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MINIMA

MITIGATING NEGATIVE IMPACTS OF MONITORING HIGH LEVELS OF AUTOMATION

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699282 [1] under European Union's Horizon 2020 research and innovation programme.

Abstract

An increase of automation in air traffic control can have negative effects on the air traffic controller's performance. The effects are known as out-of-the-loop phenomenon. The MINIMA Project will develop a vigilance and attention controller to mitigate these effects. A highly automated arrival management task will be used as a case study. Psychophysiological measurements like EEG will be used to identify the state of the Air Traffic Controller and combined with adaptive task activation. This will allow for activating tasks based on the Air Traffic Controllers state to keep their performance on a high level and to ensure safe operations.

Based on the State of the Art Report (D1.1) which analysed the out-of-the-loop phenomenon, related problems, how to detect them and how to mitigate them, this document describes the MINIMA concept. It gives details about the highly automated Terminal Manoeuvring Area selected as case study and about the route structure and procedures defined for this environment. Additionally, it describes the adaptation mechanisms that are planned to be implemented into this task environment and analysed in the MINIMA project. Additionally, the document provides information about the technical implementation of the vigilance and attention measurement that will be used to trigger adaptation of the task environment. Specifically, details about the measurement and processing of data are given.

This document will be a guideline for the development of the task environment and the vigilance and Attention Observer during work package 2 and will also be an input for the planning of the evaluation in work package 3.

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List of Acronyms

Abbreviation	Description
AA	Adaptive Automation
AMAN	Arrival Manager
AOI	Areas Of Interest
ANN	Artificial Neural Networks
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
AR	Autoregressive
BCI	Brain Computer Interface
CDA	Continuous Descent Approach
CSR	Centerline Separation Range
CST	Conjunction Search Task
CPT	Continuous Performance Test
DTG	Distance-To-Go
ECG	Electrocardiogram
EEG	Electroencephalography
FFT	Fast Fourier Transform
FMS	Flight Management System
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-Infrared Spectroscopy
GSR	Galvanic Skin Response
HMI	Human Machine Interface
IAF	Initial Approach Fixes
ILS	Instrument Landing System
ISI	Inter-Stimulus Interval
LDLP	Low Drag / Low Power Approach
MEG	Magnetoencephalography
MINIMA	Mitigating Negative Impacts of Monitoring High Levels of Automation
NINA	Neurometric Indicators for ATM

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NIRS	Near-Infrared Spectroscopy
OOTL	Out Of The Loop
PET	Positron Emission Tomography
PSD	Power Spectral Density
PVT	Psychomotor Vigilance Task
RTA	Required Time of Arrival
SA	Situational Awareness
SD	Standard Deviation
SDD	Situation Data Display
STFT	Short-Term Fourier Transform
SWLDA	Stop Stepwise Linear Discriminant Analysis
SVM	Support Vector Machine
TCS	Transcranial Doppler Sonography
TTFF	Time to First Fixation
TMA	Terminal Manoeuvring Area
XML	Extensible Markup Language

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1 Executive Summary

1.1 Problem Area

Over the past few years, the global air traffic growth has exhibited a fairly stable positive trend, even through economic immobility, financial crisis and increased security concerns. It is now clear that traffic flow patterns will become more complex, making conflicts and situations harder to identify for a human operator and will put immense pressure on the air traffic control system. In this context, several solutions have been proposed for modernizing air traffic control to meet the demands for enhanced capacity, efficiency, and safety. These different solutions rely on higher levels of automation as supported by both SESAR JU and HALA! Research Network.

On the one hand, implementing higher levels of automation can improve the efficiency and capacity of a system. On the other hand, it can also have negative effects on the performance of human operators, a set of difficulties called the Out-Of-The-Loop phenomenon (OOTL). In the current context of a continued increase in automation, understanding the sources of difficulties in the interaction with automation and finding solutions to compensate such difficulties are crucial issues for both system designer and human factor society.

While this OOTL phenomenon is considered as a serious issue in the human factors literature, it remains difficult to characterize and quantify. Detecting the occurrence of this phenomenon, or even better detecting the dynamics toward this degraded state, is an important issue in order to develop tools for evaluation and monitoring.

The general objective of MINIMA project is to improve our comprehension of the OOTL performance problem especially according to a future air traffic scenario. Further, MINIMA will develop tools to detect and compensate the negative impact of this phenomenon and a carefully selected allocation of tasks between the human agent and the automated system for the use case of a highly automated Terminal Maneuvering Area (TMA).

1.2 Description of Work

This deliverable (see the PMP [2] for an overview) provides a description of the concept behind the MINIMA project. This deliverable will present a description of the MINIMA concept regarding:

- The task environment used and its technical implementation;
- The proposed concept for vigilance and attention guidance as part of the task environment;

- The concept for vigilance and attention measurement proposed and its technical implementation (as Vigilance & Attention Observer);
- The interface between task environment and Vigilance & Attention Observer.

The aim of this document is to provide a guideline for the implementation and the planning of the evaluation study. This document uses as input the state of the art review performed previously by the consortium [3].

The deliverable starts with an introduction of the MINIMA concept (chapter 2). Then, we introduce the highly automated system used as an example for a monitoring task in ATM and the assumptions made about the available automation (chapter 3). Particularly, the MINIMA Use Case consists of a highly automated Air Traffic Control (ATC) task environment regarding the TMA. We present here the different characteristics of the MINIMA use case (i.e., airspace, traffic scenario, and simulation run configurations) but also equipage and capabilities of traffic scenario aircraft and the procedures proposed.

In chapter 4, we present the concept for vigilance and attention guidance proposed in MINIMA. Basic assumptions for the MINIMA concept formulated as initial situation are introduced. These basic assumptions were discussed with system matter experts during a workshop organized by DLR. The content and results of this workshop are presented. Ideas derived from the workshop are proposed in this section. After this, several adaptations mechanisms are depicted in sections 4.3 to 4.13 that are partially derived from the workshop.

Chapter 5 is dedicated to the technical implementation of task environment. Particularly, simulation type, simulation environment, and envisaged validation setup are described.

The following part (chapter 6) describes the concept for Vigilance and Attention Measurement. We first introduce the vigilance decrement as a major marker of OOTL phenomenon. Then, we discuss how detect change in vigilance and attention level (i.e., relevant techniques and signals available). We propose to use EEG (and particularly change in power spectrum density) as a marker for vigilance decrement and oculometric measure for attention measurement.

In chapter 7, we discuss how to technically implement Vigilance and Attention Measurement. This part is particularly critical to identify the different steps required for EEG signal analysis.

Finally, chapter 8 presents the interface between the different elements of the MINIMA concept.

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2 Introduction to MINIMA Concept

Increasing the level of automation in ATM is seen as a measure to increase the performance of ATM to satisfy the predicted future demand. This is expected to result in new roles for human operator. Human operators will often work in a supervisory or control mode rather than in a direct operating mode. Operators will mainly monitor highly automated system and intervene seldom. It can be expected that human operators in such a role are affected by human performance issues like lack of attention, loss of situational awareness and de-skilling known as out-of-the-loop phenomenon. These problems are observed in other domains like flight-crew performance in the glass cockpit.

MINIMA will address these performance issues. Its aim is to identify out-of-the-loop behaviour and to find solutions to minimize the negative impact of monitoring high levels of automation on the human operator's performance.

