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DTT

DIGITAL TECHNOLOGIES FOR TOWER

This Final Project Report is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement No 874470 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document provides the Final Project Report of the SESAR2020 Project 05 "Remote Tower for Multiple Airport". It provides a summary and conclusions of the results out of three solutions:

- *WP2 Solution 35 „Multiple Remote Tower and Remote Tower centre" (V3)*
- *WP3 Solution 97.1 „Virtual/Augmented Reality applications for tower" (TRL4)*
- *WP3 Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning" (TRL4)*

The results are put into relation to the ATM Master Plan objectives and are proven for their fit for purpose to contribute standardization and regulatory activities. In a final step the remaining R&D steps are outlined[1].

[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR3 Joint Undertaking be responsible for any use that may be made of the information contained herein.

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Executive Summary

The Project PJ.05-W2 Digital technologies for Tower proposed the development of a remotely provided aerodrome air traffic service by a "multiple" and/or "center" setting and further, aimed for to validate, in different Airport operating environments, innovative HMI modes and associated technologies.

By its solution 35 „Multiple Remote Tower and Remote Tower centre" project DTT aimed for to combine ATS services for several aerodromes from a Remote Tower Centre independent on airport location in order to make use of the valuable resource ATS provider more efficiently. In the end, airspace users benefit from a better availability of ATS throughout the day as ANSPs can provide ATS in rural regions without moving ATCOs to each region. Solution 35 brought the Multiple Remote Tower and Remote Tower Centre concept to a matured level ready for industrialization.

DTT solution 97.1 aimed to validate Virtual and Augmented Reality (V/AR) applications, including Tracking labels, in different Airport operating environments, blending real world images with computer-generated data in real-time, so to allow a reduction of ATCOs head-down time, better balanced workload and an increase of situational awareness. Further benefits enabled by the V/AR technology are: (1) the in-air gestures recognition, that allows to capture and interpret human gestures as commands so to enable a swift and immediate human-system interaction and (2) the attention guidance, which enables to monitor and guide by perceptional cues the attention of the controller towards an imminent ATC situation.

DTT Solution 97.2 aimed for to validate Automatic Speech Recognition (ASR) technologies to allow the recognition and translation of spoken language (e.g. ATCO utterances) as commands input into the ATC system. The ASR engine is supported by Artificial Intelligence (AI) / Machine Learning algorithms, which drive and boost the ASR process through a set of command hypotheses derived from the contextual knowledge, with a benefit on the workload, HMI usability and efficiency in ATCO – pilot interactions.

Those solutions positively contribute mainly to the Cost Efficiency, HP and (indirectly) Safety KPAs with increased head up time and better balanced workload, as well as increased situation awareness and controllers' productivity.

The PJ05-W2 DTT attracted plenty of European organisations to participate: ANSPs, industries, R&D and airport stakeholder intends to provide their specific competences to broaden the operational needs and technological expertise. The PJ05-W2 variety of partners and validation activities helped to adequately reflect the variety of operational needs and technical solutions, which in the end of the project consolidated into harmonized and widely accepted SESAR2020 PJ05-W2 solutions. The complete work was structured in a very collaborative way throughout all work packages and ensured the transfer of knowledge and know-how between all participants and external to SESAR2020 projects.

Solution 35 proved that SDM-210: 'Highly Flexible Allocation of Aerodromes to Remote Tower Modules' has reached V3 maturity. All Enablers for solution 35 were positively validated. The provision of remote ATS service to the remote aerodromes can be flexibly assigned (over time) to other Multiple Remote Tower Modules (MRTM) within a Remote Tower Centre (RTC). Supervisor Planning tools support an efficient deployment of staff in an RTC.

The activities performed in solution 97.1 „Virtual/Augmented Reality applications for tower" proved the technical feasibility of the AR concept in an ATC Tower, both in simulated environment and in

physical tower, presenting AR information on a head mounted display (namely the HoloLens 1 or 2, benchmark product supplied by Microsoft) to enable specific features as defined by each exercise objectives. Controllers found that the technology is very intuitive and requires short time for acquaintance. Weight of wearable devices was deemed acceptable for last generation models, while for first generation ones could lead to experience some heavy head.

The three validations which took place in Solution 97.2 *„ASR at the TWR CWP supported by AI and Machine Learning"* proved the technical feasibility of the ASR technology to capture Aerodrome ATC instructions and clearances transmitted by radio to flight crews and to use them to automate ATC system inputs. ATCOs saw the potential in applying speech recognition in a TWR environment and were able to perform their ATC tasks (even given the CWP prototypic systems) when working with ASR support. The outcomes indicated that ASR has no negative impact in terms of workload and situation awareness and therefore do not appear to reduce safety levels, while the positive results for system usability, job satisfaction and some workload measurements show the potential of ABSR in a (multiple remote) tower environment and foster to go further in maturity level.

Solution 35 reached a V3 maturity and is ready for transitioning to industrialization and later deployment. However, there are recommendations to be considered during deployment. In particular specific details for system failure and back up as well as local procedures and harmonisation need to pay attention for like:

- Based on the specific locally defined roles, the ATCO and SUP planning tools need further optimisation regarding HMI design in order to allow more intuitively assessment of the situation.
- Depending on the complexity of the SUP planning task and the SUP workload, the SUP planning tool needs to be extended by weather information and information on ATCO endorsements and ATCO availability.
- Depending on the number of aerodromes connected to an RTC complexity of the SUP planning task and the related SUP workload might heavily increase when an optimised allocation is to be aimed for. Thi cannot be solved by a human actor and would need automated optimisation support, which optimisation criteria are still to be developed in future R&D activities.
- Large RTCs inherent by a great extent flight plan data several small and other aerodromes. Flight plan data that are hardly available today and thus would be of a highest interest to a network manager (NM). Connecting RTCs and NMs would provide synergies for both and would contribute to improve the overall flow management.
- The deployment needs a safety assessment on the chosen technical system for deployment.
- Security and redundancy concepts are to be further developed and refined when implementing large RTCs.

Solution 97.1 „Virtual/Augmented Reality applications for tower" showed the potential and feasibility of V/AR solution has been demonstrated, some technical recommendations have been figured out to further improve the usability of the technology itself and associated performance.

- HMI: position, width, brightness… of symbols should be refined in order to avoid visual interference.
- The addition of an altitude filter to allow the controller to filter out a/c that are either flyovers or outside the scope of their control.
- Choice of the device: the latest generations devices are preferable due to lower weight and a wider angle of view, thus improving the experience comfort.

- It was found that controllers thought it would be enough to alert them only once for serious events, such as a runway incursion or a go-around.
- No distinction between different controller roles was made (e.g. runway controller, ground controller, assistant, supervisor), while in fact both roles may require another, more customized way of presenting the necessary information.
- Other static or dynamic information on the airport surface could be presented, such as buildings, and taxiway and runway edges (in reduced visibility), stop bars and their statuses, protected areas, closed runways etc.
- Automatic Speech Recognition could be used in the future to identify certain situations in the system (e.g. a pilot calling) and signalling to the AR device to highlight particular information (e.g. aircraft label).
- Strip-less working methods could be investigated adding planning aspects to the outside view, making it superfluous to build a mental picture with flight status strips.
- Use of the technology could also lead to a new definition of controller roles and responsibilities.
- Additional features could be integrated into the AR device view, such as video streams from cameras at gate positions that cannot be seen very well from the tower or video that zooms in on certain aspects of the operation at the gate to give an indication of the statuses for boarding and de-boarding, fuelling, catering and baggage handling.
- For some areas, it might be useful to offer detailed (camera) views inside the device, e.g. for runways where thresholds are far away from the tower or where part of the runway cannot fully be seen (gap fillers).
- For attention capturing and guidance mechanisms (without an AR device), there could be advantages when used in multiple remote tower set-ups, where one or more controllers need to maintain a mental picture of the operational situation at two different airports.

In solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning" a set of recommendations have been figured out in order to sharpen ASR operation, supported by AI and Machine Learning, among them:

- Consider a larger amount of representative training data (especially speech data from ATC operations' rooms)
- Consider pilot utterances in order to enable reasonable callsign highlighting at ATCo side and readback error detection
- Consider ABSR experience and functionality for aircraft cockpits
- Consider further applications that use the speech recognition and understanding output such as pre-filling of radar labels and flight strips, advanced readback error detection, incident analysis, on-the-job training support
- Intensify the use and enhance European-wide agreed ontology for annotation of ATC utterances
- Foster standardization of ABSR input and output content as well as format in order to improve system interoperability and comparability

1 Project Overview

The Project PJ.05-W2 “Digital technologies for Tower” (DTT) proposed the development of a remotely provided aerodrome air traffic service by a "multiple" and/or "center" setting and further, aimed for to validate, in different Airport operating environments, innovative HMI modes and associated technologies.

Solution 35 „Multiple Remote Tower and Remote Tower centre” validated the concept to provide ATS services for several aerodromes from a Remote Tower Centre independent on airport location in order to make use of the valuable resource ATS provider more efficiently.

Solution 97.1 „Virtual/Augmented Reality applications for tower” aimed for to validate Virtual and Augmented Reality (V/AR) applications, including Tracking labels, in different Airport operating environments, blending real world images with computer-generated data in real-time.

Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning” aimed for to validate Automatic Speech Recognition (ASR) technologies to allow the recognition and translation of spoken language (e.g. ATCO utterances) as commands input into the ATC system. The ASR engine is supported by Artificial Intelligence (AI) / Machine Learning algorithms.

1.1 Operational/Technical Context

1.1.1 Solution 35 „Multiple Remote Tower and Remote Tower centre”

This solution addresses the remotely provision of Air Traffic Services (ATS) from a Remote Tower Centre (RTC) to a large number of airports and its highly flexible allocation of grouped aerodromes to dedicated MRTMs. This includes the development of RTC supervisor and support systems and advanced automation functions for a more cost efficient solution. This also covers the integration of approach for airports connected to the remote centre and connections between RTCs with systems for flow management and the development of tools and features for a flexible planning of all aerodromes connected to remote tower services.

The flexible allocation can also imply that higher traffic levels should be handled by the ATCOs. While some situations might result in small delays, aerodrome capacity will not be reduced by introducing multiple remote tower concept (if more capacity is required, flexible allocation needs to be adjusted or another MRTM to be opened).

Depending on complexity as result from the specific local implementation or the associated workload, the task role for a flexible allocation of grouped aerodromes to dedicated MRTMs might be allocated either to an ATCO or to a dedicated Supervisor.

In order to enable an efficient allocation, it is assumed that a Supervisor Planning Tool that incorporates data like traffic volume/complexity and weather conditions at the different airports as well as ATCO endorsements and availability will support the RTC supervisor. The planning tool might include a what-if functionality to allow the RTC supervisor to compare different parameters.

Automation planning support tools has a possibility to assist the Supervisor in an efficient allocation of aerodromes to MRTMs (strategic, pre-tactical and tactical). In the validations, this was made through usage of more aerodromes than those within each validation, meaning not the ones operated by the

ATCOs. Validation activities used virtual aerodromes, not part of the main validation. This to support the supervisor role in an RTC with several connected airports with aim to find a more efficient allocation of aerodromes and ATCOs.

Solution 35 addresses any combination of Small Operating Environment aerodromes according to EATMA aerodrome classification (between 15K and 40K annual IFR movements), taking into consideration the different kinds of environments composed of:

- Different levels of airport complexity (RWYs, taxiways, etc.).
- Traffic volumes and their distribution over the controlled aerodromes.
- Various conditions at the different aerodromes (weather, daylight, geographical difference).
- Variable traffic mixes (VFR-IFR-mix, rotor-fixed wing, special).

The results from Solution 35 are also valid for aerodromes within category Other Operating Environment (less than 15K annual IFR movements).

1.1.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

Progresses that have been done in synthetic vision and Virtual and Augmented Reality (V/AR) fields have been applied in a number of different aviation areas from the flight deck to aircraft maintenance, including air traffic control towers, with the aim to ease the job of involved staff and to enable more seamless operations. V/AR in an ATC Tower environment supports the Air Traffic Controllers by blending real world images with computer-generated data (augmented reality) in real-time, so that visual information can be enhanced to improve identification and tracking of aircraft (or vehicles) on the airport surface. Moreover, in low visibility conditions, the lack of visual information provided by the out-of-the-tower windows view can be compensated by the massive use of synthetic vision to show digital georeferenced data that supplement the missing real vision (virtual reality).

Airport operations can benefit from this kind of advanced technologies, capable to provide beneficial automation support under low visibility conditions, but also, in good visibility situations, to present additional information in the labels to the controllers to reduce head-down time or help in case of physical obstacles that obstruct vision. When applying V/AR, the auxiliary information is merged with the OTW view and presented as an overlay on top of the real-world visual information. In this way, the controller is no longer forced to divide his/her attention between the primary visual field (e.g. out-the-window (OTW) view) and the auxiliary tools (such as paper or electronic flight strips, surface movement radar, gap-filler camera streams and alert indications), consequently reducing the so-called head-down time and increasing the Situational Awareness (SA).

In particular, alerts that are currently given in an aerodrome tower environment, such as Runway Incursion Alerting or Stop Bar Violations can be generated and the differences in attention getting in comparison with traditional tower control as well as the advantages of attention guidance can be evaluated. The optimal way to guide attention can be assessed by exposing controllers to different presentations of alert information, different symbology and/or audio alerts within an AR device. The AR device can be used in different scenarios with different traffic situations, different types of alerting with different levels of severity at selected locations in the airport movement areas. Controller reaction times, attention distribution and decision-making effectiveness for the situation to be solved can be measured and compared.

V/AR also addresses a problem related to the availability of an increased number of remote camera video feeds in the ATC tower environment. These video feeds all need to be displayed on monitors, possibly blocking important line-of-sights or in other ways obscuring the outside view. Providing the camera feeds on a Head-Mounted-Display (HMD) or a similar device could potentially solve this problem.

Hence, suitable applications of V/AR for air traffic control tower so far identified consist in visualisation tools, either based on wearable devices, e.g. Microsoft HoloLens (Figure 2) either in see-through spatial displays, investigated, as a first step, during Exploratory Research phase.

In this context, the integration of Tracking Labels in an Augmented Reality environment is considered: the label is attached to the real aircraft object and displays the most important information; the tracking label displays additional information in the case of detection of any potential conflict by the Airport Safety Net Service.

A Tracking Label integrated with the Airport Safety Nets Service allows to display advisories to the ATCO that allow him to solve a current conflict as quickly as possible. E.g. some EFS features, such as highlighting of the strip bay in case of use of the runway, can be transferred to all labels that may use the runway in the next defined lapse of time, or a square around the callsign becomes orange. In any case the current Airport Safety Net Service is preventing safety related issues.

