.2. COST-BENEFIT ANALYSIS (CBA)

The CBA for SESAR PJ05 solution 02 was calculated between 2019-2040, cause 2019 is the year of the research. Figure 17 shows the CBA model, that includes cost and benefit mechanisms as inputs, benefit-cost ratio, and payback period as outputs.

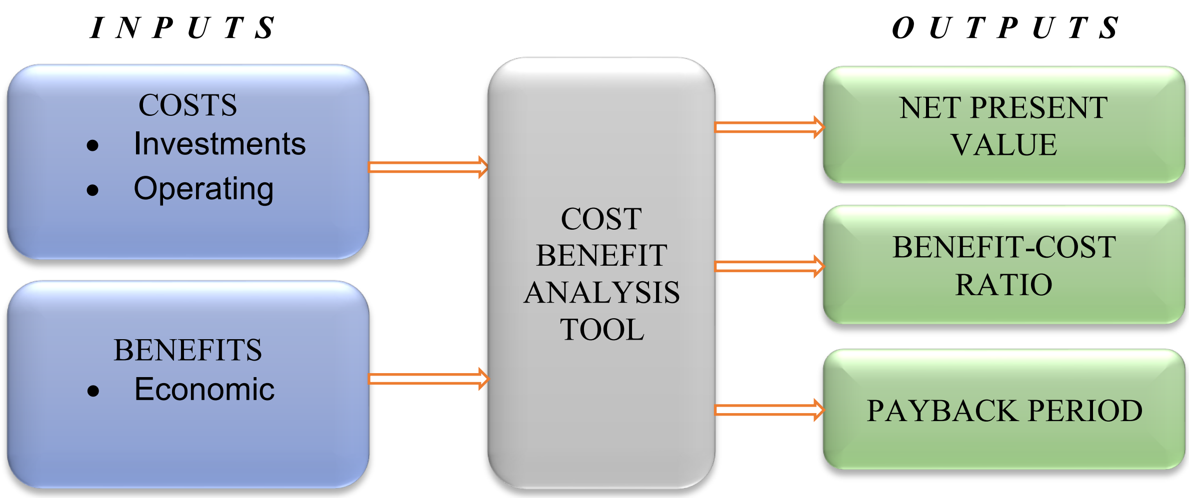

Figure 17 - PJ05.02 CBA

The following figure shows the expected benefits, expected costs and progressive cash flow for ATS provided remotely for multiple aerodromes.

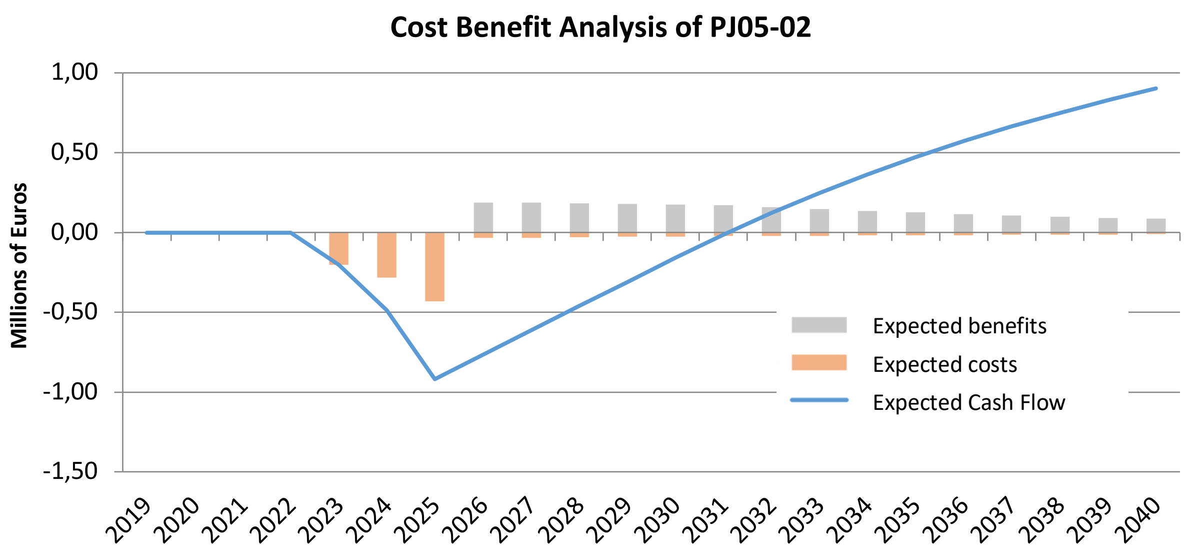

Figure 18 - PJ05.02 CBA Graph

The cost-benefit analysis shows that the implementation of Solution02, compared to a "without Solution" scenario in which these investments would not be undertaken, would generate a Net Present Value of EUR 0.9 million, with an amortisation period of 13 years. This Net Present Value was obtained considering a total investment of EUR 1.2 million.

The steps of the analysed IO solution are applicable to airports already equipped with an ATS service. If an ANSP wants to implement MRTM from zero, it must take the CBA of SESAR *Solution #12 & Solution #71 - Single Remote Tower*, combine it with this CBA and build a new model for its local characteristics based on both.

This analysis is not object of the following thesis, where the single remote tower solution was not analysed.

4.3. PJ 05 - 03 RTC WITH FLEXIBLE ALLOCATION OF AERODROMES FOR MRTM

The PJ05.03 solution has currently only reached Phase V2, while Phase V3 is in progress. Again, the goal of this solution is to increase cost efficiency, which cannot be validated directly in exercises, so the validations focused on safety and human performance.
The validations were set up as real-time simulations, performed in different locations based on different prototypes. The simulations also included the integration of the real-time simulation for the supervisor's planning tool. PJ.05-03 shall develop and validate:

- MRTMs that enable ATCOs to provide ATS service to remote aerodromes while maintaining situational awareness for 3 airports at a time.
- an RTC and the subsequent a dynamic allocation of airports between MRTMs.

These technologies must be able to support a traffic volume for simultaneous movements of:

3 airports with up to 6 simultaneous movements
20-30 movements (air and ground) per hour in total for all airports.

Traffic volumes in specific situations may deviate from this indication depending on the complexity of the traffic and other factors influencing the workload.
The Remote Tower Center (RTC) is the centralised facility that houses one or more MRTMs and from which remote ATS can be provided to one or more aerodromes.

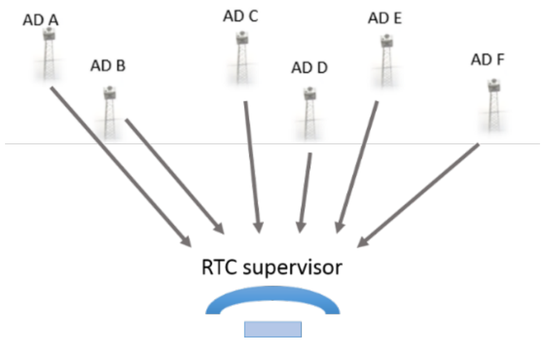

Figure 19 – RTC Supervisor Role

To achieve the goal of increasing the number of aerodromes and traffic volumes to be controlled from an RTC, two complementary approaches have been studied

- Implementation of additional automation functionalities for the ATCO in the MRTM (e.g. compliance monitoring, task prioritization) to allow an MRTM to simultaneously control more aerodromes and/or higher traffic volumes from an ATCO
- Supervisor can dynamically assign any airport to another MRTM within the Remote Tower Center (RTC) to balance ATCO workload and traffic volumes.
  Since more airports are grouped than in the PJ.05-02 solution, as interactions between multiple MRTMs are taken into account, this leads to greater complexity in planning. The supervisor will be supported in the evaluation of traffic volumes and workload by a planning tool.
- The interconnection of systems in the MRTMs/RTCs and the procedures that make it easier for ATCOs to have support for more than 3 airports.

In this way, it is easy to see how Solution PJ05-03 can be considered an evolution of Solution PJ05-02. Several MRTMs are located within a Remote Tower Center (RTC), under the responsibility of an RTC supervisor. This new figure, introduced by Solution 03, sees a person responsible for managing activities in the operations room, including the division of airport traffic and available forces. The position of RTC supervisor can be filled by an ATCO or, alternatively, it can be a separate working position for this job.

Thanks to Solution 03 the provision of remote ATS service to remote aerodromes can be dynamically assigned to any other Remote Tower Module (RTM) within a Remote Tower Center (RTC). The identification code of the related operational enhancement is:

• SDM-0210: Highly flexible allocation of airports to remote tower modules.

4.3.1. RTC SUPERVISOR ROLE

The RTC supervisor, with the support of a planning tool, is responsible for assigning the different aerodromes to the available MRTMs. The assignment is determined by taking into account various parameters, such as aerodrome information, current and forecast traffic, weather information and controller approvals. In addition, this solution adds automation support to controllers, alerting them in the event of a potential conflict.

In the event that an unforeseen event, such as an emergency situation, occurs at one of the airports, significantly increasing the ATCO's workload and compromising its ability to continue to provide ATS to all airports under its responsibility, the ATCO must be able to handle the abnormal situation by relying on other MRTMs. The following figure shows the flow from Multiple Remote Tower to Single Remote Tower and back to Multiple Operations.

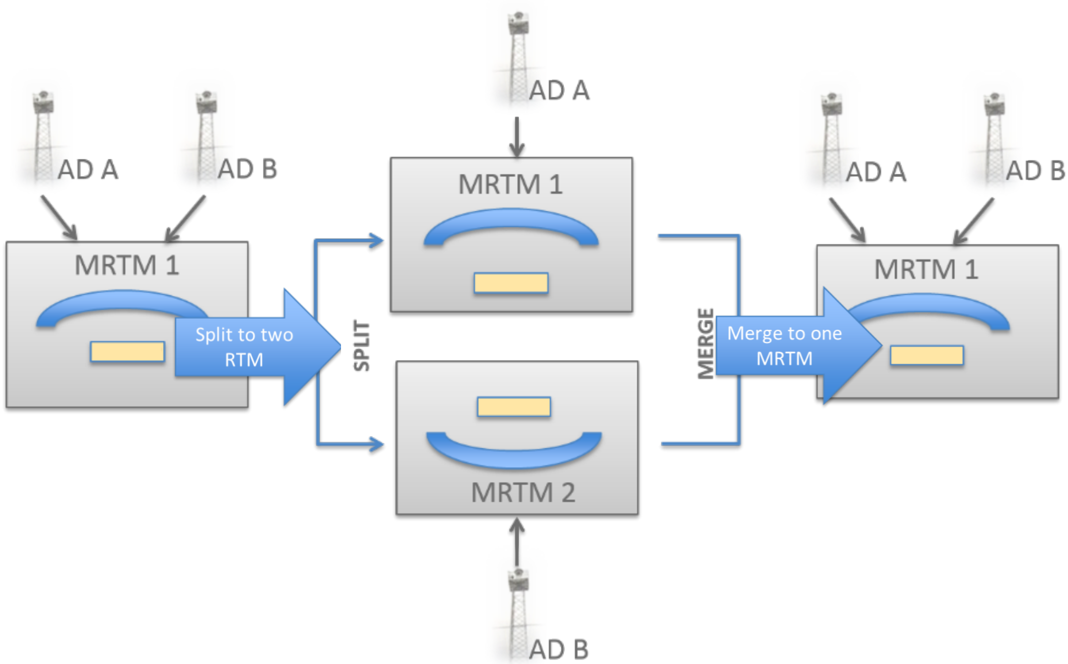

Figure 20 - Flexible Allocation Properties

4.3.2. VALIDATION OF PJ05-03 : REACH V2 PHASE

The following architecture was used for Solution 03. It should be noted that these are the Functional Blocks impacted by the mandatory Enablers of this solution; therefore, these will be the core of this solution.