In this sense, MINIMA will develop a dynamic adaptation of the task environment which is foreseen as a major requirement to keep the human 'in the loop', perfectly aware of the traffic situation. As a consequence of the developed concept, not all tasks potentially automated will be automated every time. To trigger adaptations of the automation, MINIMA will develop a real-time monitoring system that constantly measures the operators' vigilance and attention levels. This is called "Vigilance and Attention Observer" in MINMA. A component called "Adaptive Task and Support Activation", based on the measured vigilance and attention level, will decide which adaptions of the task environment should be activated. On Overview of the MINIMA Concept is shown in Fig. 1.

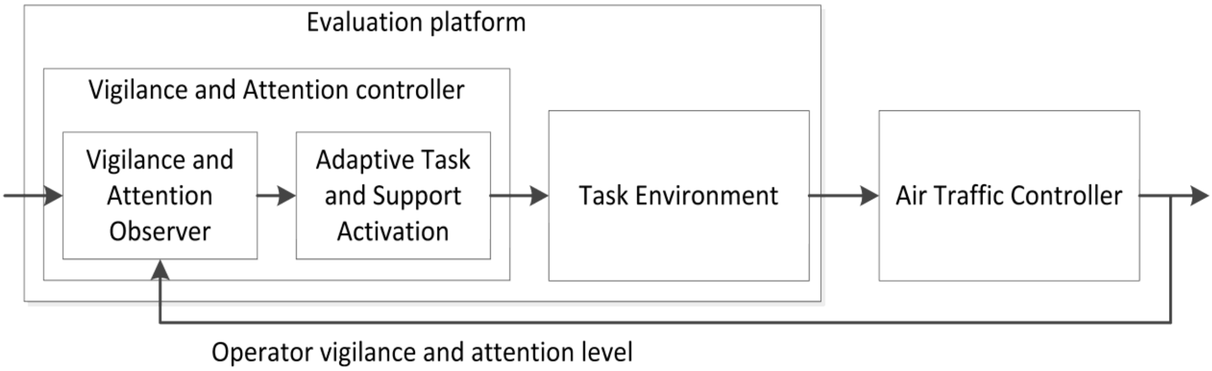

Fig. 1: Evaluation environment for MINIMA and influences of components on others

In MINIMA, a highly automated Terminal Manoeuvring Area (TMA) has been selected as use case. This task environment represents an air traffic control task as it is expected for the future: Most of the interaction with the aircraft is automated. A principle assumption of MINIMA is that Air Traffic Controllers (ATCOs) are required to intervene in a few situations as error-free automation cannot be guaranteed.

In the MINIMA use case, the arrival management will be highly automated. On-board Flight Management Systems (FMS) will negotiate with an Arrival Manager (AMAN) on 4D-Trajectories automatically. However, these trajectories are only guaranteed to be conflict free at a merging point. Conflicts between arrival aircraft at other locations, conflicts between arrival and departures, and deviations form 4D-Trajectoreis are still possible - but seldom - and need to be managed by the ATCOs.

Several adaptions mechanisms are planned to be integrated into the use case. An adaption mechanism changes the tasks that ATCos have to perform during operation, either by providing additional or by handing over task to automation temporarily. These mechanisms include different methods to guide the ATCOs attention and different tasks that can be activated dynamically during the simulation.

This document has the purpose to describe the MINIMA use case, planned adaptation mechanisms, and methods used to measure the vigilance and attention of ATCOs in the planned experiment. It will be the reference for the implementation of the Evaluation Platform during work package 2 and used as guideline for the development of a detailed evaluation plan and the conduction of the experiments in work package 3.

It should be noted that the implementation of all Adaption Mechanisms described in this document would require more effort than available. Therefore, these mechanisms are evaluated within this document and recommendations regarding the priority of implementation are given.

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3 Introduction of MINIMA Use Case: TMA Task Environment

The MINIMA Use Case consists of a highly automated ATC task environment, specifically a terminal manoeuvring area (TMA). One controller will be responsible for monitoring arriving and departing traffic. He/She only needs to intervene in cases of conflicts or emergencies but does not need to manage routine traffic. However, he/she will have additional tasks in the MINIMA adaptive automation simulation environment. The details of airspace structure, aircraft capabilities, and procedures are explained in the following sections.

3.1 Procedures

In the actual ATC practice, only controller clearances respectively default published procedures need to be followed by an aircraft. Only rough trajectories derived from the flight plan are known.

In the MINIMA project, it is assume that four-dimensional trajectories will be negotiated between board- and ground-systems. The aircraft (pilot) has to follow this trajectory. The controller will only intervene in case of too large deviations from the planned trajectory or conflicts. In these cases, a recalculation of the trajectory (see also section 4.10) or controller clearances are necessary.

Calculated trajectories of approaching aircraft might implement CDA (Continuous descent approach), LDLP (Low Drag / Low Power Approach), or other approaches deviating from standard. However, this is irrelevant for the controller monitoring task of pre-calculated air traffic based on 4D-trajectories in the MINIMA task environment.

3.2 MINIMA airspace (routes/waypoints)

The MINIMA airspace should have as less fixed structures as possible as aircraft should fly direct routes to the airport wherever possible. The majority of aircraft in the TMA will follow their negotiated four-dimensional trajectory autonomously as automation level in this scenario is high. Therefore, aircraft TMA entries should not only be possible at initial approach fixes (IAF, white squares at TMA border in Fig. 2), but also at points in alternatively allowed TMA entry areas (between several defined IAFs). The only restriction is to approach a late merging point for sequencing arrival streams at the final of a runway. Therefore, air traffic already needs to be sufficiently separated by the automation (e.g. via speed regulation) prior to reach the merge point.

Alternative arrival stream sequencing operations as trombone, point-merge, or fan will not be used in MINIMA as they induce additional route length comparing shortest direct flight route to shortest path stretched flight route to runway threshold. Thus, the main focus is on “direct” routes similar to the generic flexiGuide airspace structure [1].

The planned MINIMA airspace will functionally be implemented according to the designed route and merge point structure of Fig. 2.