Moreover, the user will be able to interact with the virtual interface by means of air gesture. Gesture recognition can be seen as a way for computers to begin to understand human body language, thus building a richer bridge between machines and humans than primitive text user interfaces or even GUIs (graphical user interfaces). These interfaces still limit the majority of input to a keyboard and mouse. Using the concept of air gesture recognition, it is possible to make the user interact with tracking labels when performing not time critical tasks, such as clearing push back. The concept is also intended to be used for navigating through the information and menus displayed, allowing the controller to perform actions such as picking, dragging and dropping AR elements, filtering the number of aircraft presented or enabling/disabling LVC display.

Additional computer-generated overlays such as ground vehicles, weather display, runway and taxiway layout and parking stands are adaptively displayed based on the specific working position and visibility condition. As the visibility conditions get worse, the number of information displayed by means of synthetic vision increases.

The Solution is aimed to operate in the Airport Operating Environment, including all types of airports that this category comprises (Very Large, Large, Medium, Small and Other).

1.1.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"*

The solution 97.2 Automatic Speech Recognition (ASR) system gets an audio signal from the controller working position (CWP) as input and transforms it into a sequence of words, i.e. "speech-to-text" following the recognition process. The sequence of words is transcribed into a sequence of air traffic control (ATC) concepts ("text-to-concepts"). For example, the word sequence "bonjour Air France two four eight six line up and wait runway two seven left" is transformed into "AFR2486 LINEUP RW27L".

The ASR system may benefit from surveillance data, flight plans, meteorological data, routing information etc. - a so called Assistant Based Speech Recognition (ABSR) system. The ABSR derives command hypotheses from the contextual knowledge to support the speech recognition engine in choosing the right recognition hypotheses. This increases the command recognition rate and minimizes the command recognition error rate.

The AI/ML applied to ASR function, supports the "Command Hypotheses Predictor" that periodically receives contextual information updates such as surveillance data, flight plan data, route information, clearance information, weather information etc. This information is used to predict possible future controller commands based on a machine learned command prediction model on historical surveillance and speech data.

The ASR function consists of the following major capabilities:

- Word Sequence Extraction

The recorded verbal utterances from the controller pilot communications are input into the automatic speech recognition engine, which outputs a list of recognized words (transcription).

The above described extracted word sequence is the input for the extraction of concepts, i.e. the extraction of ATC commands following the defined ontology (annotation).

The extracted controller commands constitute a hypothesis, which needs to be checked against any relevant contextual information. Hence, there should be a check against the currently predicted controller command hypotheses and against mouse or keyboards inputs if available. The finally checked controller commands, i.e. the most reasonable hypotheses due to the ABSR functionality chain, can then be used for further ASR applications such as presenting the recognized commands on a human machine interface (HMI).

Additional Capabilities, belonging to a specific technical implementation:

- Command Prediction

The "Command Hypotheses Predictor" periodically receives contextual information updates such as surveillance data, flight plan data, route information, clearance information, weather information etc. This information is used to predict possible future controller commands based on a machine learned command prediction model on historical surveillance and speech data.

The Automatic Speech Recognition at the Tower CWP targets to operate in the Airport Operating Environment, including all categories that are part of this group (Very Large/Large/Medium/Small/Other). The functionality can be deployed in both conventional and (multiple) remote Tower.

With regards to the potential link with remote tower concept at the end of the lifecycle, it is worth to note that PJ.05-W2-35 (Multiple Remote Tower and Remote Tower Centre) can introduce another use case for validation of ABSR technology, which does not strictly depend on the operational scenario it is used in. In fact, Multiple Remote Towers. Irrespective of monitored airports size, can be a setting for further validation of ABSR.

1.2 Project Scope and Objectives

1.2.1 Solution 35 „Multiple Remote Tower and Remote Tower centre"

Providing air traffic control (ATC) for aerodromes is a safety critical task. It needs best educated controllers and highly sophisticated and well maintained equipment, which drives costs. Other and small environment airports commonly have costs exceeding the revenue from landing fees. These airports are often an important part of the infrastructure in rural regions wherefore cost efficient solutions such as Remote Towers add a possibility to keep airports open. Furthermore, today controllers became a rare source. The remote tower concept is changing the provision of Air Traffic Services (ATS) in a way that it is more service tailored, dynamically positioned and available when needed, enabled by cost-efficient visual surveillance systems replacing the physical presence of controllers and control towers at aerodromes. Depending on complexity and requested capacity an ATCO can provide Air Traffic Control to a single or multiple aerodromes. Providing ATS for Multiple Aerodromes and its flexible allocation of aerodromes to Remote Tower Modules is the core subject of Solution 35 „Multiple Remote Tower and Remote Tower centre".

The objective of solution 35 is to increase *ATCO productivity* (i.e. reduce the number of ATCOs required) by balancing the workload between different MRTMs accommodated within a Remote Tower Centre.

The balanced workload - a workload on levels that shall be acceptable for involved ATCOs, is achieved by a flexible allocation of grouped aerodromes to dedicated MRTMs, which in the end will increase *cost efficiency*, resulting from more traffic managed by one ATCO.

By adjusted procedures and/or automation support *human performance* and *safety* will be maintained.

The Operational Improvement Step addressed in this solution is SDM-0210 "Highly Flexible Allocation of Aerodromes to Remote Tower Modules":

'The provision of remote ATS service to the remote aerodromes can be dynamically assigned (over time) to any other Remote Tower Module (RTM) within a Remote Tower Centre (RTC). RTC planning tools supporting the RTC supervisor enable an efficient usage of all RTMs and staff in an RTC.'

Five exercises in total were organised and performed at different locations based on different prototypes. The validations were conducted as both real-time simulation and as passive shadow mode trials. Workshops were held as an addition to the validation activities to obtain more data for the Safety and Human Performance report.

1.2.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

Solution 97.1 aimed to ease the tower operations and improve safety and resilience by means of augmented reality applications (e.g. Head Mounted See Through Devices) in TWR environment, including Tracking labels, to allow a reduction of ATCOs need to switch in between head down and head up views, and an increase of situational awareness, still maintaining the taxiway and runway throughput. Furthermore, the solution addressed the use of in-air gestures to investigate if it can speed up and make simpler human-system interaction. The attention control for V/AR applications enables to monitor and guide the attention of the controller, by measuring and comparing controller reaction times, attention distribution (through an eye-tracker) and decision-making effectiveness for the situation to be solved. In particular, Solution 97.1 aimed for an:

- Improved and innovative working operating environment
- Improved and innovative Human Machine interaction

- Improved usability/user confidence acceptance
- better balanced mental workload
- Increase in information accessibility and situational awareness of the ATCO.
- Increased ATCO efficiency and productivity.
- Enhanced Cost-efficiency through reduction of the workload per flight
- Enhanced Resilience by easing operations especially in low visibility conditions and by easing the interaction with the AR interface especially in low visibility conditions.

1.2.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning”*

Solution 97.2, built on earlier SESAR 2020 research results (solution PJ.16.04-02 and exploratory research project Mallorca), aimed to increase the level of automation through the use of Automatic Speech Recognition supported by AI and Machine Learning algorithms. Enabling the automatic highlight of flights to be cleared/informed and automatic clearance recognition, instead of manual action, is expected to result in a reduction of potential errors in flights selection/clearance input, thus reducing task demand, while improving operational efficiency (increased timely task execution). In particular solution 97.1 aimed for an:

- Increased safety through increased situational awareness
- Improved and innovative Human Machine interaction
- Improved usability/user confidence acceptance
- better balanced mental workload
- Increase in information accessibility and situational awareness of the ATCO.
- Increased ATCO efficiency and productivity.
- Enhanced Cost-efficiency through reduction of the workload per flight

1.3 Work Performed

Each solution has been defined in terms of scope, name, relevant OI and EN, target Operational environment, initial maturity level, position w.r.t. ATM MP scope. For each solution KPA, performance benefits, Validation targets, OEs have been identified in coordination with PJ.19-W2-WP4.