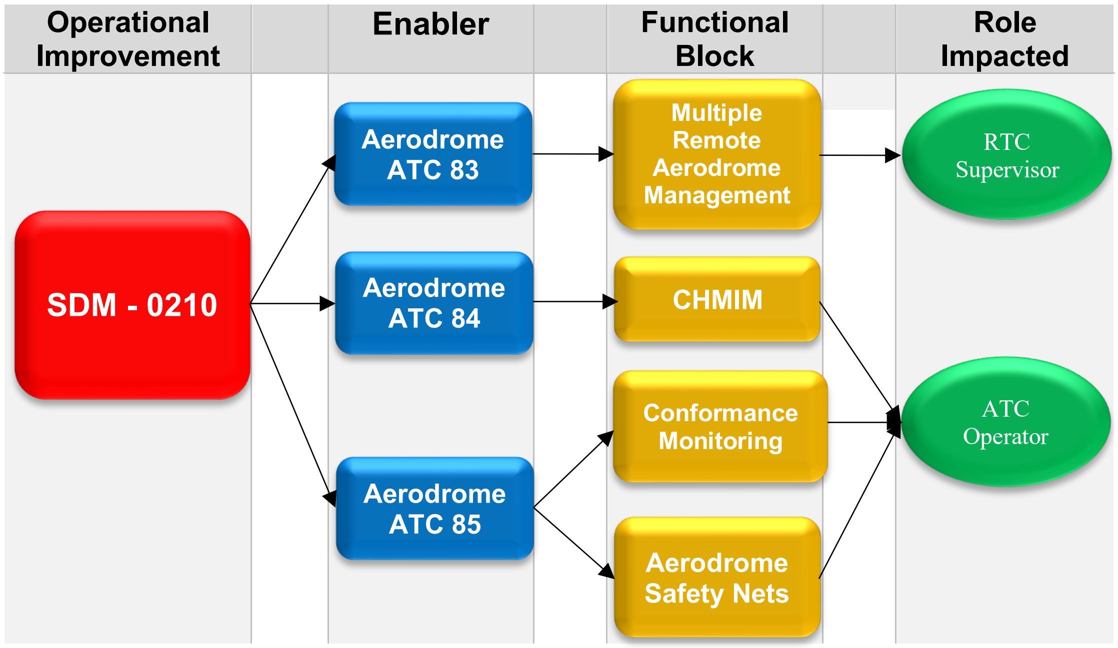

Figure 21 - SDM 0210 Scheme

The following four validations were executed in order to reach V2 maturity for Solution 03:

EXE-05.03-V2-3.1 - ON

Validation Exercise description

The operational scope of this exercise concerns the provision of ATS to three airports using one or two MRTMs, each managed by an ATCO, depending on the decision of the Supervisor and specific events (emergency and traffic overload situations) using a real-time simulation platform integrated with a smart strip planning tool.

The set traffic volume simulates a traffic peak to identify potential problems and develop solutions. The validation platform consisted of the following main parts:

1) Visualisation System (panoramic view) with overlays and labels
2) PTZ camera panel
3) Support displays (radar + ground radar)
4) Planning panel and flight data handling system
5) Pad for ground communication channels

Figure 22 - "ON" Validation Platform

The CWP configuration used is top-down, while the flight strip system and radar screens use a left-to-right columnar airport representation. The panoramic view was fixed at 200° with the support of a manual PTZ and labels for all vehicles.

Weather information (wind direction and strength, crosswind, tailwind, visibility, QNH) and RWY information (ICAO aerodrome code, RWY direction) are presented in a wind rose on both ends of the RWY. Different types of representation have been adopted to allow the ATCO to have a high level of situational awareness; here are some examples:

if a RWY was blocked by the ATCO on the flight strip system, the outer circle of the compass rose would turn red to indicate the blockage on the panoramic view. A squelch indication in the panoramic view (coloured bars at the top of the panorama of each aerodrome) and on the flight strip system was integrated to show which aerodrome the transmission came from, highlighting all bars and flight strips of the corresponding aerodrome. The tower frequencies were coupled, while the ground frequencies were not, allowing the use of telephone lines to contact the APP, DAM and MET office via the buttons on the flight strip system. This made coordination between aircraft, ground, services and approach (adjacent sector) possible.

Conclusions

ATCOs were able to provide ATC to a maximum of three aerodromes at a time. Situational awareness, workload and safety were not significantly compromised, and in high workload situations, the split procedure was an effective mitigation to balance the workload. Further results and recommendations are given below.

Technical feasibility

The electronic smart strip system with planning tool is effective, but the input devices should be more effective and intuitive, e.g. the input itself should be improved to be as quick and natural as possible. In addition, visual aids such as the wind rose and coloured squelch indication are considered useful.

When splitting the aerodrome to another location, ATCOs assuming traffic control must be able to see the panoramic view and listen to all radio frequencies to gain situational awareness. After separation, information on aerodromes that are no longer in charge (visual, radar, flight strip) must be obscured or switched off and frequencies decoupled.

Performance assessments

Shifting the management of an aerodrome is an effective and appreciated measure to balance the workload. The transfer procedure tested did not have a negative impact on workload or situational awareness, but should be further developed to allow for a quick transfer.

The bottleneck was found to be the amount of communication and time on frequency in high workload situations. Multiple remote control is another factor contributing to complexity; its impact and interaction with the workload must be extensively studied for implementation and regularly monitored in live operations.

Recommendations

In addition to opening a new position when splitting an aerodrome, a more flexible allocation of aerodromes should be further investigated, e.g. by splitting an aerodrome with an already active ATCO position; furthermore, the workload should be continuously monitored for the individual ATC position in order to trigger a separation procedure before the ATCO is overloaded. More automation, such as advanced speech recognition and the use of machine learning approaches, are considered promising candidates for increasing ATCO support.

Training sessions should be longer than simulations. Training should focus on aerodrome layout, procedures and operations, as well as on HMI management, technical features and special properties in the context of multiple remote towers.

EXE-05.03-V2-3.2 – COOPANS

Validation Exercise description, scope

Fast Time Simulation

The aim of the fast time simulation was to evaluate the possible benefits of a planning tool for supervisors that could be used for a flexible allocation of airports in a remote tower center with multiple remote tower modules. The idea behind this long-term planning tool was to support supervisors in combining airports within the same RTC in the most efficient way. The main objective of the study was to find out how well the Supervisor Planning Tool was accepted by supervisors.

Real Time Simulation

The operational purpose of the real-time simulation was the delivery of ATS to three aerodromes in an operational environment simultaneously from one MRTM by an ATCO, testing split and merge operations from one independent MRTM to another, basing the transfer decision on the timing of the aerodrome's transfer on the traffic provided by the planning tool. The visual presentation system (VP) allows the ATCO to adjust the viewing angle according to his personal needs and preferences. The Electronic Flight Strip (EFS) display had built-in functionality to manage navigation aids and aviation lighting for all aerodromes. Also part of the real time configuration were the voice communication system (VCS) for communication between ATCOs and air/ground traffic and pseudo-pilot positions covering all traffic at all simulated aerodromes.

The main objective was to validate the ability of ATCOs to safely perform air traffic control from one MRTM to three aerodromes in the operational environment simultaneously, while maintaining situational awareness, in order to positively impact the cost-benefit ratio.

Platform Used

Fast Time Simulation

For the fast-time validation of a Supervisor Planning Tool, NLR developed a prototype of a long-term planning tool. This prototype allowed the supervisor to examine the workload levels for each airport during the working day. The workload levels defined with this new tool proved to be identical to those previously used for the COOPANS exercise in PJ05.02.

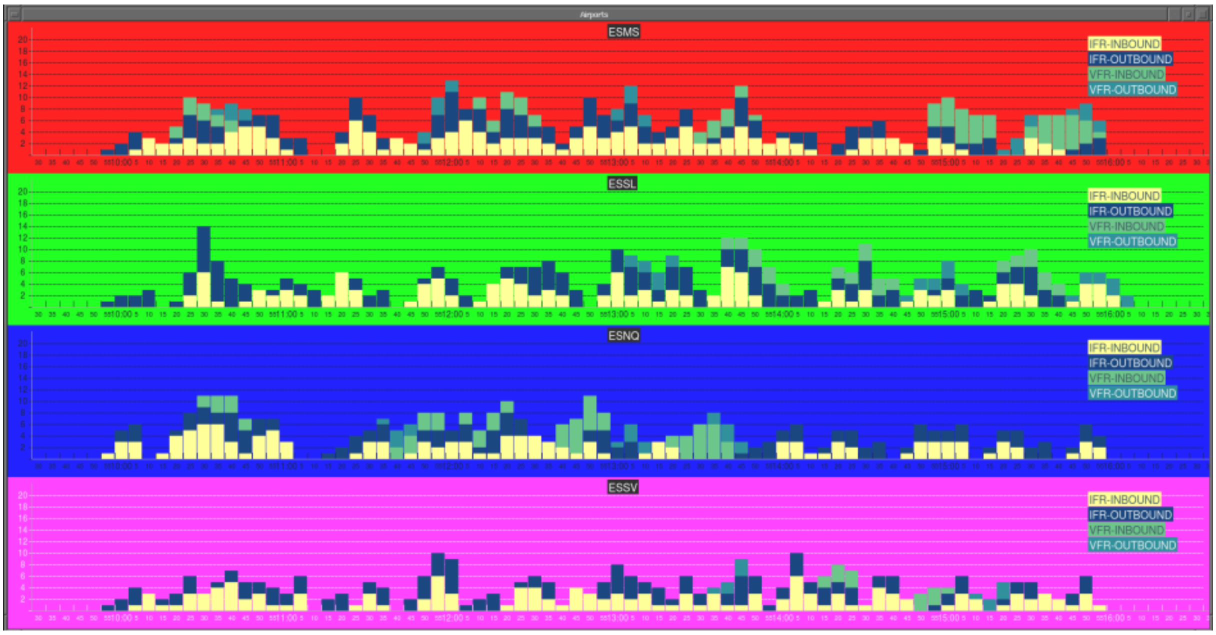

Figure 23 - Daily airport planning in 5-minute intervals provided by the tool

In this tool, the planned workload for the next 60 minutes was shown to the controller for each airport individually in one-minute intervals. The same concept was applied for the long-term workload, with the predicted workload based on the planning data for the entire day in five-minute intervals.