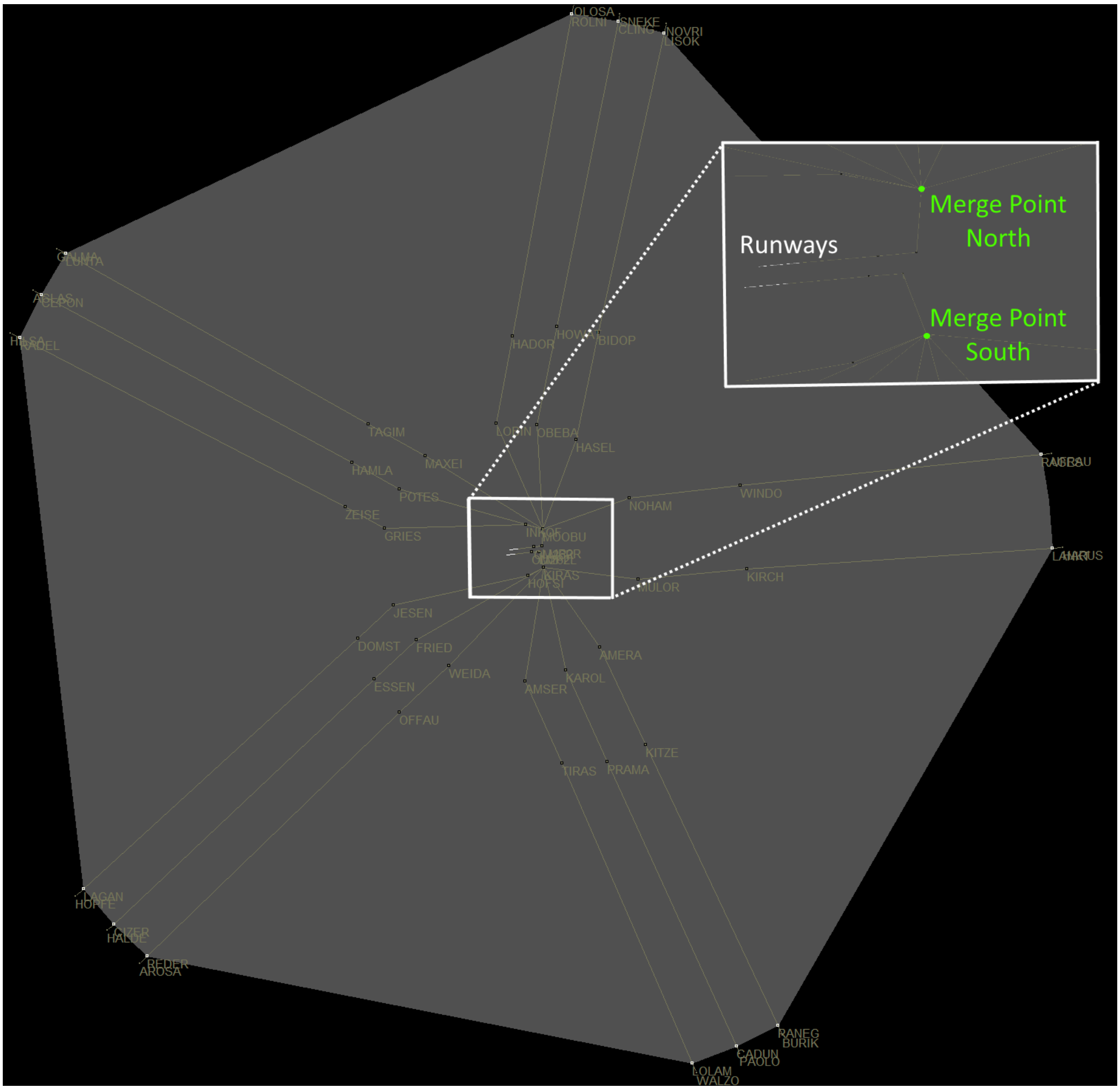

Fig. 2: MINIMA Airspace (Terminal Maneuvering Area) with one merge point for each runway

This structure consists of three independent routes from the northern, western, south western and south eastern direction as well as two routes from the eastern direction. The free corridors ("triangle" between runways and IAFs) in the west are reserved for departures. Arrivals normally enter the TMA at the white initial approach fixes. But they may also enter the TMA at alternative points in the route-free (non-western) corridors. Those aircraft will join standard routes at the brown waypoints in the centre of the structure.

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As the runway configuration and specific requirements in the environment of a real airport do not play an important role for MINIMA, the selection of a simulation airport is not very critical. However, modelling a generic or reality-based airport and TMA takes a lot of effort. Therefore, a typical airport with two runways is sufficient. Two runways offer the possibility for mixed and single mode operation per runway (arrival, departure).

As Munich has two runways and is typically and frequently used for simulation, a layout very similar to Munich will be used in MINIMA. However, only the 26L/26R configuration will be used as the cardinal direction of runway use as automation effects should be comparable. All aircraft approaching from the north do mandatorily have to pass the northern merge point to land on runway 26R. The analogue way (southern merge point for 26L) is true for aircraft approaching from the south. Departures will fly westbound accordingly.

3.3 Equipage and capabilities of traffic scenario aircraft

A filed flight plan already includes a basic spatial-temporal trajectory of an aircraft. Intended route, route points, start time, cruising altitude, and speed allow for rough estimation of the four dimensions (latitude, longitude, altitude, time). However, the start time is not guaranteed at an airport. A deviation regarding the start time leads to trajectory deviations of multiple nautical miles respectively minutes.

Accuracy of trajectories can be increased with technical equipment and regular trajectory updates based on actual data. A Flight Management System (FMS) is a flight computer with a navigation data base on board an aircraft. With for example ground-, satellite-, or inertial-system based data, position and thus the planned route to the runway threshold can be updated. The FMS adapts flight parameter such as heading, altitude, and speed to precisely fly on the pre-programmed flight route. Therefore, an FMS is able to hold target times at significant waypoints with its calculated speed and without wind influence. Depending on the manufacturer, technical equipment, and activation of its functionalities different accuracies in holding target times may be reached [5].

Aircraft with a standard FMS reach waypoints in different conditions with a precision of roughly half a minute [6]. 4D-FMS with required time of arrival (RTA) also consider parameter “time” when calculating trajectory and speed. Hence, they reach better timely accuracy which is about five seconds [6], [7], [8].

For the MINIMA environment we assume that equipment degree with advanced 4D-FMS is 100%. Hence, all approaching aircraft will follow their once planned trajectory with only little deviation

Planning systems such as an arrival manager (AMAN) compute complete aircraft trajectories and derive advisories for controller commands. Radar data that are updated every 5 seconds are the basis for trajectory calculation. In a first step, the lateral aircraft path from its actual to its target position is determined. Then the earliest and latest possible target time for each aircraft and the scheduled time that needs to be in these intervals are calculated. A four-dimensional trajectory taking into account different runways and constraints (e.g. regarding altitude) is computed afterwards. This trajectory is send to the aircraft’s 4D-FMS so that aircraft can follow these trajectories.

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3.4 MINIMA traffic scenario

The MINIMA traffic scenario for the above described airspace will be quite dense as automation will optimize traffic flow during normal operations. The scenario includes a mix of aircraft approaching and departing from the airport.

At least three 45-minutes (which is a roughly estimated simulation run duration) traffic scenarios are needed, as Training, Baseline, and Solution runs are planned. The traffic will be comparable in all scenarios. There should be a rate of roughly 30 arrivals per hour and runway as well as 15 departures per hour and runway. The scenario will not contain overflights. The weight category of aircraft consists of one third "heavy" and two thirds "medium". Typical callsigns of Munich airport will be used, but changed between different scenarios to avoid learning effects. The starting points of aircraft will be outside the TMA. These points are moved to different positions almost semi-circle-wise rotating around the runways due to airspace structure (again to avoid learning effects of study participants). The aircraft routes will hardly have any conflicts during scenario time as MINIMA assumes a well-functioning automation with only very few necessary controller actions.

3.5 MINIMA simulation run configurations

All of the traffic scenarios will be supported by an air traffic simulator that is responsible for proceeding radar tracks of each aircraft. This simulator will also provide the aircraft behaviour triggered by automatically executed controller commands in all simulations. Those controller commands (e.g., DESCEND, REDUCE) are calculated by an Arrival Manager (AMAN) and send to the simulator on time. Nevertheless, the controller is still able to insert additional commands for each aircraft via the mouse interface of the radar display. Departure aircraft radar tracks will also be generated by an air traffic simulator without following AMAN trajectory calculation respectively automatic commands. All scenarios have to ensure that they are almost free of conflicts except of those conflicts, the controller should detect in very seldom cases.