1.3.1 *Solution 35 „Multiple Remote Tower and Remote Tower centre”*

In SESAR 1 the concept for Single Remote Tower (SDM-0201), Contingency Remote Tower (SDM-0204) and Multiple Remote Tower for two very small aerodromes (SDM-0205) was developed. Based on this work the concept for Multiple Remote Tower was expanded in SESAR 2020 to cover more airports at a time and more traffic that is controlled from one MRTM. While PJ05 SDM-0207 (PJ.05.02 wave 1) is expected to reach V3 maturity in wave 1, PJ05 SDM-0210 (PJ.05.03 in wave 1) is expected to reach V2 maturity level in wave 1. Solution 35 is the successor of solution PJ.05.03 and to be validated up to V3 level in wave 2. This concept for solution 35 was validated in several validation activities and validation platforms. Simulations were performed to in a safe wave develop the concept with abnormal use cases and degraded modes of operations, this with ATCOs as test subjects. The validated concept aims at providing input for EASA for having common regulations for approval of CWPs (that approved CWPs from one NSA are approved for all ANSPs with minor local implementation).

Solution 35 is described as SDM-0210, 'RTC with Flexible Allocation of Aerodromes to MRTMs'. The solution aims at increasing cost efficiency. The objective for this solution was to develop and validate:

- A MRTM which allows ATCOs to provide ATS service to remote aerodromes while maintaining situational awareness for three airports simultaneously.
- The RTC and the dynamic allocation of airports between MRTMs.

The Remote Tower Centre (RTC) is the centralised facility housing MRTMs where the provision of a remote ATS can be provided to one or more aerodromes from each MRTM. To achieve this goal of increased number of airports connected to the RTC and larger traffic volumes to be controlled from a MRTM, three enablers were to be developed and validated as described in the OSED document [3]:

1) Additional automation functionalities for the ATCO were added into the MRTM (e.g. conformance monitoring, task planning and prioritisation) in order to be able to allow more airports and/or higher traffic volumes to be controlled simultaneously from one MRTM by one ATCO.

2) The supervisor was enabled to dynamically allocate any airport to another MRTM within the remote tower centre (RTC) in order to balance ATCO workload and traffic volumes. As more airports are grouped than for SDM-0207 (solution PJ.05-02 in wave 1) (up to all airports within a remote tower centre being grouped), this results in a much higher complexity regarding planning. The Supervisor was supported in evaluating traffic volumes and workload by a planning tool.

3) A harmonisation of systems in the MRTMs/RTC and a harmonisation of procedures which make it easier for the ATCOs to hold endorsements for more than three airports.

It was expected that a supervisor role will change with the flexible allocation of airports to MRTMs. This required that the supervisor is provided with supervisor planning tools.

Furthermore, the highly flexible allocation of airports to MRTMs within an RTC required the following items to be investigated:

- Support of ATCO situational awareness
  The MRTM needs to be designed in a way that it supports ATCO situational awareness integrating all the information from the different airports. HMI guidelines needed to be applied in order to find the balance between providing all information required at a certain moment while avoiding clutter of information. Use of automation tools supporting ATCO situational awareness was validated.
- Handover between MRTMS
  Handover procedures and features for transferring an airport from one MRTM to another were to be defined and validated.
- Planning and allocation of airports and staff to MRTMS
  Roles and tools related to planning were to be established considering aspects like planning allocation of operators, airports and MRTMs which are closely interlinked.
- Role of Supervisor
  The role for the supervisor were to be defined and validated.

Validation was performed using Real Time Simulations on different validation platforms focusing on the two different airport environments. One Shadow mode trial took place. Validations focused on *Small* environment airports and *Other* environment airports (according to EATMA definition). Human

Performance and Safety was validated through questionnaires in all validation exercises and a common workshop for consolidation of results.

Real Time Simulations for at least three *Other* environment airports in multiple mode:

- DLR validation proving the feasibility and challenges of a large Remote Tower Centre with up to 15 connected aerodromes operated by two real and virtual ATCOs and a Supervisor Planner Position with automated planning support.
- Indra, delivering results on visual reproduction environment for control of three aerodromes simultaneously and technical support systems for the ATCOs in a MRTM including approach for all airports.
- COOPANS, validation platform delivering results on visual reproduction and HMI for control of three airports simultaneously with a mix of IFR and VFR traffic. Development of handover functionality for a flexible allocation of aerodromes.
- ENAV, validation platform delivering results on mixed weather at the airports in a Multiple Remote Tower Module.
- DFS, validation of a Multiple Remote Tower Module for three airports simultaneously.

HP and SAF workshop, was performed with ATCOs from all validation activities on PJ.05.02 together with PJ.05.03 to consolidate and develop requirements for Safety and Human Performance. All results are referred to in the Validation Report (VALR) [4][7].

1.3.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

The **Solution 97.1** brought innovation in terms of human machine interface in Tower, by equipping the ATCOs with Augmented Reality devices aiming to reduce the need to switch from head up to head down position, with impacts in terms of Human Performance, Safety, and resilience. The developed solutions include the implementation of also the human-system interaction through the use of in-air gestures, and the attention control for V/AR applications to monitor and drive the attention of the controller. The technical feasibility of the concept has been investigated through a set of technical validation exercises in different Airport operating environments, with different layout complexity, traffic volumes and meteorological conditions. Different configurations were realized to enable specific features according to each exercise objectives: Tracking Labels, Air Gestures, Attention Capture and Guidance in V/AR environment.

Virtual and Augmented Reality applications for tower has been validated through a chain of three technical validation exercises:

- one RTS conducted by NLR in April 2021 at NARSIM Validation Platform in Schiphol environment, with focus on Attention Guidance aspects;
- one RTS on Tracking Labels and Air Gestures based on V/AR technology conducted by ENAV/UNIBO at UNIBO CAVE simulator, in March 2022 in Bologna airport environment;
- one Shadow Mode validation on Tracking Labels and Air Gestures based on V/AR technology conducted by ENAIRE/CRIDA in February 2022 at Vitoria Airport.

1.3.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"*

In the frame of **Solution 97.2**, recognition of controllers' utterance has been investigated with the aim to automatise the command input into the ATC system, aiming at improving the ATCOs productivity.

The use of the developed solutions was investigated in different Airport operating environments, with different layout complexity, traffic volumes, including multiple remote tower environment.

Automatic Speech Recognition applications for ATC Tower has been validated through a set of three technical exercises:

- One Real Time Simulation addressing Speech Recognition in a multiple remote tower environment performed by INDRA and HUNGAROCONTROL in Asker in December 2021.
- One Real Time Simulation addressing Speech Recognition at Braunschweig simulating a multiple remote airport controller working position adapted from existing airports, led by DLR in February 2022.
- One Real Time Simulation addressing Speech Recognition at Rome simulating Sofia airport, led by LEONARDO in May 2022.

Details about each of the validation exercise listed above are provided in the concerned deliverables (common to both Solution 97.1 and 97.2):

- Validation assumptions, objectives, plan — TVALP ([17])
- Description of the Validation platform — AN ([22] to [27])
- Operational scenarios and Results — TVALR [19]
- Description of system architecture — TS/IRS (and its Annexes) [1]
- Evaluation of costs and benefits — CBA [20]
- Validation objectives for next phase — iTVALP for TRL6 [16]

Furthermore, BIM (normally part of OSED) has been included as additional evidence in the TVALP, according to relevant guidelines. Concerning the Solution management, progress meetings have been held fortnightly since the beginning. Stellar Register has been kept updated (dates, risks, actions, CR...). Risks have been monitored, with an eye on COVID emergency. Coordination actions have been put in place with PJ.19-W2, for PCIT coordination, for the data input into EATMA and SE-DMF databases, to set the CBAT, to drive the Security assessment activity, to agree and share Validation Targets as well as OEs, and for CR refinement and submission.