It was thus possible to create all combinations of traffic between the various airports, allowing the supervisor to distribute the forces of the ATCOs as efficiently as possible.

Real Time Simulation

The simulation platform consisted of one MRTM for simultaneous ATC on three aerodromes in the operational environment and a second MRTM to which the ATCO could divide a desired aerodrome, if desired. These two MRTMs were mutually independent.

The real-time simulation platform featured VPs with a 330-degree view of each aerodrome with left and right scanning and zoom in/out functionality, layout display panel, EFPS (electronic flight strips), management of aeronautical lights, and management of navigation aids. Also in this simulation we find the innovative VCS voice communication system and PTZ cameras.

Conclusions

Technical feasibility

Except for a request from the controllers to have a smoother interaction with the system and a more user-friendly management of the control window, both simulations reached the conclusion of technical feasibility.

Electronic flight strips are considered indispensable, well integrated into the technical system, using flight plan information.

Performance assessments

a) Fast Time Simulation

In general, the supervisor tool was perceived as a valuable contribution. It was intuitive and, even though it was only a prototype, already very usable. Furthermore, the tool is supposed to reduce simulation and planning time in future developments. However, attention must be paid to what the tool should or should not do. It should not be interpreted as a tool that predicts the upcoming traffic load. On the contrary, it should be clear to all users that they can use it for planning, but still be aware of unforeseen changes that may lead to higher peaks in workload or lower capacity.

b) Real Time Simulation

ATCOs were partially capable of executing simultaneous ATSs to three aerodromes at a time from an MRTM. Operational procedures, aerodrome configuration, traffic complexity and traffic level had a direct impact on situational awareness and workload.

It must be underlined that the workload was considered critical, with the possibility of an unexpected increase in a very short time. Splitting to another MRTM is a must and additional staff must be always available to help the ATCO in charge. The need to split and join one MRTM to the other in a timely manner is crucial to safely provide a simultaneous ATS.

Recommendations

a) Fast Time Simulation

One of the recommendations concerns instrumentation scales, which should all be the same or, at the very least, adjustable. Regarding easiness of control, this could be easily achieved, for example, by using drag-and-drop functionality or by making it possible to right-click on an airport and select it to add it, along with the corresponding times and loads.

If a controller is very familiar with one airport but not with another, this must also be considered. Therefore, it should be an advantage to be able to include and exclude factors from the workload calculation. Other pints that could be included in the tool are: staff status, weather conditions, ATCO rating, and monthly planning staff.

b) Real Time Simulation

The main suggestions and recommendations that came out of this training exercise are as follows:

- A combined colour code should be adopted to make it easier to distinguish aerodromes, or even better to assign a colour to each aerodrome so that previously seen information linked to that colour can be cognitively reconnected.
- The supervisor could provide guidance to advise the ATCO in a reasonable time when to apply split and merge.
- The airport should retain the same color code and position after the split, and the EFS bays should also remain in the same position on the display after the split function is applied and should be available to the ATCO that initiated the airport transfer until the other ATCO assumes full control of the airport. The display of all airports should be maintained until both ATCOs are comfortable with the traffic situation.
- The wind variable should also be displayed in the VP as additional information for wind direction and intensity.
- Activation of PTZ cameras should be simple and without too many commands.

EXE-05.03-V2-3.3 - INDRA

Validation Exercise description

The validation exercise for Solution 03 focuses on the long-term planning tool that supports the RTC supervisor in allocating airports in each MRTM.

The validation method used by Avinor was real-time simulation in the platform provided by INDRA and INDRA NAVIA.

The role involved in the validation was the Remote Tower Center Supervisor, the new role introduced by the Remote Tower Center concept. Two ATCOs from Avinor participated in the validation, both in the role of Supervisor. The Remote Tower Planner tool supported the Supervisor in developing the different tasks.

The RTC Supervisor is responsible for determining the optimal allocation of aerodromes in the MRTMs available in the RTC. A group of 15 Norwegian aerodromes, a mix of AFIS and ATC aerodromes, was considered for the validation exercise.

Conclusions

Through the V2 validation, an initial concept evaluation was conducted. The aim was to determine the distribution of 15 airports among up to 11 MRTMs, seeking the optimal allocation based on airport characteristics, expected demand, and METEO information.

Technical feasibility

The distribution of aerodromes among the MRTMs, color-coding, and display of alerts was found to be acceptable from the supervisor's point of view. One improvement needed is in the planning tool, either by adding more features or improving existing ones.

Performance assessments

The validation exercise demonstrated that a planning tool for the supervisor would allow the optimal distribution of aerodromes among the MRTMs available in the RTC to be found. While working with the tool, the controllers' level of situational awareness was good. They were confident and relied on the tool.

It was concluded that the supervisor's workload needs to be evaluated in more detail, as it could vary locally depending on the amount of responsibility, they would have in addition to finding the optimal allocation of aerodromes.

Recommendations

The following recommendations should be considered in V3 validations:

- Introduce a more complex context to test the RTC supervisor's ability to find the optimal allocation when subjected to additional workload or distracting elements that are inherent in a supervisor's daily work.
- Evaluate the work of the Supervisor and the performance of the scheduling tool in the Remote Tower Center to verify the proper development of coordination between Supervisor and controllers, especially during a reallocation process.

EXE-05.03-V2-3.5 – DFS

Validation Exercise description

The operational scope of this validation exercise included the simultaneous provision of ATS to three airports with up to 45,000 annual movements from an MRTM by an ATCO. All airports have a single runway and a simple layout of the manoeuvring area. The exercise was performed as a real-time simulation through the DFS tower simulator validation platform, augmented by the prototype visual and voice communication systems.

Conclusions

Technical feasibility

In general, all the instrumentation worked optimally and was essential to provide ATS service to 3 airfields simultaneously. The only request made by the ATCO was to improve the ability to work in advance of events.

Performance assessments

In general, the exercise revealed that:

- The ATCO should minimize the need to focus on a given situation for a "longer period" on several aerodromes at a time. It should be taught that safety is absolutely prioritized over efficiency.
- Simultaneous landings and/or take-offs can be handled in the following
- During an emergency situation, a strong preference has been expressed to maintain the aerodrome with the emergency flight and, if possible, relocate other aerodromes.
  As an alternative to relocating aerodromes, the workload could be reduced by one additional person taking over all coordination tasks.
- The transfer of an aerodrome from one MRTM to another is very similar to the current job transfer to another ATCO and should be supported by a checklist such as those already in place for station transfer. During the transfer procedure, both ATCOs should have the same flight plan and surveillance information available for that aerodrome.
- The workload of ATCOs increases as VFR traffic increases.

EXERCISES OVERALL CONCLUSIONS

The three real-time validations (COOPANS, DFS, and ON) demonstrated that ATCOs can provide ATS to three aerodromes simultaneously with up to 25 movements per hour and up to 6 simultaneous movements. Safety and human performance were shown to be at an acceptable level. In general, the workload could be balanced on an appropriate average level for each MRTM; however, this reduced capacity could lead to reaching a limit in high traffic situations. Situational awareness was kept good for all exercises, but should be improved with appropriate system design. At the V3 level, situations where workload may increase rapidly should be examined to verify that the ATCO has sufficient means of mitigation to maintain workload and situational awareness at an acceptable level.

All ATCOs reported that they had an extraordinary training effect after providing the ATS in the simulations for about 2 days and felt much safer than at the beginning of the trials. The ATCOs' attention must cover several spatial areas and

In these operations, systems support within the MRTM helps ATCOs maintain situational awareness and effectively reduce the monitoring workload.

Two validations (COOPANS and INDRA) indicated that the supervisor planning tool can support flexible assignment of airfields and personnel to MRTMs in a remote tower center. However, additional parameters need to be included in the V3-level planning tool and the operator workload calculation needs further study.

4.3.3. COST BENEFIT ANALYSIS (CBA)

The Figure 24 shows the benefits, costs and cumulative cash flow for remotely provided ATS for multiple aerodromes (4 aerodromes) from a remote tower center with MRTM and highly flexible allocation capabilities in case of stand-alone implementation.

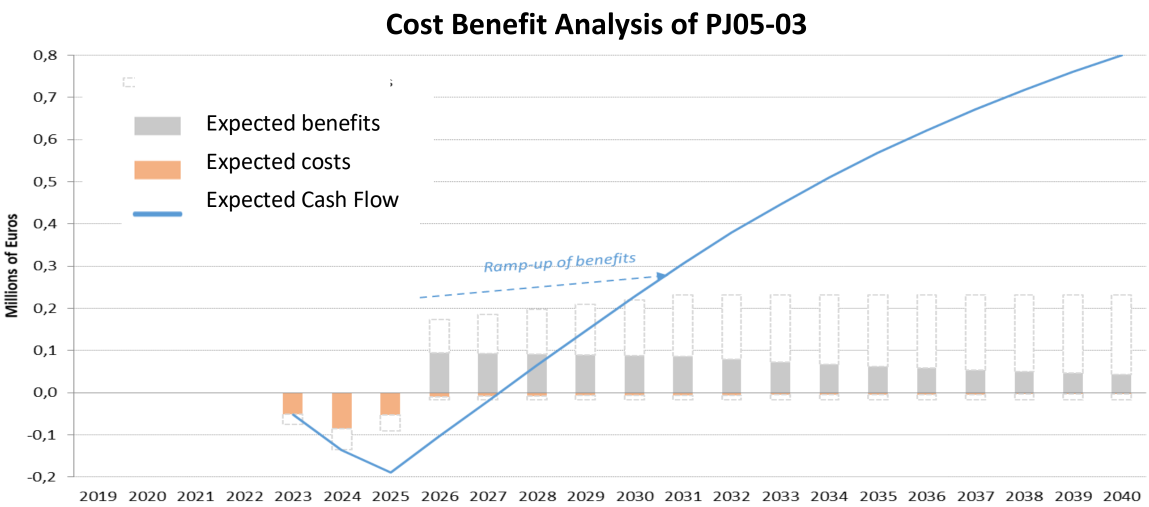

Figure 24 - PJ05.03 CBA Graph

Figure 24 cover assumptions for the years from 2023 to 2040.