The AMAN will only generate one trajectory for each aircraft in the MINIMA use case. Most of the aircraft will follow their trajectory within acceptable deviations until landing. In case a controller gives a clearance to an aircraft, this aircraft will switch to manual mode. The AMAN will not plan a trajectory for this aircraft and this aircraft will only fly as instructed by the controller. The trajectories of other aircraft will not be updated automatically. The controller is responsible for finding or creating a new position in the arrival sequence for the manually guided aircraft.

New trajectories are only generated if explicitly requested by the ATCO. This can be done using the system described in section 4.10.

The system configuration regarding availability and adaptivity of support will differ. The first scenario configuration is for training with different support steps, the second one is a baseline scenario with no adaptive automation support (but with static automation support), and the third one includes adaptive support as stated in the MINIMA idea.

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4 Concepts for Vigilance and Attention Guidance

This chapter describes possible adaptations mechanisms that can be implemented into the MINIMA Case Study. It starts with a brief description of the problems that are expected (section 4.1) and should be tackled by the adaptations mechanisms. The next section (4.2) describes a workshop with ATCOs that was conducted to generate ideas for adaption mechanisms. The brief description of the problem was used to develop a tailor made questionnaire that helped to cooperate with and collect feedback from system matter experts.

After this, several adaptations mechanisms are depicted in sections 4.3 to 4.13 that are partially derived from the workshop. Each of these mechanisms is assessed regarding the expected influence on the ATCO, i.e. it's potential to help with the reduction of situation awareness and to mitigate other problems triggered by highly automated workplace, and regarding the effort that is expected by the project members to be necessary to implement this mechanism in the simulation environment. Based on that, recommendations for implementation are given.

4.1 Initial Situation

Because the concept formulated in this chapter depicts future air traffic control, the initial situation formulates basic assumptions that the concept is built on. Monitoring is a main task of radar ATCOs and is the mechanism to enable the ATCO to detect deviations between the preplanned and the real traffic situations. As mentioned in the previous chapters, through an increase in automation for air traffic control in the future, it is expected that information processing of ATCOs is changing. This most definitely leads to a shift in the current ATCOs task, from interacting to monitoring. This raises concerns especially for the impact onto human performance. A major bottleneck is seen in the visual attention of the ATCO for monitoring the traffic and keeping the vigilance and attention on a safe level.

As an example, it is a normative behaviour that the ATCO should monitor all aircraft to detect any hazardous events as early as possible (like crossing routes). If this is done by an almost perfect automation, interaction is reduced to situation were the automation cannot find a solution. In this case the automation probably guides the attention of the ATCO to the problem at hand. The ATCO has now to make the decision, but might not be complete ready for this particular situation because his knowledge of the situation is degraded due to the fact that he/she was just monitoring.

Assumptions that describe the initial situation for this concept are:

1. In the future the automation will increase for ATC.
2. The ATCO task will shift from more interaction to more monitoring.

3. Less interaction leads to longer reaction times and out-of-the-loop problems in case an error occurs or interaction is required.

4.2 Workshop

A workshop concerning the future ATC was conducted between the 17th and 21th of October in 2016. Participants were ATCOs recruited from the approach Munich (n = 4). The four (2 female, 2 male) participants had an average age of 39.3 years (standard deviation (SD) = 6.1). The average work experience as an ATCO had a mean of 20.5 years (SD = 9.2). They all had a valid licence for Munich approach.

A power point presentation was used to instruct the participants about the MINIMA project and its intentions. The presentation also included an example of the type of initial situation the project is developed for. A tailor-made questionnaire (Table 1) was used to structure the workshop with each participant individually. The questionnaire was used as a guideline to make the workshop between the four participants comparable. It was structured in three major parts: the situation today, the future, and demographic information. The first part (Id 1 to 17) looked especially at situations today that had less traffic and therefore decreased workload. The second part (Id 18 to 23) looked at a potential future development and information that the ATCOs would use to minimise out-of-the-loop developments. The third part was to collect the demographical information.

The results of the workshop are aggregated in Table 1. The answers of all participants were summarized and discussed by the three human factor experimenters to decide for a final wording of the answers. Also the additional answers given separately to the questionnaire were integrated into the final answers.

Table 1 Tailor-maid questionnaire and aggregated answers

Id	Question	Answer
1	What are your actions if the situation does not demand your full capacity?	Communication with the goal of staying awake (Independent from the ATC task)
2	Which information do you only collect, if you have enough time?	Weather / Predicted Minimum Separation / Parking Position (Runway selection) / expected approach time (at holding)
3	Which ATC related task would you perform if you had more additional time?	Training of junior ATCOs
4	What are examples for the increase of automation at your current workplace?	Increase of additional Information (AMAN-Sequence)
5	Which influence has the increasing automation on your current work procedures?	Less flexibility and creativity
6	What type of aid do you use to have all relevant information always available?	Label (e.g., colour or speed vector)
7	How do you avoid the out-of-the-loop	Not a problem at the moment

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Id	Question	Answer
	problem, today?	
8	Which type of flight strips do you use?	Electronic flight strips
9	Which type of aircraft tagging or highlighting do you use?	Colour change and speed vector
10	Which information do you acquire with high frequency due to its frequent change?	QNH; Mode-S IAS; label information (depending on the workplace)
11	Which information do you acquire with high frequency due to its high relevance?	Position; Altitude, Speed
12	Which information do you acquire with high frequency due to its complexity?	None
13	Which tasks could you imagine to perform additionally in the future?	Control larger sector
14	How would less radio communication and more datalink influence your work procedure?	Less channel blockage
15	How would you use spare time that a highly automated system generates?	More additional information to the pilot
16	What advantage could you imagine in a highly automated workplace?	Increase of capacity and better work situation
17	What disadvantage could you imagine in a highly automated workplace?	Loss of skills (for example the estimation of distance)
18	Which information relevant to your work would you like to receive additionally, in the future?	Correct displayed weather information
19	Could information about fuel be of service to you?	No
20	Could information about incidents throughout the flight be of service to you?	No
21	Could information about transit passengers be of service to you?	FCFS, exception for the same airline
22	Could information about the pilot be of service to you?	No
23	Which aid to memory could you imagine for the future?	None

The results in Table 1 show that even today low workload phases force the ATCO to perform other tasks to keep their attention on a safe level, like work unrelated communication or physical task. The results also show that the current ATCO task is balanced between the controlled traffic and the information needed by the ATCO. The label contains all important information to control the traffic.

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Additional information is only required to increase the quality of service, the ATCO wants to provide to the pilot. Also, not all participants supported this increase in quality of service.

The questions concerning the future development, considering highly automated systems, showed almost no input. This might depend on the shift from the expected interaction to monitoring the task environment. In the opinion of the participants, the additional resources of attention could be used to evaluate weather information to better anticipate or increase the service information for the pilots. No additional information regarding the state of the aircraft or the pilot is deemed to be necessary for ATCOs.

The following sections contain the major ideas for vigilance and attention guidance within MINIMA, derived from the workshop results.