The Communication and Dissemination Plan has been submitted with action plan for sol 35 and 97.x and continuously updated as a live document.

1.4 Key Project Results

1.4.1 Solution 35 „Multiple Remote Tower and Remote Tower centre"

The validation exercises have shown that solution 35 (SDM-210: 'Highly Flexible Allocation of Aerodromes to Remote Tower Modules') has reached V3 maturity. All Enablers for solution 35 were positively validated.

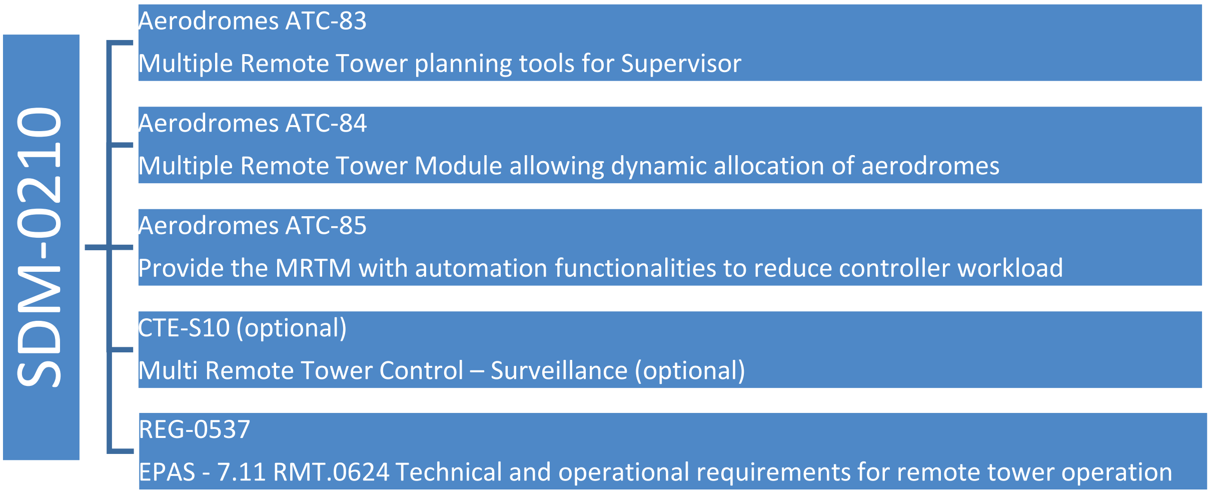

Figure 1: OI and enablers for solution 35

ATCOs could work with a flexible allocation of aerodromes to MRTMs that was either initiated by a handover to or from another MRTM or initiated by the SUP who assessed the situation based on the SUP planning tool. Both approaches worked well and it might be chosen based on the specific local situation in the RTC which one to implement. If the ATCOs are responsible for the flexible allocation, workload buffers for this task need to be considered. Managing a higher number of aerodromes in an RTC should be supported by a SUP role.

The validation exercises were based on quite a diversity of specific local environments and specific validation platforms. While the general concept could be successfully validated, the exercises revealed the differences in the local environments and specific platforms that need to be addressed in the deployment phase.

ATCOs were always aware which aerodrome was displayed in which position within the MRTM.

A checklist should be used by the ATCOs for handover of aerodromes between MRTMs.

ATCOs agreed that their roles and responsibilities when providing ATS to multiple aerodromes with flexible allocation were clear and acceptable. It was clear to the ATCOs who was responsible for monitoring of traffic and for initiating an aerodrome allocation.

The need for a dedicated training on ATCO/SUP teamwork to deal with abnormal situations or degraded modes was raised by both ATCOs and supervisors.

The SUP role should cover the following tasks with respect to the flexible allocation of MRTMs:

- plan allocation of aerodromes to MRTMs
- plan staffing of the MRTMs
- monitor the situation at the MRTMs

- support the ATCO in cases of high workload (e.g. emergencies or degraded mode),
- trigger allocation of aerodromes to MRTMs

The workload associated with these tasks might be quite different depending on the specific local implementation (e.g. big RTC with many aerodromes vs. 2-3 aerodrome RTC). Depending on the specific local implementations the SUP role might also cover different general coordination and administration tasks.

Depending on the associated workload the SUP Role might therefore be allocated to either an ATCO or a dedicated Supervisor Planner position.

In an operational environment the information on ATCO availability as well as on ATCO endorsements and MET information needs to be included in the SUP planning tool.

1.4.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

The technical feasibility of the Augmented Reality in Tower has been demonstrated and prototypes developed and implemented had a positive impact on the ATCOs' performance, reducing the need to switch from head up to head down position and keeping the workload at an acceptable level. Situational awareness, potential for human error, trust, acceptance, job satisfaction, and perceived safety, especially in low visibility conditions, were measured, with promising impacts on for the cost efficiency performances. Nevertheless, improvements could be achieved by increasing the synthetic field of view and enhancing the label design and positioning.

The introduction of V/AR Air Gesture HMI interaction was proved to be technically feasible when dealing with not-time-critical tasks but, in order to achieve a higher level of maturity and have a positive impact on human performance, some usability improvements shall be considered.

Concerning the attention guidance, reaction times might decrease when using AR guidance, because controllers did not have to look down onto displays for information. Having callsigns in view and not being constrained to head down mode by information displayed on the TSD or the flight strips, is deemed efficient and convenient. Safety increased as controllers could give instructions more efficiently when using AR device (based on the information received from the safety nets). No negative effects on workload or SA were found during the experiment.

1.4.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"*

Solution 97.2 has extensively addressed the Automatic speech recognition and understanding for air traffic control (ATC) communication in simulated tower and ground environments, analysing the recognition rates and human performance of air traffic controllers (ATCos). Three validation exercises with 22 ATCos from four different European air navigation service providers were conducted in Germany, Norway, and Italy. The validated Artificial Intelligence-based prototypes of Assistant Based Speech Recognition systems (ABSR) supported ATCos in fulfilling tasks in a ground and tower environment as well as multiple remote tower environment, respectively. Thus, in any relevant ATC display, (1) recognized callsigns of ATCo utterances have been highlighted, (2) fully recognized commands were shown, and (3) the ATCo was able to manually manipulate the ABSR output if needed or (4) the output was automatically accepted by the ATC system otherwise.