The period 2023-2025 is assumed as the investment period. Benefits will begin in 2026, when the remote tower center with highly flexible allocation of aerodromes to MRTMs is operational. The costs presented in the graph following the investment period refer to the operational cost of the technology related to PJ.05-03.

From 2026 to 2031, the benefits increase year by year, as cost savings are not realized immediately, but increase over time as ANSPs are unable to immediately adjust their staff and other resources. From 2031, the solution was considered to be fully in operation, so the monetized benefits are total from this year until the final period.

4.4. PJ 05 - 05 ADVANCED AUTOMATED MET SYSTEM

Adverse weather conditions cause significant disruption to flight schedules and are the cause of around 13% of primary delays in Europe. However, the impact can be mitigated by the timely sharing of high quality, accurate, reliable and readily available weather information to enable effective planning and decision-making. More accurate weather information can aid flight planning, resource planning and route planning, and can help avoid unnecessary delays.

PJ.05-05 solution aims to provide automated and semi-automated MET observational data of significance for aviation. The PJ.05-05 solution is expected to be supported by the following enabler:

• Aerodrome-ATC-92: Real-time airport weather observation service with artificial intelligence algorithms. This enabler is an optional part of SDM-0207 of Solution PJ.05-02.

There are two different options for implementing the advanced automated MET system solution:

1) Fully automated mode - the system automatically performs the calculation of cloud cover and prevailing visibility from camera images. The system is able to recognise phenomena using a combination of sensors and algorithms. The system in this mode automatically uses the available inputs to compose the final meteorological report, which is distributed to interested parties.

2) Semi-automatic mode - images and videos from the dual VIS and IR cameras, together with data from other MET sensors at the airport, are available to the human remote MET observer, who using these inputs manually determines cloud cover, prevailing visibility and phenomena. In semi-automatic mode, the remote MET observer composes the final meteorological report from the available inputs using the dedicated HMI. The final meteorological report is then distributed to interested parties.

4.4.1. VALIDATION OF PJ05- 05 : REACH TRL4

The Advanced Automated MET System solution addresses airports where the Remote Tower is in operation, or it can operate on other airports independently.

Regarding the validation approach, the TRL4 trials focused on providing advanced MET capabilities to significantly improve current automated weather observation capabilities. To reach TRL4 maturity of this solution, a validation exercise was performed:

EXE-05.05-TRL4-5. - LPS

It is a simulation and measurement campaign developing real-time airport weather observation service with AI algorithms. The Advanced Automated MET System improved the possibility of automatic observations in the three most problematic parameters:

- ✓ Visibility - by marking various points as visible or not.

- ✓ Clouds - by means of an entire image of the sky from which it is possible to identify the cloud cover, identify the various cloud layers and estimate their height.

Conclusions

We can conclude that the technology can help all airports in the world, either in an automated way, with remote observation, or with human observation to help human observers or forecasting Centers.

Technical feasibility

The camera was correctly able to rotate and tilt to capture images of the entire sky in the visible (VIS) and infrared (IR) spectrum. Unfortunately, the IR images taken by this camera could not be used to obtain a single image of the entire sky, however, another IR camera was installed to provide the missing information on cloud brightness temperature to identify the various cloud layers.

The Advanced Automated MET system showed great potential, as using the remote observer (semi-automated mode of the system) gave very satisfactory results. Although in fully automated mode there are more limitations to deal with and the results are not so much better than other instrumentation, there is also the potential to improve in the future and increase the level of performance.

Performance assessments

The validated PJ05-05 solution has the potential to bring benefits in terms of:

- Safety: by providing more comprehensive automated weather observations and mitigating the drawbacks of the current state of the art AWOS (Automatic Weather Observing System) in observations.
- Cost efficiency: The ability to operate without local human observers can certainly reduce costs.

4.4.2. COST BENEFIT ANALYSIS (CBA)

4.4.2.1. FULLY AUTOMATED MODE

The figure below shows the expected benefits, expected costs and expected cash flow for the remotely provided MET service for a single remote airport implementing the solution in fully automated mode.

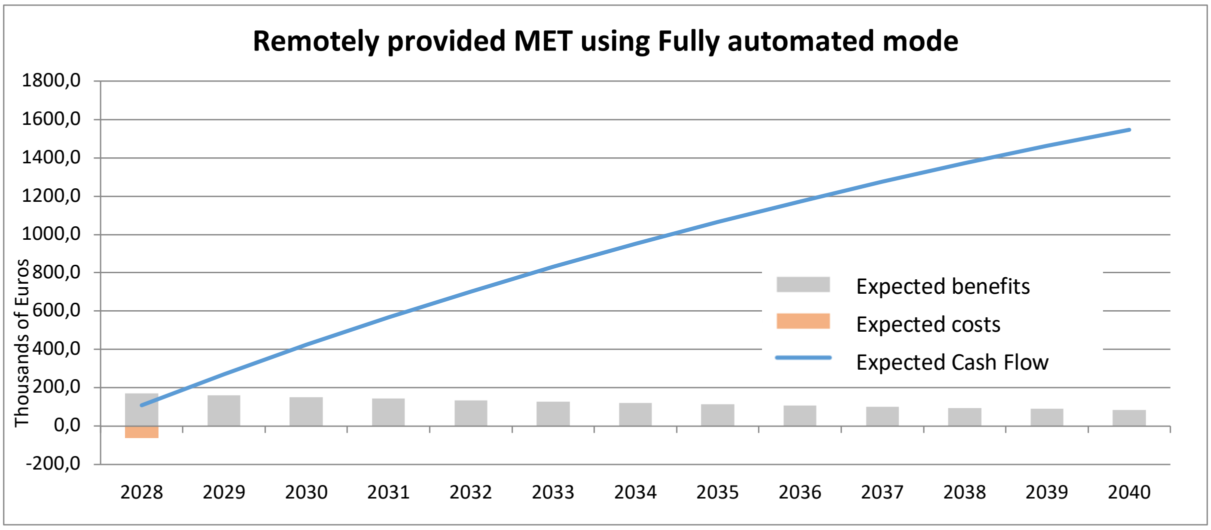

Figure 25 – MET Fully automated CBA

A significant cost reduction will be achieved from the first year, as personnel costs represent a substantial part of the total costs compared to investment and operating costs.

Furthermore, the automatic provision of extended MET information for airports where there is no human MET observer has a positive impact on all users, as the current automatic MET information provision capabilities do not contain all aeronautically significant data. Therefore, the usability of such an airport will be improved due to the better quality of the MET information provided, with the benefit of remaining up-to-date on the weather situation.

It is expected that the main benefits of providing MET information remotely will be appreciated in places where it is already difficult to find qualified personnel or to motivate them to relocate

4.4.2.2. SEMI-AUTOMATED MODE

The figure below shows the expected benefits, expected costs and expected cash flow for the remotely provided MET service for a single remote airport implementing the solution in semi automated mode.

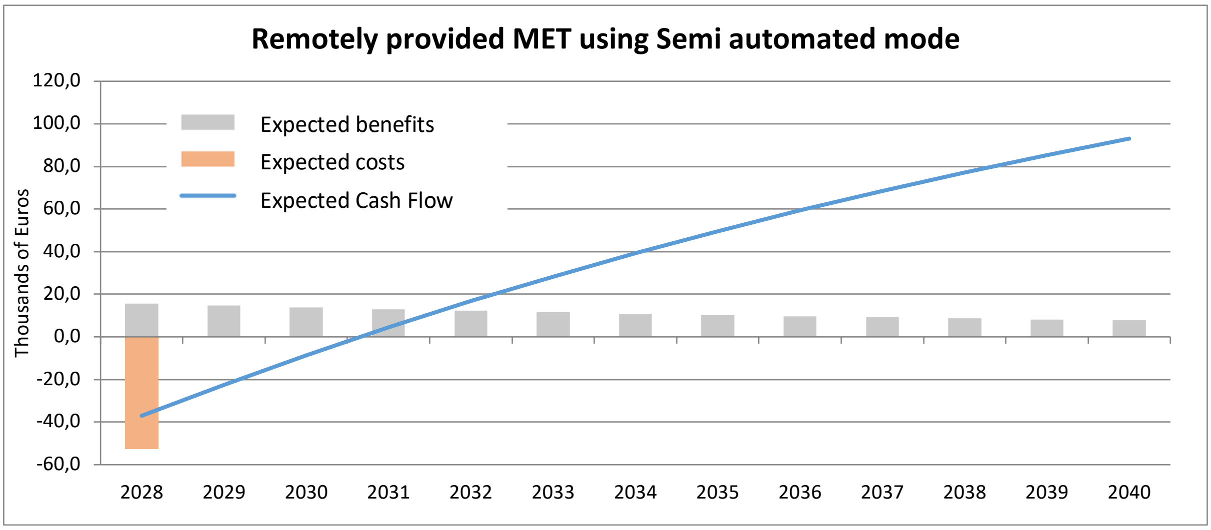

Figure 26 – MET Semi automated CBA

The implementation of the semi-automated mode for the provision of the MET service for a single airport appears to have been successful in its fourth year of operation. As already mentioned in the previous chapters, this solution is currently at TRL4 maturity level. Although the financial figures are not expected to change in any way, one of the elements to be investigated is the ability of the MET observer to manage the remote MET service provision for more than one airport at the same time.

Furthermore, the non-monetary aspect assessed for the fully automated mode is also applicable for this mode.

5. SESAR 2020 WAVE 2 – PJ05-W2-DTT

The PJ05-W2-DTT was born in 2019 to deal with the exponential growth that technology has experienced in the last few years. Hardly a ten-year project can be completed with the same technological idea as at the beginning; SESAR is aware of this and in its Wave 2 has attempted a different approach of PJ05, divided into 2 parts:

- *PJ.05-W2-35- Multiple Remote Tower and Remote Tower Center*

  Solution 35 represents the continuous validation of PJ05 already started in SESAR and previously divided into the well-known 3 parts. Compared to Wave 1, it has improvements to solve problems discovered through exercises and a more comprehensible and ergonomic look.

- *PJ.05-W2-97 - HMI Interaction modes for Airport Tower*

  The solution addresses the development of new human-machine interfaces (HMIs). In particular, it addresses the use of two technologies new to the world of aviation; augmented virtual reality (A/VR), to enhance the controller's senses and situational awareness, and the Automatic Speech Recognition (ASR) tool, which aims to interact vocally with the HMI.