4.3 Air Ground Communication

4.3.1 Description

Air Traffic Controllers normally communicate with the pilots of the controlled aircraft via radio to give instructions. As described in in section 3.2, the aircraft follow an automatically generated trajectory in the selected case study and further instructions are only necessary in a few situations. Further, it is assumed that the trajectory and these instructions could also be transmitted automatically via datalink. Consequently, the case study could be used without radio communication at all. On the other hand, additional radio communication events could be introduced to exchange other information or to check the information transmitted via datalink so that the radio communication effort could be increased. This allows switching between datalink communication and radio communication as adaptation mechanisms.

Another aspect of the air ground communication that can be modified is the way in which ATCO give their commands. Conventionally, voice commands are directly transmitted to the aircraft. However, these commands could be processed by speech recognition software at the ground previously. This would allow an automation to adapt more quickly to the human operator's intentions. Another possibility would be to enter commands via mouse. The instructions could be transmitted to the aircraft by datalink or by radio communication channels using to use text-to-speech software. Using this method would also allow an assistance to understand the controller's intention and to adapt to it.

When simulating conventional radio, ATCOs would give instructions via a simulated radio system and simulation pilots (pseudo-pilots) would have to read back the instructions and to enter them into the simulation.

If the controllers have to enter the instruction to the system manually via mouse, instructions will uplinked to the aircraft. As the instruction is already entered by the controller, no pseudo-pilots will be needed to enter the instructions into the simulation. Additionally, it is assumed that all data typically required by an ATCO will downlinked from the aircraft and can be displayed. Thus, requests are only necessary in case additional information is required.

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4.3.2 Operational modes

The following operational modes could be used for the datalink usage:

1. Trajectories are negotiated between on-ground and on-board systems automatically via datalink. Handovers to other sectors are handled by the system. Instructions, which are only necessary in case of deviations, are entered into the system via mouse and are transmitted via datalink (or text-to-speech).
2. Trajectories are negotiated between on-ground and on-board systems automatically via datalink. When entering a sector, a conventional handover is executed via radio telephony. Instructions, which are only necessary in case of deviations, are entered into the system via mouse and are transmitted via text-to-speech (or datalink).
3. Trajectories are negotiated between on-ground and on-board systems automatically via datalink. When entering a sector, a conventional handover is executed via radio. Instructions, which are only necessary in case of deviations, are given directly via radio.
4. Like above. Additionally, pilots have to report their expected overfly time for the merging point at initial contact and in case this time changes. Controllers have to confirm these times.

4.3.3 Expected influence

Operational Mode	Justification	Influence
1	This mode represents the highest level of automation. It represents the drastic step to abolish radio communication completely.	Baseline It is expected that using mouse input would result in a higher workload than caused by conventional radio communication
2	In this mode radio communication is still available but not used for instructions. However, communication is established by hand-overs and initial calls in case a datalink communication is not possible.	As handovers are required in this mode, it is expected that the workload increases. Additionally, a positive on situation awareness is expected as controllers need to interact with the aircraft/pilot.
3	This mode uses radio communication to give the ATCO a better sense of the quick execution of instructions by receiving the readback directly from the pilot.	As deviations will occur only seldom, the difference to mode 2 is expected to be small. However, talking to the pilots directly could have a positive impact on ATCO's sense of control and acceptance of this mode.
4	In this mode, the overfly times are additionally transmitted via radio communication with the aim to improve the controllers situation awareness of these times and the deviations.	This mode is expected to increase the ATCOs' workload and – if they are not overloaded – their situation awareness as this mode requires them to check the overfly times.

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4.3.4 Evaluation

The effort to realize all modes is low, as most of the functionally is already available and was used in similar projects. As the effort for all modes is low and different effects on the ATCOs are expected, it is recommended to implement this adaptation strategy.

4.3.5 Requirements

Identifier	Requirement
REQ-MINIMA-TS-04035-0010	The ATCO's User Interface (Radar screen) shall support mouse commands
REQ-MINIMA-TS-04035-0020	The Speech Communication between ATCO's and Pilots shall be simulated
REQ-MINIMA-TS-04035-0030	Simulation Pilots (Pseudo-pilots) shall have the possibility to enter commands into the simulation

4.4 Attention guidance with eye tracker

4.4.1 Description

The system monitors the eye movement of the operator and determines, based on a normative model of attention distribution, which areas are monitored insufficiently or not at all (monitoring loss). Additional information is provided to the ATCO to update his/her situation awareness in this specific area. The normative model of attention distribution describes how much attention should be given to the different areas of the screen or the different elements on the screen. The real attention distribution will be compared to the model. Aircraft will be highlighted if differences are detected. For example, a simple model could define that each aircraft has to be in the focus of attention at least every 10 seconds. If an air traffic controller does not focus on this aircraft for more than 10 seconds, this aircraft will be highlighted to catch attention. A more complex model could evaluate the situation and calculate priorities for each aircraft, e.g. aircraft changing their level or aircraft close to other aircraft need to be monitored more closely. The development of such a model requires close cooperation with ATCOs.

4.4.2 Operational modes

1. Eye tracking is on and attention guidance is off
2. Eye tracking and attention guidance with low salience is on (text message).
3. Eye tracking and attention guidance with high salience is on (graphical highlighting).

4.4.3 Expected Influence on the ATCO

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Operational Mode	Justification	Influence
1	This mode is the “stand-by mode”. Attention guidance is off but it could be switched on without delay as eye tracking data is measured and evaluated.	Baseline Nothing is presented to the ATCO.
2	This mode is needed in case the vigilance is slightly reduced.	Messages with low salience guide are only used if the vigilance level is slightly decreased. They might create additional workload for the ATCO.
3	This mode is needed in case the vigilance is more than slightly reduced.	Message with high salience guide are only used if the vigilance is reduced more than slightly. As the messages are pushed to the foreground, it is expected that they have strong influence on the visual attention.

4.4.4 Evaluation

One advantage of attention guidance with an eye tracker is its scalability. Depending on different vigilance values different operational modes can be defined and therefore the influence is adjustable. Especially for operational mode 3, we expect a measurable impact on the vigilance level.

Even though additional software has to be developed and several interfaces between the existing radar simulator and radar display have to be implemented it is recommended to implement this adaption mechanism. As an adaption based on the ATCOs attention is one of the core ideas of MINIMA, a high priority is assigned to this mechanism.

4.4.5 Requirements

Eye Tracking System

An eye tracking system to capture the ATCO monitoring behaviour

Identifier	Requirement
REQ-MINIMA-TS-04045-0010	The eye tracking system shall be available.
REQ-MINIMA-TS-04045-0020	The eye tracking system shall be calibrated for the environment in which the experiment is conducted.

Normative model

A normative model to evaluate the situation and the expected attention on the system

Identifier	Requirement
REQ-MINIMA-TS-04045-0030	The normative model of monitoring behaviour shall identify areas that require attention
REQ-MINIMA-TS-04045-0040	The normative model shall combine the live eye movement data and simulated traffic data and identify the areas that are not monitored

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	enough.
REQ-MINIMA-TS-04045-0050	The normative model shall have an interface with the eye tracking system, the radar display and the radar simulation.
REQ-MINIMA-TS-04045-0060	Dependent on the vigilance level of the ATCO, the radar display shall select the corresponding salience level.

Radar display

Identifier	Requirement
REQ-MINIMA-TS-04045-0070	The radar display shall have a low salience mode and present the areas delivered by the normative model as text
REQ-MINIMA-TS-04045-0080	The radar display shall have a high salience mode and visually highlight the areas delivered by the normative model.