1.5 Technical Deliverables

Reference	Title	Delivery Date[2]	Dissemination Level[3]
Description			
Solution 35			
D2.1.020	D2.1.020 - PJ.05-W2-35-V3 OSED	02.12.2022	PU
This document addresses the Operational Services and Environment Description, the Safety and Performance Requirements and Interoperability Requirements for solution PJ05-W2-35 at V3 maturity level.			
D2.1.040	D2.1.040 - PJ.05.35 V3 TS	06.12.2022	PU
Technical Specification provides the description of system architecture, scenarios, use cases and requirements specification covering functional, non-functional and interfaces requirements related to both solutions. The final version includes as Annexes the Part II (Safety Assessment Report), Part IV (HP Assessment Report), and (though not initially foreseen for Technological Solutions), the Part V (Performance Assessment Report)			
D2.1.050	D2.1.050 - PJ.05.35 V3 CBA	16.11.2022	PU
The Cost Benefit Analysis document aims at providing an analysis of the benefits and costs for the deployment of both solutions. The CBA forms part of the data pack and supports development and deploying of new technologies. The initial costs were estimated based on standard inputs and expert judgement.			
D2.1.060	D2.1.060 - PJ.05.35 V3 VALR	16.08.2022	PU
The Validation Report describes the scenarios, results of validation exercises defined in Validation Plan and how they have been conducted, and provides a set of relevant conclusions and recommendations.			
Solution 97.1 and 97.2			
D3.1.022	D3.1.022 - Technical Requirements (TS/IRS) Final	13/10/2022	PU
Technical Specification provides the description of system architecture, scenarios, use cases and requirements specification covering functional, non-functional and interfaces requirements related to both solutions. The final version includes as Annexes the Part II (Safety Assessment Report), Part IV (HP Assessment Report), and (though not initially foreseen for Technological Solutions), the Part V (Performance Assessment Report)			
D3.1.030	D3.1.030 - Initial Technical Validation Plan (TVALP)	09/06/2020	PU
The initial Validation Plan for TRL6 provides the approach to the validation of the next maturity level.			
D3.1.033	D3.1.033 - Technical Validation Plan (TVALP) Final version	01/12/2021	PU
The Technical Validation Plan provides the Validation assumptions, objectives, plans of the technical exercises.			
D3.1.051	D3.1.051 - Technical Validation Report (TVALR) Final	30/09/2022	PU

[2] Delivery data of latest edition

[3] Public or Confidential

The Validation Report describes the scenarios, results of validation exercises defined in Validation Plan and how they have been conducted, and provides a set of relevant conclusions and recommendations.			
D3.1.071	D3.1.071 - CBAT Final	26/10/2022	PU
The Cost Benefit Analysis document aims at providing an analysis of the benefits and costs for the deployment of both solutions. The CBA forms part of the data pack and supports development and deploying of new technologies. The initial costs were estimated based on standard inputs and expert judgement.			

Table 1: Project Deliverables

2 Links to SESAR Programme

2.1 Contribution to the ATM Master Plan

Code	Name	Project contribution	Maturity at project start	Maturity at project end
PJ.05-W2-35	Multiple Remote Tower and Remote Tower centre	Additional automation functionalities for the ATCO are added into the MRTM (e.g. conformance monitoring, task planning and prioritisation) in order to be able to allow more airports and/or higher traffic volumes to be controlled simultaneously from one MRTM by one ATCO. The supervisor can dynamically allocate any airport to another MRTM within the remote tower centre (RTC) in order to balance ATCO workload and traffic volumes	V2	V3
PJ.05-W2-97.1	Virtual/Augmented Reality applications for tower	Solution contributes to the reduction of ATCOs head-down time and increase of resilience and situational awareness. The use of in-air gestures for user interaction can speed up and make simpler human-system interaction. Attention guidance in AR devices enables to drive the controllers' attention towards imminent safety events while reducing reaction times.	TRL2	TRL4
PJ.05-W2-97.2	ASR at the TWR CWP supported by AI and Machine Learning	Enabling the recognition and translation of spoken language (e.g. ATCO commands) into the system, thus reducing human error and workload, while improving HMI usability and efficiency in performing interactions.	TRL2	TRL4

Table 2: Project Maturity

2.2 Contribution to Standardisation and regulatory activities

2.2.1 Solution 35 „Multiple Remote Tower and Remote Tower centre"

Regulatory support and guidance is available to facilitate safe implementation of multiple remote tower control and to provide a basis for its further development and industrialisation. This regulatory activity is captured in:

- EASA Guidance Material on remote aerodrome air traffic services, Decision 2019/004/R, Issue 2 still valid, Issue3 published as NPA
- ED-240A, MINIMUM AVIATION SYSTEM PERFORMANCE STANDARD FOR REMOTE TOWER OPTICAL SYSTEMS, ED-240B in preparation

The above NPA recognised, at the time of publication, there was two SESAR solution published related to multiple mode of operation (Solution #52 for 'two low density aerodromes') together with SDM-0207-Multiple Remote Tower Module.
It can therefore be expected that, subject to the validation of PJ.05 solutions, EASA further update its regulatory material to soften some recommended limitations as well as mitigation measures for how to handle related risks, in multiple mode of operation, taking into account the increased level of maturity.
A new REG-XXX enabler, linked to SDM-0210, could capture this potential regulatory activity.

2.2.2 Solution 97.1 „Virtual/Augmented Reality applications for tower"

Side to the Regulations currently applicable to ATC Towers concerning the working environment risk factors, V/AR devices characteristics, such as weight and consequent impact on mental/physical strain, should be in line with the country occupational health and safety regulations. Solution 97.1 results have outlined that the latest generation devices are lighter and therefore preferrable for a comfortable use throughout the working session. Colours and appearance of visual cues should be in the hands of ATM system providers to design the user experience in accordance with the many feedback received by involved controllers on label size, duration of alerts etc.

As from results of PJ.16-04 on Attention Guidance, it would be beneficial if input and output channels are standardized. On the output side, a standardized interface between the HMI and the support system e.g. in case of highlighting aircraft labels would ease communication between different hardware/software manufacturers.

Besides, AIXM should be considered for the exchange of digital aeronautical information / data.

As part of PJ.05-W2-97.1 activities, a communication of the findings and results of the Solution to EUROCAE Technical Advisory Committee has been carried out. As a result of this coordination, some guidance has been provided with regards to the standardisation needs:

- EUROCAE ED-87E "MASPS for A-SMGCS including Airport Safety Support Service Routing Service and Guidance Service" should be considered for the Virtual and Augmented Reality functionalities, e.g. for the identification and alignment of elements in the V/AR devices.

- It is recommended that the development of specific ATC applications on existing COTS products is conducted keeping in consideration the safety requirements for this environment.

2.2.3 Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"

PJ.16-04 developed an ontology for the transcription of controller commands (En-Route, approach, tower) as well as for the hypotheses input and output transcription standard, that has been shared and agreed among some of the major European ANSPs, ATM system providers and research institution and that can be treasured as a good basis for future proposals on standardisation of content and format, i.e.: speech-to-text with a number of word sequence hypotheses, text-to-concept based on the ontology for ATC utterances and preparations in order to feed succeeding applications such as runway error detection, formats such as JSON for content transmission, and many aspects more to enable comparability and interoperability.

Standard could be identified for the voice sampling rate (kHz).

The ontology for ATC commands has been further enhanced. The need for standardising the phraseology for the speech recognition within the TWR domain has been assessed as part of the solution activities. However, it has been agreed that there is not a strong need to convert the ontology into a standard, since sticking the phraseology to a mandatory standard would difficult the deployment of the concept throughout the different dependencies (for instance, there would be problems for using local languages).

As part of PJ.05-W2-97.2 activities, a communication of the findings and results of the Solution to EUROCAE Technical Advisory Committee has been carried out. As a result of this coordination, some guidance has been provided with regards to the standardisation needs for ASR:

- There is not an existing standard for Voice Recognition in the ATM environment. An assessment of this need should be performed in further stages of the developments.
- Outside the ATM environment, there is an existing standard that is relevant for the solution: ISO/IEC 30122-2:2017, which provides the technical criterions and test methods of voice commands and its speech recognition engine. It is recommended that this standard is taken into account when developing the ASR functionality for ATM.
- Proposals for standardisation of the content and the format for input and output of assistant based speech recognition systems should be identified, i.e., speech-to-text with a number of word sequence hypotheses, text-to-concept based on the ontology for ATC utterances and preparations in order to feed succeeding applications such as runway error detection, formats such as JSON for content transmission, and many aspects more to enable comparability and interoperability.
- The usage of commercial-off-the-shelf products is not feasible for the ATM environment. Therefore, dedicated products developed for this environment would match better the expectations and requirements for deploying the concept in ATM.
- The ontology for ATC commands has been further enhanced. The need for standardising the phraseology for the speech recognition within the TWR domain has been assessed as part of the solution activities. However, it has been agreed that there is not a strong need to convert the ontology into a standard, since sticking the phraseology to a mandatory standard would difficult the deployment of the concept throughout the different dependencies (for instance, there would be problems for using local languages).