Developed in SESAR 2020 Wave 2 and also available in the SESARJU eATM Portal, available in chapter 4 page 26 of this thesis, the two PJs represent the latest version of the Remote Control Tower. The main difference between the two projects is that, while the first one, like the entire Wave 1 of SESAR 2020, is designed for a remote tower application, Solution 97 is designed for application in the classic local tower.

Due to company know-how and secret documentation, very limited information is available on this subject. In order to be able to bring my paper to the next level, I personally went to the Open Day presented at the University of Bologna's Forlì campus, where on the 26 October 2022, exercises were carried out to take the validation of the two projects to the next level.

5.1. PJ.05-W2-35 – MULTIPLE REMOTE TOWER AND REMOTE TOWER CENTER

Within Solution 35, the validation and improvement of the main features of remote air traffic is ongoing:

- Remotely provision of Air Traffic Services (ATS) from a Remote Tower Center (RTC) to more than 1 airport simultaneously from a remote tower position/module
- Flexible and dynamic allocation of airports to different Multiple Remote Tower Modules (MRTMs) with a maximum of three airports allocated to each MRTM
- RTC Supervisor that can dynamically allocate any airport to another MRTM within the Remote Tower Center (RTC) in order to balance traffic volumes and ATCOs workload between different MRTMs
- Supervisor Planning Tool for the RTC Supervisor
- Additional automation functionalities for the ATCO

Where the targetd airdromes are "Small Enviroment" aiports (15 000 to 40 000 annual IFR movements) with limited technology and simple layout commonly staffed by a single ATCO.

The latest version of the RTC is now composed of one RTC Supervisor position and several Remote Tower Operator positions; the Forlì simulation at the ENAV Academy envisaged the implementation of only 2 RTM positions, but in future implementations the goal will be to achieve coverage of 13 RTMs + 1 RTM Spare & 1 RTC Supervisor.

Figure 27 - RTC Ops Room

ENAV 's next steps already include the completion of 2 Remote Tower Control Centers (RTCC):

- RTCC Brindisi (13 RTM) fully operational in 2026
- RTCC Padova (13 RTM) fully operational in 2029

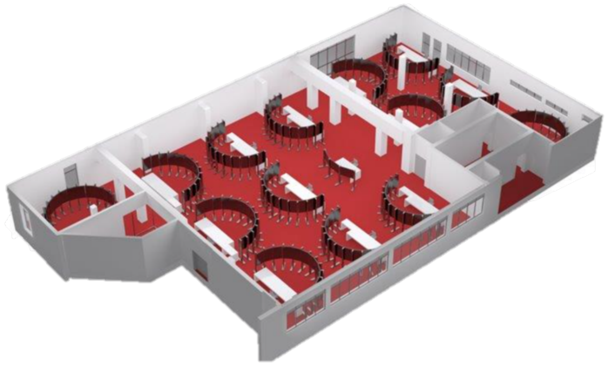

Figure 28 - RTCC design

5.1.1. RTC Supervisor CWP

Let us go into the details of the operator station and analyse the new instrumentation at its disposal; it will be equipped with Supervisor Planning Tool (developed by IDS AirNav & NAIS), MOVES (developed by Techno Sky) and VCS to interact with ATCOs. In addition to these new technologies, the RTC Supervisor has at his disposal a monitor equipped with Flight Data Processing (FDP) and a touch-screen interface for quick calls with ATCOs.

5.1.1.1. Supervisor Planning Tool – New Design

Figure 29 – Workload Distribution

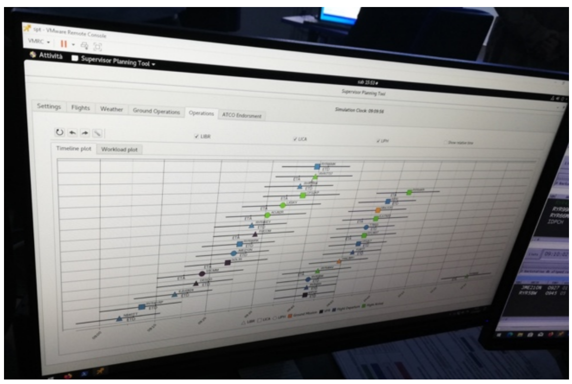

Figure 30 – Radio Occupancy Distribution

Tool that allows the remote tower supervisor to analyse the workload distribution individually for each controller (each column represents a controller) every 10 minutes. By means of a special colour scale, the system can identify the type of traffic to be controlled by the controller and, by checking in the dedicated window on the right, which airports the respective station is controlling. If an ATCO is handling too much traffic, the corresponding column will turn with a red border and the RTC supervisor will take action. The supervisor's method of reasoning will be based on the type of traffic controlled by the controller and is quite simple:

- The departure and start-up request traffic is the less challenging and therefore requires less mental effort by the controller.
- Arrival and VFR (visual flight) traffics engage the controller much more.

The supervisor at this point can take several actions; he can decide to delay VFRs from entering controlled airspace, move some traffic to another controller or try to call the competent ACC and request an anticipation of the flight.

The Supervisor Planning Tool also has the ability to show how much traffic could potentially come into radio contact in a certain time range and will also redistribute traffic in function of this, to avoid interference and overlapping of radio communications as much as possible. The supervisor will then have the ability to optimally distribute the workload and to assess the chosen configuration through a what if analysis of both MRTMs, dynamically changing the allocation of the airports.

Some ideas for improving this technology presented by the controller concern the correspondence between the workload column and the corresponding controlled aerodromes, since at the moment the two pieces of information are dislocated and are only highlighted when the controller clicks on the specific column. It might be conceivable to implement this information directly on the workload columns.

5.1.1.2. MOVES

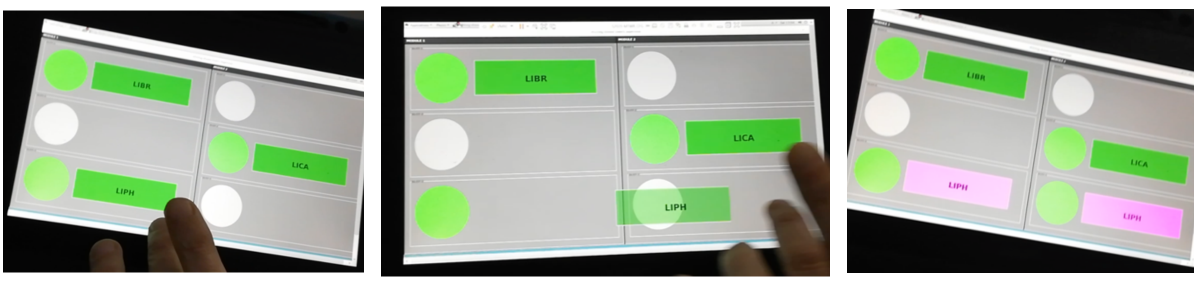

Figure 31 - Transfer of airport management

As the name suggests, the tool assists the supervisor in switching the command of an aerodrome from one MRTM to another.

As can be seen in the image, each column corresponds to an MRTM (which can manage a maximum of 3 aerodromes at the same time) and, simply by making a hand gesture, the supervisor can initiate the air traffic handover procedure.

In a first phase, the aerodrome that has been moved continues to be displayed by the first ATCO; this procedure is intended to facilitate the smooth passage of information between the two modules. Once the second RTM is controlling the situation, the Supervisor may, depending on his experience and the complexity of the traffic at the shifted aerodrome, completely hand over the aerodrome to his new ATCO.

5.1.2. MRTM CWP

The ATCO station is considerably more complex than what we are used to seeing. The strips have become digital e-strips, located inside an E-CWP, which also displays information about the runway in use and air navigation and landing assistance information, a new design of PTZ cameras and a digital OTW that replaces the classic real view. There is also a communication interface for coordination with the bodies involved and VCS system for communication with the RTC supervisor.

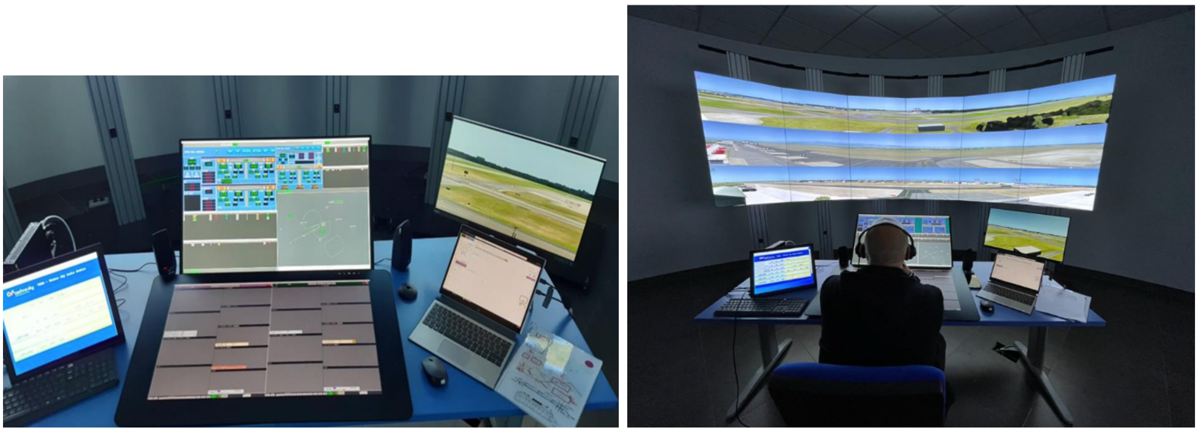

Figure 32 - Single Module Working Position

5.1.2.1. Electronic Flight Progress Strips (EFPS)

The e-strips allow the controller to have a cleaner control of the aircraft; while now the information is all accumulated on paper strips, the e-strips keep only the current flight status information, archiving the previous ones. The ATCO manages the handling of the strips by means of a special pen, with which he can also manually write down flight information on the strip. The archiving of information is a fundamental part of the programme; today each paper strip is kept in the airport archives for several years, for traceability purposes or to study the increase in efficiency of the ATS service.

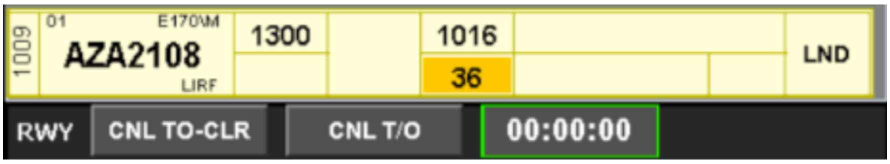

Figure 33 - EFPS During Operations

Improvement points suggested by the exercise controllers concern the possibility of being able to enlarge with a simple gesture, e.g. double touch on the strip, the information on the EFPS, which is now present but very small in size.