4.5 Attention guidance to separation conflicts (Short term conflict prediction)

4.5.1 Description

Whenever a situation arises that is classified as potential loss of separation or might become a future loss of separation if the ATCO does not interact, the system highlights the affected aircraft. In order to do so, the system calculates the distances between all aircraft based on the current position and the predicted trajectories and detects all separation conflicts between these trajectories. A separation conflict is detected and highlighted if the distance between two aircraft is predicted to be below 3 NM horizontally and below 1000ft vertically.

4.5.2 Operational modes

1. No highlighting is provided.
2. Highlighting for potential separation conflicts within the next 30 seconds is provided.
3. Highlighting for potential separation conflicts within the next 60 seconds is provided.

4.5.3 Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This mode is needed in case help systems are deactivated.	Baseline Nothing is presented to the ATCO.

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2	This mode is activated in case the vigilance is slightly reduced.	Potential Conflicts that are imminent within the next 30 seconds are highlighted. This leads to guidance of attention restricted only to high priority situations.
3	This mode is activated in case the vigilance is more than slightly reduced.	As extension to operational mode 2 this mode shows also potential conflicts that are within the next 60 seconds. It is assumed that an increase of the prediction time comes with an increase of false alarm rate. Consequently, this mode will guide the attention to more situations (including non-critical false alarms) and is expected to increase ATCO's workload.

4.5.4 Evaluation

The advantage of attention guidance by conflict is that the prediction is scalable. However, an increased prediction is expected to come with an increased false alarm rate. Depending on different vigilance values different operational modes can be defined to present conflicts. As similar systems have already been analysed and a large effort is required for the implementation into the MINIMA task environment, it is recommended to implement this adaption with lower priority.

4.5.5 Requirements

Conflict identification

The simulator evaluates the situation and identifies the potential conflicts.

Identifier	Requirement
REQ-MINIMA-TS-04055-0010	The simulator software should predict future aircraft position and detect potential conflicts based on these positions.
REQ-MINIMA-TS-04055-0020	The Interfaces with the radar display should allow the transmission of potential separation conflicts.

Radar display

Identifier	Requirement
REQ-MINIMA-TS-04055-0030	The radar display should visually highlight potential separation conflicts.

4.6 Attention guidance to actual trajectory deviations and actual losses of separation

4.6.1 Description

The system described in 4.5.4 is based on predicted and planned trajectories. Therefore it consequently inherits the risk to make false prediction and to miss critical situation. The following system uses only the actual situation as shown on the radar screen as input and calculates the distance between the aircrafts. It is assumed that the reliability of the system is nearly as high as the accuracy of the radar screen and it is unlikely that this system misses a critical situation.

A drawback of not considering predictions is that either the reaction time to solve the situation or - if additional separation buffers are included – a high false alarm rate will be inevitable.

The system detects the following situations and highlights the involved aircraft:

- Current separation conflicts (horizontal separation below 3 NM and vertical separation below 1000 ft)
- Close aircraft (horizontal separation below 5 NM and vertical separation below 2000 ft)
- Lateral deviations from route greater 1 NM
- Violation of altitude restrictions greater 500 ft

4.6.2 Operational modes

1. No highlighting is provided
2. Highlighting of lateral deviation, violation of altitude restrictions, and current separation conflicts
3. Highlighting of same as in mode 2 and additionally close aircraft

4.6.3 Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This mode is needed in case help systems are deactivated.	Baseline Nothing is presented to the ATCO.
2	In this mode, only high priority situations are highlighted. As close aircraft are not highlighted, the false alarm rate is expected to be low.	This mode will highlight only imminent conflicts. This leads to guidance of attention restricted only to high priority situations.
3	In this mode, also close aircraft are highlighted. This increases the false alarm rate but gives the ATCO the possibility to avoid critical situations.	As this mode will also highlight situation with a potential for conflicts and is expected to have a high false alarm rate, it has the potential of being disturbing. The risk is that ATCOs ignore the alarm completely and do not detect situation with losses of separation between aircraft.

4.6.4 Evaluation

While a principle assumption of MINIMA is that an error-free automation cannot be guaranteed, this type of attention guidance will be able to detect all losses of separation and close aircraft reliably as

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it is only based on the current position of the aircraft. However, it is expected to come with a high false alarm rate and the interesting question is if this is suitable from a human factors perspective or if ATCOs will tend to ignore the alarm. Therefore – and because the effort required for the implementation is only medium – it is recommended to implement this adaptation mechanism.

4.6.5 Requirements

Conflict identification

Identifier	Requirement
REQ-MINIMA-TS-04065-0010	The simulator software shall evaluate the situation and detect current separation conflicts and close aircraft
REQ-MINIMA-TS-04065-0020	The simulator software shall evaluate the situation and detect deviations from the route
REQ-MINIMA-TS-04065-0030	The simulator software shall evaluate the situation and detect violations of altitude restrictions
REQ-MINIMA-TS-04065-0040	The Interfaces with the radar display shall allow the transmission of conflicts and close aircraft.

Radar display

Identifier	Requirement
REQ-MINIMA-TS-04065-0050	The radar display shall visually highlight current conflicts and close aircraft

4.7 Attention guidance to aircraft that cannot meet agreed target times

4.7.1 Description

Like the attention guidance system described in section 4.5, the attention guidance system described in the following section is also based on prediction. This system checks if the position of aircrafts on their route is according to the last agreed trajectory. If there is a difference, there is the risk that this aircraft might be too late or too early and that it will cause a conflict with another aircraft. If deviations above a threshold of 0.5 NM are detected, the aircraft is highlighted. For example, the difference is shown in the aircraft label.

4.7.2 Operational modes

1. No highlighting is provided
2. Aircraft that cannot meet the agreed times are highlighted

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4.7.3 Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This mode is needed in case help systems are deactivated.	Baseline Nothing is presented to the ATCO.
2	This mode is activated when the vigilance is reduced.	This mode is expected to improve the ATCO's Situation Awareness regarding deviations from 4D-Trajectories.

4.7.4 Evaluation

Deviations from the agreed times should only occur seldom during simulation. For this reasons, ATCOs may fail to check for deviations regularly and miss to detect a deviation in time. This system could help to detect deviations early. Also the effort expected to be required for its implementation is acceptable. Consequently, it is recommended to implement this adaption mechanism.

4.7.5 Requirements

Conflict identification

Identifier	Requirement
REQ-MINIMA-TS-04075-0010	The simulator software shall evaluate the situation and detect deviations of agreed from actual times
REQ-MINIMA-TS-04075-0020	The Interfaces with the radar display shall allow the transmission of target times and deviations.

Radar display

Identifier	Requirement
REQ-MINIMA-TS-04075-0030	The radar display shall show target times and highlight deviations

4.8 Centerline Separation Range

4.8.1 Description

The Centerline Separation Range (CSR) [9][10] is a visual hypothetical aircraft final visualization (see Fig. 3) similar to HungaroControl's tool MergeStrip [11].