3 Conclusion and Next Steps

3.1 Conclusions

3.1.1 *Solution 35 „Multiple Remote Tower and Remote Tower centre"*

Solution 35 proved that SDM-210: 'Highly Flexible Allocation of Aerodromes to Remote Tower Modules' has reached V3 maturity. All Enablers for solution 35 were positively validated.

In a nutshell, the provision of remote ATS service to the remote aerodromes can be flexibly assigned (over time) to other Multiple Remote Tower Modules (MRTM) within a Remote Tower Centre (RTC). Supervisor Planning tools support an efficient deployment of staff in an RTC.

The supervisor planning tool should provide information like actual and forecasted traffic, ATCO availability and endorsements and weather conditions.

The planning tool might include a what-if functionality to allow the supervisor to compare different parameters.

Based on the specific locally defined roles, the ATCO and SUP planning tools need further optimisation regarding HMI design in order to allow more intuitively assessment of the situation.

MRTMs should be able to host up to three aerodromes.

ATCO licensing and endorsements can be kept with the aspect that an ATCO need a local endorsement for each aerodrome which the ATCO will work with in a flexible RTC. Future deployment can find similarities between airports within a cluster to enable a common endorsement for all aerodromes within such a cluster.

3.1.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

The activities performed in the project lifecycle proved the technical feasibility of the AR concept in an ATC Tower, both in simulated environment and in physical tower, presenting AR information on a head mounted display (namely the HoloLens 1 or 2, benchmark product supplied by Microsoft) to enable specific features as defined by each exercise objectives. Controllers found that the technology is very intuitive and requires short time for acquaintance. Weight of wearable devices was deemed acceptable for last generation models, while for first generation ones could lead to experience some heavy head.

The proposed solution was proved to be helpful to the ATCOs in reducing the time spent in Head Down position looking at the HDE with respect to the reference scenario: as the labels of the involved aircraft were in view, there was no need to look down to consult the deck physical equipment, so the overall head down time to monitor the airport situation was reduced. The improvement in terms of information accessibility resulted in a beneficial impact on situational awareness, which can be built faster and easily be maintained. Furthermore, potential for human error, trust, acceptance, job satisfaction, and perceived safety, especially in low visibility conditions, improved, leading to a beneficial effect for the cost efficiency performances. Nevertheless, in the future, a further improvement of these factors could be achieved with a fine tuning of the virtual interface design characteristics, such as the size/position of flight tags (to avoid overlaps) or possibly the look and feel of displayed overlays or by increasing the synthetic field of view and enhancing the label design and positioning.

Specific V/AR overlays implemented to provide attention guidance in case of runway incursions or go-around detection were deemed very effective and efficient, and furtherly improvable with some design adjustments (e.g. reconsidering duration and position of some alerts). Anyhow, V/AR guidance allows the ATCO to be more rapid with instructions concerning safety-relevant events. The attention cues positively affected human error (amongst other things) and the head-up time was improved in the solution scenarios. In some cases, the perceived potential for Human Error decreased thanks to the V/AR system especially for ground controllers.

Additionally, laboratory tests showed V/AR applications improve Resilience by increasing situational awareness in Low visibility conditions while maintaining workload within acceptable limits. The use of the glasses was shown to be beneficial to safety at night or in LVC, provided that the surveillance data feed is reliable, without data dropout and tag jumps.

Adequacy of usability level seems to vary depending on the maturity of the specific implementations and is negatively affected in case of interface design and hardware issues, so that several potential improvements to the design have been identified, to be fixed before the concept can be introduced. This is even more true for the Air Gesture solutions, where workload can be negatively affected due to the usability issues related to this specific application.

3.1.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"*

The three validations which took place in Solution 97.2 proved the technical feasibility of the ASR technology to capture Aerodrome ATC instructions and clearances transmitted by radio to flight crews and to use them to automate ATC system inputs.

The main findings from the overall validation exercises can be summarized as follows:

- In general, ATCOs saw the potential in applying speech recognition in a TWR environment and were able to perform their ATC tasks (even given the CWP prototypic systems) when working with ASR support. The outcomes indicated that ASR has no negative impact in terms of workload and situation awareness and therefore do not appear to reduce safety levels, while the positive results for system usability, job satisfaction and some workload measurements show the potential of ABSR in a (multiple remote) tower environment and foster to go further in maturity level.
- Encouraging feedback from ATCOs regarding acceptance and trust in the system indicate that the level of ASR technical performance was acceptable and consistent with human capabilities.
- Different results of recognition rates were collected at the three validations: a callsign recognition rate of 81-98%, a command recognition rate of 65-91%, and a slight reduction in ATCo workload on a low workload level.
- The quantitative and qualitative feedback of ATCOs were good and motivating to go beyond TRL4 and would have been even better if the full potential of ABSR accuracy have been offered to them.
- Positive reactions from ATCOs in terms of usability suggest a high quality of user experience when interacting with ASR and its related functions. Nevertheless, some degree of training

would be required for ATCOs to better understand "behaviours" of ASR and also to learn how to proactively adapt their speech to the tool.
- The "hook" function (the highlight of the label of aircraft addressed, as soon as it is pronounced by controller) was found to bring benefit to tower controllers' situation awareness.
- Safety aspects were addressed across all runs and no specific safety issues were identified during the validation exercise.
  The data shows that ATCos speak differently, i.e., closer to phraseology if being supported by ABSR (i.e., solution runs have higher command recognition rates that baseline runs; in the latter, the speech was analysed as well, but the output was not shown to the ATCo). On one hand, this might be, because they get better support if recognition rates are higher, on the other hand, it might be due to the pure awareness of working with speech recognition in the background. If ATCos are sticking closer to ICAO phraseology just by pure presence of an ABSR system, that could already be a safety feature.

3.2 Plan for next R&D phase (Next steps)

3.2.1 *Solution 35 „Multiple Remote Tower and Remote Tower centre"*

Solution 35 reached a V3 maturity and is ready for transitioning to industrialization and later deployment. However, there are recommendations to be considered during deployment. In particular specific details for system failure and back up as well as local procedures and harmonisation need to pay attention for like:

- Based on the specific locally defined roles, the ATCO and SUP planning tools need further optimisation regarding HMI design in order to allow more intuitively assessment of the situation.
- Depending on the complexity of the SUP planning task and the SUP workload, the SUP planning tool needs to be extended by weather information and information on ATCO endorsements and ATCO availability.
- Depending on the number of aerodromes connected to an RTC complexity of the SUP planning task and the related SUP workload might heavily increase when an optimised allocation is to be aimed for. Thi cannot be solved by a human actor and would need automated optimisation support, which optimisation criteria are still to be developed in future R&D activities.
- Large RTCs inherent by a great extent flight plan data several small and other aerodromes. Flight plan data that are hardly available today and thus would be of a highest interest to a network manager (NM). Connecting RTCs and NMs would provide synergies for both and would contribute to improve the overall flow management.
- The deployment needs a safety assessment on the chosen technical system for deployment.
- Security and redundancy concepts are to be further developed and refined when implementing large RTCs.