5.1.2.2. E-CWP

The E-CWP consists of two different areas:

- A lower one, consisting of 2 columns for each airport controlled by the RTM. This allows the management of e-strips in pecial bays, programmed to subdivide the flight progress strips into relevant fields.

- An upper, dynamic one that provides information about the runway, weather conditions via the Automated Weather Observing System (AWOS), Radar view to manage the approach of aircraft to the runway, and Flight Data Processing (FDP).

Figure 34 - E-CWP

5.1.2.3. PTZ CAMERAS – NEW DESIGN

The new PTZ camera design consists of a touch screen monitor acting as OTW PTZ Controller and a PTZ Monitor. Through a quick touch, the controller can fluidly move through space and zoom in on specific points of the airport.

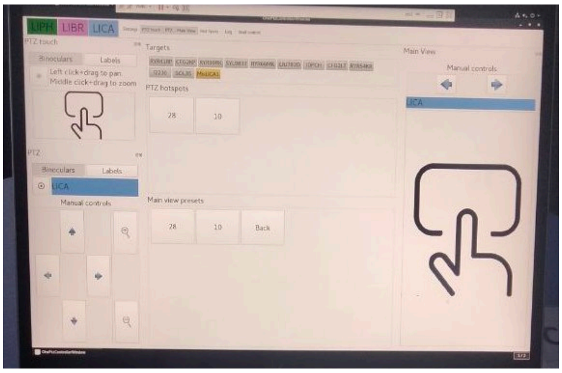

Figure 35 - PTZ Controller

Figure 36 - PTZ Monitor

5.1.2.4. OTW

The OTW represents a key element for remote control, aiming to replicate the controller's view of the airport field. Out-the-Window view is realised through n.6 55" 4K monitors for a seamless view of the airport(s).

Figure 37 – OTW

5.2. PJ.05-W2-97 - HMI INTERACTION MODES FOR AIRPORT TOWER

The solution addresses the development of new human machine interface (HMI) interaction modes and technologies in order to minimize the load and mental strain on the Tower controllers. The SESAR solution shall consider modern design and development approaches and methodologies such as modularity, adaptive automation, etc. The new HMI interaction modes include the use of in-air gestures, attention control, user profile management systems, tracking labels, virtual and augmented reality, etc.

Remote Tower Services (RTS) provide an opportunity for continued operation of airports and rural development. The costs for performing Air Traffic Service (ATS) are high and could be reduced, particularly at low to medium density airports, by provision of Air Traffic Services (ATS) from a remote tower. In order to do this, the Multiple Remote Tower needs a high level of efficiency that must not translate into less security. The focus on maintaining situation awareness becomes an increasingly important factor with multiple remote tower operations, therefore additional automation functionalities e.g. voice recognition, conflict detection, and conflict resolution advisories should be developed in order to gradually increase the operating range of the concept.

The efficiency of using the CWP HMIs for the airport tower requires improvements by exploiting the latest mature technologies and new interaction modes e.g. touch, gesture, voice, etc... This project will develop two main solutions that are expected to provide Improved cost-efficiency, Increased safety & Increased ATCO efficiency . This three main solution are named Solution 97.2 , Solution 97.1, Solution 97.3.

5.2.1. SOLUTION 97.1 – VIRTUAL/AUGMENTED REALITY APPLICATIONS FOR TOWER

The main purpose of this solution is to eliminate a potential problem of reduced visual attention. Its operational impact can be summarized as the 'head up' and 'head down' problem. Head down times for ATCOs at an airport refer to those times when the ATCO is not looking out of the window but at any other display. The monitoring of the OTW in the remote tower working position is therefore described as 'head-up' work. From an operational point of view, head-down time must be kept to a minimum, because the ATCO in the tower must react as quickly as possible to any unexpected events. These unforeseen events are most likely to be detected by visual surveillance, by looking out of the tower windows or by a panoramic video presentation.

To reduce head down time, a new method of controlling the auxiliary displays had to be designed, through a more dynamic user interface. This new technology needed to have clear features:

- Immersive - With a greatly enlarged field of view
- Ergonomic - Make users comfortable with a fit system designed for long term use
- Instinctual - Touch, hold and move things naturally.

V/AR fuses real-time real-world images with computer-generated data (augmented reality), so that visual information can be enhanced to improve the identification and tracking of aircraft (or vehicles) in and around the airport. In low visibility conditions, synthetic vision can display georeferenced digital data that complement the missing real vision (virtual reality).

When using V/AR, the auxiliary information is merged with the out-of-window (OTW) vision and presented as an overlay to the real-world visual information. In this way, the controller's attention is no longer forced to be divided between the primary field of view (OTW) and auxiliary instruments (such as paper or electronic flight strips, radar for surface movements, camera streams for gap filling and alarm indications), thus reducing 'head down' time and increasing situational awareness.

The virtual reality application allows controllers to interact with tracking tags through a series of aerial gestures and to issue authorizations for non-time-critical activities (start-up, push-back). In addition, the attention guidance function can be activated by inputs from external sources, such as the security network or airport sensors, to visualise perceptual cues and direct the attention of air traffic controllers to a specific event.

Computer-generated overlays can also be displayed adaptively by means of synthetic vision, e.g. in low visibility conditions.

5.2.1.1. HOLOLENS 2 TO PERFORM AUGMENTED REALITY

To realise augmented reality for the controllers, SESAR decided to rely on the best product around today for viewing augmented reality: Microsoft HoloLens 2.

HoloLens 2

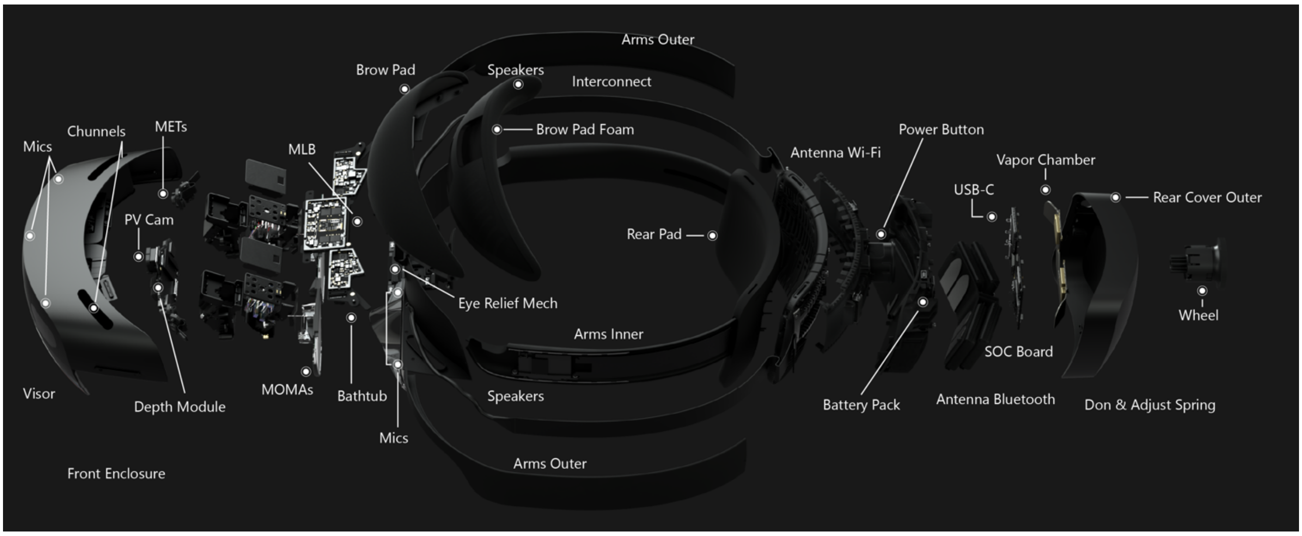

Figure 38 - HoloLens2 Exploded view
[from learn.microsoft.com]

The Hololens2 is Microsoft's take on augmented reality, which they call "mixed reality".

Mixed Reality (MR) is being applied in many different fields, such as medical science, education or industrial design. It is in the continuum spanned by related technologies such as Virtual Reality (VR) and Augmented Reality (AR). VR changes the entire surrounding environment into a virtual form and allow interactions between the user and the virtual word. AR augments the real-world by including graphics, sounds, and touches feedback through AR devices. However, AR does not facilitate interactions between users and the virtual objects added to the real-world scene. MR combines the advantages of the two, scanning the surrounding real-world environment to build a model, and then adds the needed virtual object in this environment. Users can directly interact with virtual objects (by operations such as scaling, rotation, or translation) in the real environment using their hands (or other devices). Furthermore, virtual objects can also interact with real objects in the mixed reality world.

Using multiple sensors, advanced optics, and holographic processing that melds seamlessly with its environment, these holograms can be used to display information, blend with the real world, or even simulate a virtual world.

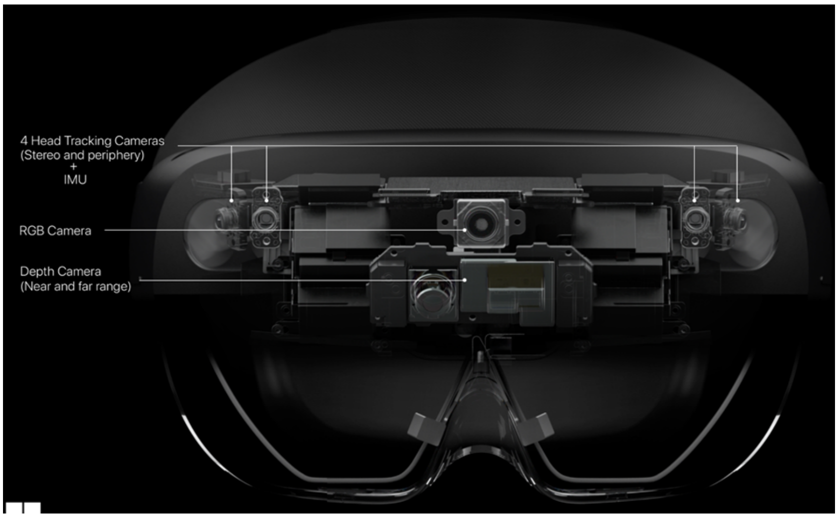

Figure 39 - HoloLens2 Front View
[from learn.microsoft.com]

HoloLens2 has a plethora of optical sensors, with two on each side for peripheral “environment understanding” sensing, a main downward facing depth camera to pick up hand motions, and specialized speakers that simulate sound from anywhere in the room.