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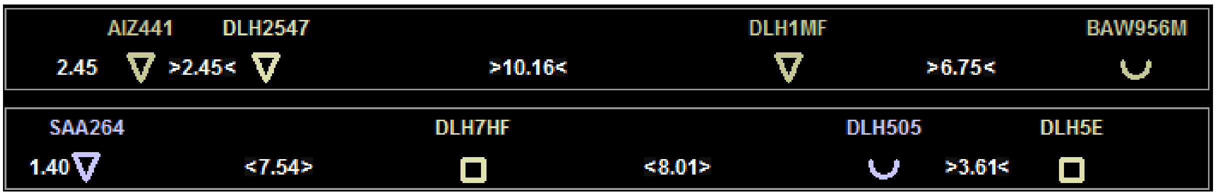

Fig. 3: Centerline Separation Range

The calculated remaining flight distances of all approaching aircraft relative to other aircraft are displayed as distance-to-go (DTG) in nautical miles on one single arrival flow line for each runway (white numbers). When summing up all DTGs of previous aircraft in the sequence, the DTG of the current aircraft results (e.g. sum up 1.4 + 7.54 + 8.01 to get the DTG of DLH505). The angle brackets indicate the trend of increasing or decreasing relative separation between two sequenced aircraft since last radar update. Aircraft are coloured depending on their weight category (e.g., light, medium, heavy). The geometry is to distinguish between real (triangle) and projected aircraft positions. If there are multiple parallel runway centerlines, these will be reflected in the number of CSRs. In MINIMA, all arriving aircraft will be projected on the CSR. It will not show aircrafts only on the Centerline.

All objects move from the right to the left of the display depending on their speed. The leftmost number shows the distance to threshold. The CSR is displayed below the radar situation on the same display.

4.8.2 Operational modes

1. Centerline Separation Range is off (not visible)
2. Centerline Separation Range is on (visible)

4.8.3 Expected Influence

Operational Mode	Justification	Influence
1	This mode is needed in case help systems are deactivated.	Baseline Nothing is presented to the ATCO.
2	In this mode, the CSR supports the ATCO in assessing the distance between aircraft as expected to be at the runway.	On the one hand, the CSR may have a positive impact on the ATCOs' Situation Awareness as it helps to detect aircraft getting to close to each other. On the other hand, only the arrival time at the merging point is automatically deconflicted. Aircraft could be following their trajectory exactly as planned and still be involved in a conflict. These type of conflicts could be more difficult detect when the ATCO's attention is focusing on the CSR.

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4.8.4 Evaluation

The CSR is already implemented and was applied in previous projects. However, it is currently not possible to switch it on and off during simulation regarding changing activation values. As the CSR is already available and the effort to make it adaptable is expected to be low, it is recommended to implement this mechanism.

4.8.5 Requirements

Identifier	Requirement
REQ-MINIMA-TS-04085-0010	The CSR should be adaptable during simulation (switch it on and off)

4.9 Advisories

4.9.1 Description

The trajectories generated by the AMAN will have phases of climb/descent in altitude, increase/decrease in speed. In the MINIMA application example, the aircraft will enter new phases included in the agreed trajectory automatically.

If the aircraft were guided conventionally, the ATCO would have to give a clearance if an aircraft needs to enter a new phase of climb/descent or change its speed. It is possible to extract these necessary controller commands from the trajectory. This functionality was developed to support the controller by showing these commands as "Advisories". The advisory for a controller can include aircraft callsign, command type, command value, and a countdown, when this command should be executed by the pilot. An example could be "AFR376 DESCEND Alt 4000 15s" (see also Fig. 4). These advisories can either be displayed in a stack or directly at the radar label.

Fig. 4: Advisory countdown (yellow) shown at the controller radar display

As the aircraft follow their trajectories automatically and ATCOs do not have to give clearance in the MINIMA use case, they could be unaware of the changes of aircraft behaviour. For example, an aircraft can start to descend without the ATCO noticing. In MINIMA, the "Advisories" could help to

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increase the ATCOs awareness regarding the behaviour of the aircraft and changes in the flight profile, e.g., by just showing these Advisories or by requesting the ATCO to confirm these Advisories.

In case Advisories are not confirmed, the related changes of the flight profile are not executed by the aircraft. These aircraft are no longer guided automatically, but have to be guided manually by the ATCO.

4.9.2 Operational modes

1. No Advisories are shown
2. Advisories are shown
3. Advisories are shown. The ATCO has a specific amount of time to veto. If the ATCO does not veto, the aircraft will execute the related clearance automatically.
4. Advisories are shown. The ATCO has a specific amount of time to confirm the Advisory. If the ATCO does not confirm the aircraft will not execute the related clearance and the aircraft has to be guided manually from now on.

4.9.3 Expected Influence

Operational Mode	Justification	Influence
1	This mode is the default mode as all systems are deactivated.	Baseline Nothing is presented to the ATCO.
2	In this mode, Advisories are just presented.	On the one hand, this mode guides the attention towards changes of aircraft behaviour and could have a positive impact on Situation Awareness. On the other hand, the ATCO is also just monitoring is this mode. Thus, it might not help to solve OOTL Problems or has just a small effect.
3	In this mode, the ATCO has the possibility to intervene. This gives him a better control over the aircraft.	As the ATCO has the possibility to veto and to intervene, this mode should give the feeling of being more engaged. This could reduce the effects of the OOTL Problem.
4	In this mode, the ATCO is required to confirm Advisories.	As the ATCO must confirm every clearance, this mode is expected to increase the workload. These advisories are suited to guide the aircraft along their agreed trajectories. As long as the ATCOs agree to this, they do not have to intervene. This could lead to the problem of overtrust and the ATCOs could tend to confirm every Advisory without checking it.

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4.9.4 Evaluation

Different modes to react to vigilance decrements are possible and positive effects to reduce OOTL Problems are expected. However, it is expected that a large effort is required to implement the generation of Advisories. Therefore, the implementation work package should focus on the implementation of the other adaptation mechanism first.

4.9.5 Requirements

Advisories are already implemented. However, the different modes have to be implemented.

Identifier	Requirement
REQ-MINIMA-TS-04095-0010	An Advisory-System may extract Advisories form Trajectories
REQ-MINIMA-TS-04095-0020	If the corresponding mode is active, the ATCo may have the possibility to veto an Advisory
REQ-MINIMA-TS-04095-0030	If the corresponding mode is active, the ATCo may have the possibility to confirm an Advisory
REQ-MINIMA-TS-04095-0040	It may be possible to change the mode of the Advisory-System during simulation

4.10Sequence optimization

4.10.1Description

The AMAN calculates an optimized sequence for the arriving aircraft. The trajectories are generated in such a way that the aircraft arrive at the merging point according to the planned sequence. The AMAN adds aircraft entering the planning horizon of the AMAN to the list. However, except for adding new aircraft, the list will not be updated automatically. If ATCOs would like to update the list, they have to modify the sequence manually (e.g. using drag and drop on a sequence display).

Having the possibility to modify the sequence would allow offering a new kind of service to airlines. Airlines have additional restrictions that are not met today. Considering that increasing automation reduces the workload of controllers and that safety is kept on the same level, the services provided by ATCOs could be increased. It could be possible for airlines to change sequences of their arriving aircrafts if it only affects their own aircraft. This can only happen if the aircraft of one airline are in sequence and are controlled by the same ATCO. This additional task is triggered by airlines that already know the sequence of their arriving aircraft and would like to change. This could be simulated with an additional tool that provides the special demands issued by airlines and pilots.

4.10.2Operational modes

1. No request regarding sequence optimization
2. Additional request by the airlines, concerning changes, have to be incorporated.