3.2.2 *Solution 97.1 „Virtual/Augmented Reality applications for tower"*

Though the potential and feasibility of VAR solution has been demonstrated, some technical recommendations have been figured out to further improve the usability of the technology itself and associated performance.

The presentation of the information was deemed satisfactory, with some mentions of improvements for future phases:

- HMI: position, width, brightness… of symbols should be refined in order to avoid visual interference;
- The addition of an altitude filter to allow the controller to filter out a/c that are either flyovers or outside the scope of their control
- Choice of the device: the latest generations devices are preferable due to lower weight and a wider angle of view, thus improving the experience comfort;
- It was found that controllers thought it would be enough to alert them only once for serious events, such as a runway incursion or a go-around. After acknowledgement via focussing on the area of interest, they would only need guidance from that point on (e.g. location of conflict, label information). Monitoring the actions of controllers to repeat alerts was not appreciated. For future work this means that we have to look into the question. Whether the nuisance was perceived because of the time values used, or whether a repeating alerts would make sense in other conditions, such as Alerts with several severity levels (repeat alert if a new severity level is reached and the controller does not pay attention to the area of interest) or Simple warnings of high traffic intensity in certain areas of the airport (with less intrusive symbols or aural alerts).
- No distinction between different controller roles was made (e.g. runway controller, ground controller, assistant, supervisor), while in fact both roles may require another, more customized way of presenting the necessary information.
- Other static or dynamic information on the airport surface could be presented, such as buildings, and taxiway and runway edges (in reduced visibility), stop bars and their statuses, protected areas, closed runways etc.
- Automatic Speech Recognition could be used in the future to identify certain situations in the system (e.g. a pilot calling) and signalling to the AR device to highlight particular information (e.g. aircraft label).
- Strip-less working methods could be investigated adding planning aspects to the outside view, making it superfluous to build a mental picture with flight status strips.
- Use of the technology could also lead to a new definition of controller roles and responsibilities, where the AR logic determines (or is fed with) the sequence of operations and the course of actions that need to be carried out by a particular individual in the tower. Obviously, such novel arrangements would require a high degree of automation and a clear delegation of authority, particularly in system failure situations.
- Additional features could be integrated into the AR device view, such as video streams from cameras at gate positions that cannot be seen very well from the tower or video that zooms in on certain aspects of the operation at the gate to give an indication of the statuses for boarding and de-boarding, fuelling, catering and baggage handling.

- For some areas, it might be useful to offer detailed (camera) views inside the device, e.g. for runways where thresholds are far away from the tower or where part of the runway cannot fully be seen (gap fillers).

- For attention capturing and guidance mechanisms (without an AR device), there could be advantages when used in multiple remote tower set-ups, where one or more controllers need to maintain a mental picture of the operational situation at two different airports.

3.2.3 *Solution 97.2 „ASR at the TWR CWP supported by AI and Machine Learning"*

A set of recommendations have been figured out in order to sharpen ASR operation, supported by AI and Machine Learning, among them:

- Consider a larger amount of representative training data (especially speech data from ATC operations' rooms)
- Consider pilot utterances in order to enable reasonable callsign highlighting at ATCo side and readback error detection
- Consider ABSR experience and functionality for aircraft cockpits
- Consider further applications that use the speech recognition and understanding output such as pre-filling of radar labels and flight strips, advanced readback error detection, incident analysis, on-the-job training support
- Intensify the use and enhance European-wide agreed ontology for annotation of ATC utterances
- Foster standardization of ABSR input and output content as well as format in order to improve system interoperability and comparability

4 References

4.1 Project Deliverables

4.2 Project Communication and Dissemination papers

[28]D3.1.092 - D3.1.092 - Sol 97 Communication and Dissemination Plan, 21/10/2020

Appendix A Glossary of Terms, Acronyms and Terminology

A.1 Glossary of terms

Term	Definition	Source of the definition
Air Gesture	Gesture recognition is a type of perceptual computing user interface allowing computers to capture and interpret human gestures as commands via mathematical algorithms. Gestures can originate from any bodily motion or state but commonly originate from the face or hand. Users can use simple gestures to control or interact with devices without physically touching them.	SOL 97.1
Attention Guidance	The Attention Guidance system guides the attention of air traffic controllers via perceptual cues towards an imminent ATC situation, either determined by attention guidance logic or an external safety net system. Prioritization of events criticality (e.g. RMCA, CMAC, CTAC alert) will select how the ATCo's attention shall be raised.	SOL 97.1
Automatic Speech Recognition	An Automatic Speech Recognition (ASR) system gets an audio signal as input and transforms it into a sequence of words, i.e. "speech-to-text" following the recognition process. The sequence of words is transcribed into a sequence of ATC concepts ("text-to-concepts") using an ontology. For example: The word sequence "Lufthansa two alpha altitude four thousand feet on QNH one zero one four reduce one eight zero knots or less turn left heading two six zero" is transcribed into "DLH2A ALTITUDE 4000 ft, DLH2A INFORMATION QNH 1014, DLH2A REDUCE 180 OR_LESS, DLH2A HEADING 260 LEFT". The resulting concepts can be used for further applications such as visualization on an HMI.	PJ.16-04
Conventional Input devices	Expression used to identify the current, legacy devices as keyboard, mouse and trackball. It is used as the reference system.	PJ.16-04
Tracking labels (in AR environment)	A label attached to a real a/c object, displaying the most important information; the tracking label displays additional information in the case	SOL 97.1

	of detection of any potential conflict by the Airport Safety Net Service.	
Virtual/ Augmented Reality	V/AR in ATC Tower environment supports Air Traffic Controllers by blending in real-time real world images with computer-generated data (augmented reality), so that visual information can be enhanced to improve identification and tracking of a/c (or vehicles) on the airport surface. Moreover, in low visibility conditions, the lack of visual information provided by the out-of-the-tower windows view can be made up for by the massive use of synthetic vision to show digital georeferenced data supplementing the missing real vision (virtual reality). Airport operations can benefit from such advanced technologies, capable to provide beneficial automation support under low visibility conditions. Benefits are available in good visibility conditions as well, providing the controllers with additional information content in the labels to help if physical obstacles obstruct vision or to reduce head-down time.	SOL 97.1

Table 3: Glossary

A.2 Acronyms and Terminology

Term	Definition
ABSR	Assistant Based Speech Recognition
ADD	Architecture Definition Document
AI	Artificial Intelligence
AR	Augmented Reality
ASR	Automatic Speech Recognition
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATM	Air Traffic Management
A/C	Aircraft

COTS	Commercial Off the Shelf
CWP	Controller Working Position
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology
HMI	Human Machine Interface
HPAP	Human Performance Assessment Plan
IRS	Interface Requirements Specification
ISA	Instantaneous self-assessment of workload technique
ML	Machine Learning
NARSIM	NLR ATC Research Simulator
OSED	Operational Service and Environment Definition
PI	Performance Indicator
SecAP	Security Assessment Plan
SESAR	Single European Sky ATM Research Programme
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
SPR-INTEROP/OSED	Safety and Performance Requirements – Interoperability / Operational Service and Environment Definition
SUT	System Under Test
TS	Technical Specification
TSAP	Technical Safety Assessment Plan
TVALP	Technological Validation Plan
TVALR	Technological Validation Report
TWR	Tower
VALS	Validation Strategy
VP	Validation Plan
VR	Validation Report
VR	Virtual Reality
VS	Validation Strategy

Table 4: Acronyms and technology

Appendix B Additional Material

B.1 Final Project maturity self-assessment