The Hololens2 also has several microphones, an HD camera, an ambient light sensor, and Microsoft’s custom “Holographic Processing Unit” that they claim has more processing power than the average laptop. All this comes together to sense the spatial orientation of the unit in the room, track walls and objects in the room, and blend holograms into the environment.

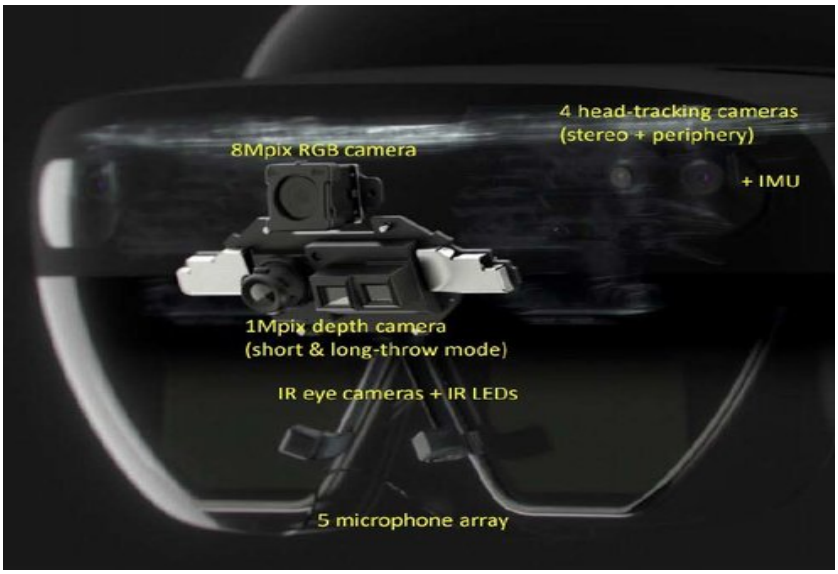

Figure 40 - HoloLens2 Detailed
[from learn.microsoft.com]

Thanks to the Hand Tracking, Eye Tracking and Spatial Mapping functions, the HoloLens 2 allow the ATCO operator to enhance his senses and be able to manage traffic in the most ergonomic condition possible.

The HoloLens2 will give the ATCO the ability to have labels with the name of the aircraft and other useful information directly next to the controller's graphical representation, allowing him to generate screens wherever he wants in space, e-strips, weather conditions and more. He can also decide to open an arrival or departure procedure and keep it as a hologram next to the monitor.

This technology opens the way to a world of possibilities, both in education and application. Its display is made up of several digital layers, so as the visibility decreases, it will be possible to increase the digital support that HoloLens provide to ATCO. Operational information is reported as overlays in the adaptive HMI. Less head down operations increase the ATCO focus on traffic, decreasing the "visual pollution" thanks to less screens.

5.2.1.2. INFORMATION OVERLAY : METEO

Figure 41 - Meteo Information

5.2.1.3. INFORMATION OVERLAY : DEPARTURE LABEL

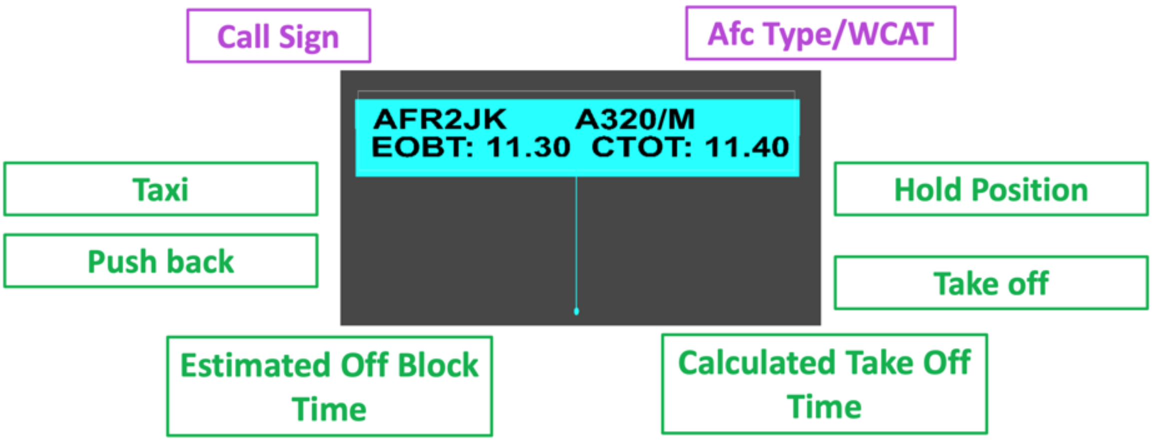

Figure 42 - Departure label

5.2.1.4. INFORMATION OVERLAY : ARRIVAL LABEL

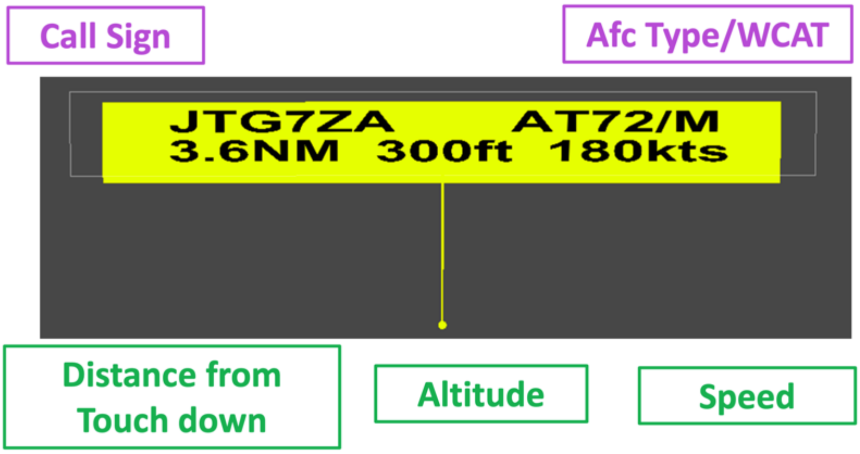

Figure 43 - Arrival Label

5.2.1.5. AIRPORT LAYOUT OVERLAY

In low visibility condition the out of tower view becomes a synthetic representation of the reality. The colour of the layout also give ATCO information on runway status, for example taxiway closed or not available.

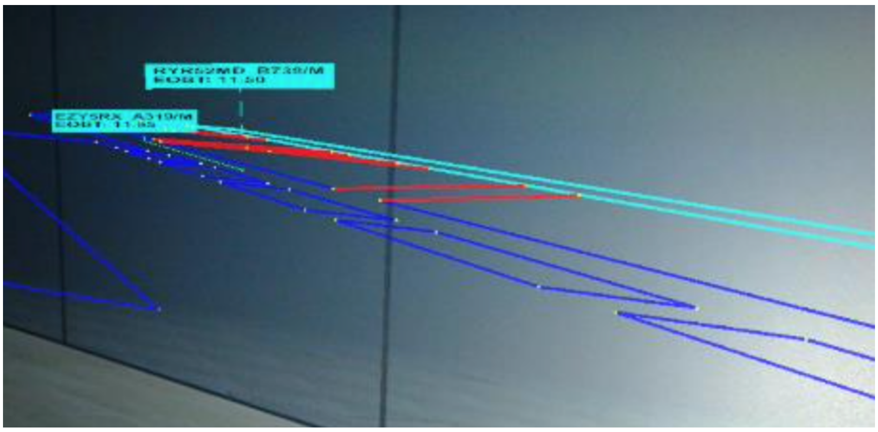

Figure 44 - Layout Overlay

5.2.1.6. AIR GESTURE

Air gestures are movements made by the controller with his hands in the air, in front of his eyes. Using hand tracking function, they identify the movement made by the controller, allowing the controller to spend less time on less critical choices, by authorising them through a simple hand gesture as shown in the image below.

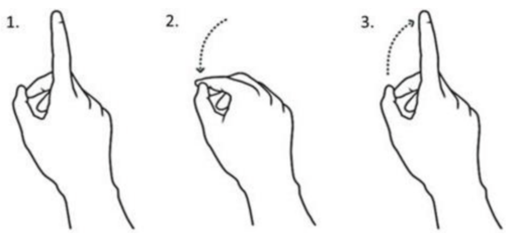

Figure 45 - Approval gesture

5.2.2. SOLUTION 97.2 – IMPROVING CONTROLLER PRODUCTIVITY BY ASR AT THE TWR CWP

Automatic Speech Recognition (ASR) system that transforms audio signals into a sequence of words (speech-to-text transcription). The transcribed words are then transformed into air traffic control concepts (text-to-concept annotation). This can be supported by modules of an assistant-based speech recognition system (ABSR), such as prediction and extraction of commands. The set of predicted commands is derived via machine learning algorithms from current and historical contextual knowledge (surveillance data, route information, transcripts and previous annotations, etc.). This increases the rate of command recognition and minimizes recognition errors in ABSR systems. The extracted concepts are combined with the recognised ATC commands and presented on an HMI for further acceptance or possible correction by the controller.

5.2.3. SOLUTION 97.3 – MULTI TOUCH INPUT DEVICES

No public information is available regarding Solution 97.3

6. CONCLUSIONS

According to Deep Blue's Human Performance Assessment, workload and situational awareness were always maintained at acceptable level in the solution scenarios. Moreover, both supervisors agreed that it was feasible and acceptable to provide supervision to 3 aerodromes.

The concept is confirmed to be feasible and acceptable as situation awareness, workload, acceptance, usability and safety were above tolerable threshold for all solution scenarios (except from acceptance in safety solution scenario 6).

Reference1

- Normal operations
- two aerodromes with majority of traffic
- Mainly IFR traffic (>75%)
- Low visibility for LIPH (fog) decreasing up to 500 m

Solution1

- In addition to Reference1 conditions:
  - Supervisor position and flexible allocation
  - tasks prioritization functionality for ATCO

Solution6 - Degraded/Failure

- Solution1 in degraded mode:
  - OTW failure in one Module recovered after few minutes but with 1 screen lost

✓ There was even a slight reduction of the workload and increase of the Situational Awareness, user acceptance and safety for the solution scenarios compared to the reference scenarios thanks to the support of the supervisor.

✓ Situational Awareness, workload, acceptance and safety were below the acceptable level only for reference scenario 3, in which the ATCO had to manage 3 airports without the support of the supervisor.

Reference3

- Normal operations
- two aerodromes with majority of traffic
- IFR-VFR balanced

- ✓ Recommendations were mostly related to local operational environment needs (e.g., position of buttons) or technical limitations (e.g., integration of live data in supervisor planning tool) rather than to the concept itself. The HMI needs to be further refined in relation to the specific operational environment needs before the deployment.

Feedback from controllers showed that the prototype for V/A-R supports controllers in maintaining an acceptable level of workload, (team) situation awareness, the potential for human error, trust, acceptance, job satisfaction, and perceived safety. Moreover, time spent in head-up increased in the solution scenario with respect to the reference scenario.
The prototype for V/AR with Safety Nets improved the perceived safety performance.

- ✓ Usability can be improved by designing the tracking labels in a way that they do not overlap each other and/or cover the background.

- ✓ Air Gestures need to be refined so that ATCOs do not have difficulties using them. It should be considered to use Air Gestures only for non-critical clearances.

My personal vision of the future of air traffic control is a combination of the two Solutions presented in SESAR 2020 Wave 2. Just imagine an RTM with the Overlays and Kinect technology that are implemented in Solution 97 today; we could have all the benefits of the remote control tower plus the technological assistance of Mixed Reality, with the associated Air Gestures.

The future of air traffic control is now more than ever the subject of a major technological challenge that will see its design and the role of ATCOs change forever.

BIBLIOGRAPHY AND SITOGRAPHY

[1] Fürstenau, Norbert. (2014). Virtual and Remote Control Tower - Research, Design,Development and Validation. 10.1007/978-3-319-28719-5.

[2] https://thinking-space.com/en-au/air-traffic-control-furniture-2/

[3] Papenfuß, Anne & Moehlenbrink, Christoph. (2011). The opportunities and challenges of team work in remote tower center operations.

[4] N. Changuel, B. Sayadi and M. Kieffer, "Control of Multiple Remote Servers for Quality-Fair Delivery of Multimedia Contents," in IEEE Journal on Selected Areas in Communications, vol. 32, no. 4, pp. 746-759, April 2014, doi: 10.1109/JSAC.2014.140407.

[5] Fürstenau, Norbert & Mittendorf, Monika & Ellis, Stephen. (2013). Quantifying Virtual Control Tower Decision Making using Visual Discrimination of Aircraft Maneuvers.

[6] Peters, Martin & Papenfuß, Anne. (2012). Analysis of Critical Situations at Remote Tower Operated Airports.

[7] Male, Henry Kenneth. (2015). Security Risk Assessment of a Remotely Operating Tower. 10.13140/2.1.1762.6401.

[8] Keller, Karl-Heinz & Jakobi, Jörn. (2014). Remote Tower Operations (Keller, Jakobi).

[9] Barrowclough, Oliver & Swendgaard, Hans & Dokken, Tor & Andersen, Odd. (2015). Geometric Modelling for 3D Support to Remote Tower Air Traffic Control Operations.

[10] Cordeil, Maxime & Dwyer, Tim & Hurter, Christophe. (2016).

[11] Herrera, Ivonne & Smoker, Anthony & Pinska-Chauvin, Ella & Feuerberg, Beatrice & Schwarz, Michaela & Laursen, Tom & Josefsson, Billy. (2015). RESILIENCE ENGINEERING (RE) IN DESIGN: INITIAL APPLICATION OF A NEW RE ASSESSMENT METHOD TO THE MULTIPLE REMOTE TOWER CONCEPT.

[12] https://www.airport-technology.com/sponsored/remote-air-traffic-control-tower/

[13] https://www.internationalairportreview.com/article/156908/the-rise-of-multi-remote-towers/

[14] https://dblue.it/blog/digital-remote-control-towers/

[15] Kearney, Peter & Li, Wen-Chin & Braithwaite, G. & Greaves, Matthew. (2017). The Investigation Human-Computer Interaction on Multiple Remote Tower Operations. 301-309. 10.1007/978-3-319-58472-0_23.

[16] Communication from the Commission to the Council and to the European Parliament COM(2008) 750 final of 14.11.2008

[17] European ATM Masterplan Edition 2020 https://www.sesarju.eu/masterplan2020

[18] Josefsson, Billy & Polishchuk, Tatiana & Polishchuk, Valentin & Schmidt, Christiane. (2017). Scheduling air traffic controllers at the remote tower center. 1-10. 10.1109/DASC.2017.8102018.

[19] Single Programming Document - Year 2017-2019 https://www.sesarju.eu/sites/default/files/SJU_Single_Programming_Document_2017_vFinal_14.12.2016.pdf

[20] Communication from SESAR Programme Committee Meeting 03 of 05.07.2017

[21] Special Report No 18/2017: The Single European Sky https://op.europa.eu/webpub/eca/special-reports/single-european-sky-18-2017/it/

[22] SESAR 2020 Multi-annual Work Programme https://www.sesarju.eu/sites/default/files/documents/SESAR%202020%20Multi_Annual%20Work%20Prog ramme%20V1.0.pdf

[23] Bernd Korn*, Christiane Edinger. Sebastian Tittel*, Thomas Pütz**, and Bernd Mohrhard **,*Institute of Flight Guidance, German Aerospace Center, DLR, Braunschweig, ** DFS Deutsche Flugsicherung, Research and Development, Langen, “Sectorless ATM - Analysis and Simulation Results”, ICAS2010 (27th International Congress of the Aeronautical Sciences)

[24] López-Araquistain, Jaime & Campaña, Iván & Bergesio, Luca & Portas, Juan. (2017). Experimental prototype for remote tower system design. 1-16. 10.1109/ICNSURV.2017.8011957.

[25] Friedrich, Maik. (2017). Overview of Remote Tower Activities in SESAR 2020. Eine Übersicht über die Aktivitäten in PJ05 wurde gegeben.

[26] Kearney, Peter & Li, Wen-Chin & Braithwaite, G.. (2018). Human Performance Assessment of Multiple Remote Tower Operations Simultaneous Take-Off and Landing at Two Airports. 10.1007/978-3-319-91122-9_47.

[27] Lopez, Marta & Pelchen-Medwed, Renée & Carbo, Laura & Botezan, Dana. (2018). Safety and Human Performance assessing Remote Tower.

[28] Aricò, Pietro & Reynal, Maxime & Di Flumeri, Gianluca & Borghini, Gianluca & Sciaraffa, Nicolina & Imbert, Jean-Paul & Hurter, Christophe & Terenzi, Michela & Ferreira, Ana & Pozzi, Simone & Betti, Viviana & Marucci, Matteo & Telea, Alexandru & Babiloni, Fabio. (2019). How Neurophysiological Measures Can be Used to Enhance the Evaluation of Remote Tower Solutions. Frontiers in Human Neuroscience. 13. 10.3389/fnhum.2019.00303.

[29] Barrowclough, Oliver & Briseid, Sverre & Muntingh, Georg & Viksand, Torbjørn. (2019). Real-time processing of high resolution video and 3D model-based tracking in remote tower operations.

[30] Reynal, Maxime & Aricò, Pietro & Imbert, Jean-Paul & Hurter, Christophe & Borghini, Gianluca & Di Flumeri, Gianluca & Sciaraffa, Nicolina & Florio, Antonio & Terenzi, Michela & Ferreira, Ana & Pozzi, Simone & Betti, Viviana & Marucci, Matteo & Babiloni, Fabio. (2020). Involving Hearing, Haptics and Kinesthetics into Non-visual Interaction Concepts for an Augmented Remote Tower Environment. 73-100. 10.1007/978-3-030-41590-7_4.

[31] Kredentsar, S. & Yastrub, Maksym. (2020). IMPLEMENTATION PROSPECTS OF THE REMOTE TOWER CONCEPT IN UKRAINE. Electronics and Control Systems. 1. 10.18372/1990-5548.63.14531.

[32] eukert, Maximilian & Meyer, Lothar & Josefsson, Billy. (2020). Multi Remote Tower - Challenge or Chance? An Empirical Study of Air Traffic Controllers Performance. 611-618. 10.1007/978-3-030-60703-6_78.

[33] Pan, Weijun & Luo, Yuming & Han, Shuai & Zhong, Linfeng. (2021). Summary of Reliability Analysis Methods of Remote Tower System. IOP Conference Series: Earth and Environmental Science. 693. 012062. 10.1088/1755-1315/693/1/012062.

[34] hao, Quan & Dong, Min & Shen, Zhiyuan & Yang, Rui & Wang, Hong. (2021). Integrating Ergonomics Into Safety Management: A Conceptual Risk Assessment Model for Tower Controllers at Multiple Altitudes. IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3091528.

[35] van Schaik, Frans & Roessingh, Jan & Bengtsson, J. & Lindqvist, G. & Fält, K.. (2022). The Advanced Remote Tower System and Its Validation. 10.1007/978-3-030-93650-1_18.

[36] an Schaik, Frans & Roessingh, Jan & Lindqvist, G. & Fält, K.. (2022). Detection and Recognition for Remote Tower Operations. 10.1007/978-3-030-93650-1_3.

RINGRAZIAMENTI

Eccoci giunti alla parte meno importante della tesi, ma anche l'unica che starete leggendo, probabilmente anche perché l'unica parte in italiano.

Qui non troverete particolare inventiva o estro creativo, bensì l'elenco delle persone che voglio ringraziare perché hanno tutte contribuito a farmi crescere e diventare la persona che sono oggi.

Volevo partire ringraziando i miei genitori, Donato e Katia. Spero davvero che siate orgogliosi di me, dei sacrifici che ho fatto e dei traguardi che ho raggiunto nella vita…ma continuate a guardare perché è solo l'inizio.

Ringrazio i miei fratelli, Ivan e Alice, mia cognata Sophia e mio nipote Filippo. Siete le persone che colorano la mia vita.

Un ringraziamento speciale va alla mia compagna di vita Sofia, che da ormai 7 anni mi sopporta, mi sopporta, mi sopporta e mi supporta. Sei la mia stella polare, il mio faro nella notte e il mio fuocherello caldo della sera davanti al quale rifocillarsi. Non smetterò mai di apprezzare ogni tuo piccolo gesto.

Infine, volevo ringraziare gli amici che mi sono stati accanto e tutti i colleghi di Advolo. Siete stati dei sinceri confidenti, ottimi compagni di percorso e una piccola famiglia che mi ha fatto crescere tantissimo dal punto di vista professionale, giorno dopo giorno, un problema ed uno sbaglio alla volta.

Oggi concludo a testa alta un percorso pieno di soddisfazioni anche se è stato faticoso combinare studio e lavoro. Mi scuso con tutte le persone sopra citate se negli ultimi 5 anni non ci sono sempre stato o se non ho dedicato loro abbastanza attenzione, ero focalizzato nei miei obiettivi.

Spero di avervi tutti al mio fianco il più possibile in questo percorso che è la vita, impegnandomi ad essere oggi una persona migliore di ieri, ma peggiore di domani.