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4.10.3Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This mode is needed in case help systems are deactivated.	Baseline
2	In this mode, airlines can make requests	Based on the already AMAN optimized sequence request from the airlines are send to the ATCO. This service tasks could help to increase the attention to the arrival sequence.

4.10.4Evaluation

Changing the sequence based on request from the airline could increase the workload of ATCOs. As this type of task depends on an external party to request the service, it might be suitable to simulate request during periods of low vigilance but this not a realistic assumption. If request of airlines are possible, they should be possible independent of the ATCO's current state. Also the effect of this method is strongly connected to the traffic situation. It can only be applied if the traffic is high and aircraft are delayed to fit into the sequence, so that it is possible to reduce this delay by changing the position within the sequence. Additionally, a high effort is required for implementing this system. Consequently, it is recommended to implement this mechanism only if possible after all other adaptions have been implemented.

4.10.5Requirements

AMAN and airline sequencing

Identifier	Requirement
REQ-MINIMA-TS-04105-0010	The AMAN may process input from the simulation but also from the ATCO.
REQ-MINIMA-TS-04105-0020	The Interfaces with the radar display may allow the transmission of sequence.
REQ-MINIMA-TS-04105-0030	The AMAN may be able to switch between the different modes of sequence generation during simulation

Radar display

Identifier	Requirement
REQ-MINIMA-TS-04105-0040	The radar display may visually present the AMAN sequence.
REQ-MINIMA-TS-04105-0050	The radar display may visually present the request from the airlines fitting to the current arrival sequence.
REQ-MINIMA-TS-04105-0060	The radar display may allow the ATCO to change the current AMAN sequence.

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4.11 Provision of additional information to increase service

4.11.1 Description

This idea is also considering that the safety is kept on the same level trough automation and that the ATCO has more time to provide better service. The ATCO should provide the aircraft with additional information that are not provided today and that could be of relevance for the pilots. The task is triggered by the pilots that request the information. The ATCO then can decide if his workload allows him to provide the requested information. Examples for requests are: predicted minimum separation, additional weather information, or the parking position.

4.11.2 Operational modes

1. No additional request are made from the pilots
2. The pilots request one additional service information
3. The pilots request several additional service information

4.11.3 Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This mode is needed in case the vigilance is on a normal level.	Because no additional requests by the pilots are made no change in the ATCO behaviour is expected.
2	This mode is activated in case the vigilance is slightly reduced.	This mode lets the pilots make one additional request per arrival and the ATCO has to perform the information search. This leads to increased attention on the arriving aircraft.
3	This mode is activated in case the vigilance is more than slightly reduced.	This mode lets the pilots make more than one additional request per arrival. The ATCO has to widen his search for information and therefore increase his attention even more to the arriving aircraft.

4.11.4 Evaluation

As information has to be prepared, the radar display has to be changed, participants have to be trained especially for the requests and pseudo pilots have to be trained to react differently within the operational modes. Overall a high effort is connected with this adaptation mechanism.

In this adaptation mechanism, an external party has to request the service. While it might be simulated that requests only occur during periods with a specific level of vigilance, it seems to be unlikely that a service will be available based on the vigilance level of the air traffic controller in reality. Additionally, as there are other possibilities to exchange information, ATCOs might question

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whether this task makes sense and might not accept it. For this reasons, only a lower priority should be assigned to the implementation of this adaptation mechanism.

4.11.5Requirements

Identifier	Requirement
REQ-MINIMA-TS-04115-0010	The radar display may visually present additional information, e.g. in a sub menu of the label, that can be requested by pilots
REQ-MINIMA-TS-04115-0020	A list of pilot requests may be available for each scenario
REQ-MINIMA-TS-04115-0030	Information that can be requested may be defined for all aircraft in each scenario
REQ-MINIMA-TS-04115-0040	Participants may to be trained to find the requested information on their screen

4.12Adaptation of Sector Size

4.12.1Description

One result from the workshop is that it is a common method to balance the workload of ATCOs today by splitting or merging their airspace sectors. If high amounts of traffic are expected, the sector is split so that the traffic can be handled by two controller positions. The same could be applied in MINIMA. However, as the route structure of the MINIMA application example is different from today, common methods to divide sectors cannot be applied.

Considering the route structure described in section 3.2 the following regulations could be possible. First, the two runways normally would be the responsibility of two ATCO. However, as due to the high automation both sectors could be combined so that one ATCO is responsible for the arrival traffic for two runways.

A second possibility is to hand over aircraft from adjacent sectors earlier. The ATCO would be responsible longer for each individual aircraft and consequently would have to handle more aircraft at a time.

4.12.2Operational modes

1. One runway, normal hand over form adjacent sectors
2. One runway, early hand over
3. Two runways, normal hand over
4. Two runways, early hand over

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4.12.3Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This is the default mode	Baseline
2	In this mode, only the hand over time of aircraft is changed	The workload for the ATCO is expected to increase. By defining when aircraft are handed over, it is possible to decide about the extent of the increase.
3	In this mode, the ATCO is responsible for two runways.	The workload is expected to increase. Assuming that the traffic is similarly distributed between two runways, the taskload of the ATCO will double.
4	In this mode, both adaptions are activated.	If both adaptations are activated, this is expected to have a strong impact on the workload. It is probably only suitable when the amount of traffic is low.

4.12.4Evaluation

The effort for being able to combine two sectors during the simulation seems to be high. Additionally, the effect of giving a second sector with nearly the same amount of traffic to an ATCO could be very drastic. On the other hand, by handing over aircraft earlier, a continuously adjustable increase of the workload could be realized. This adaption is also easier to implement. It is recommended to focus on the earlier handover aspect of this adaption mechanism. Only a low priority should be assigned to the implementation of the adaption of the runway responsibility.

4.12.5Requirements

Identifier	Requirement
REQ-MINIMA-TS-04125-0010	The position where aircraft are handed over from adjacent sectors may be adaptable
REQ-MINIMA-TS-04125-0020	The responsibility for the runways may be adaptable
REQ-MINIMA-TS-04125-0030	The simulated traffic NOT controlled by the participant of the simulation may be controlled (either by automation or manually)

4.13Training on the Job / Additional Questions to keep up situational awareness

4.13.1Description

When measuring Situation Awareness during an experiment by asking question about the current situation, an unintended effect is that participants prepare for the questionnaire. Thus by measuring

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Situation Awareness it could actually be improved. Here, the idea is to use this effect to influence the ATCO's situation awareness by integrating such questions regarding the current situation into the simulation. However, by having to answer to questions, ATCOs are distracted form their actual tasks which could decrease their Situation Awareness. Consequently, this mechanism has to be designed very carefully. Such questions could also be used for training on the job.

Questions related to the actual air traffic situation will be asked according to Endsley's three levels in her definition of situation awareness: "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988, p.792 [12]).

Example questions for perception are (see also Fig. 5):

- Does AUA234 actually fly above FL80?
- Which heading is AFR456 actually flying?
- How many aircraft are in the TMA?

Example questions for comprehension are:

- Which aircraft actually violates its minimum altitude?
- Is DAL765 flying eastwards?
- Is SAS321 in your responsibility?

Example questions for projection are:

- How many aircraft will land during the next 5 minutes?
- Will aircraft DLH789 and BAW987 get in conflict during the next three minutes if they proceed with their current flight characteristics?
- Will SWR432 be on the centerline in 30 seconds?

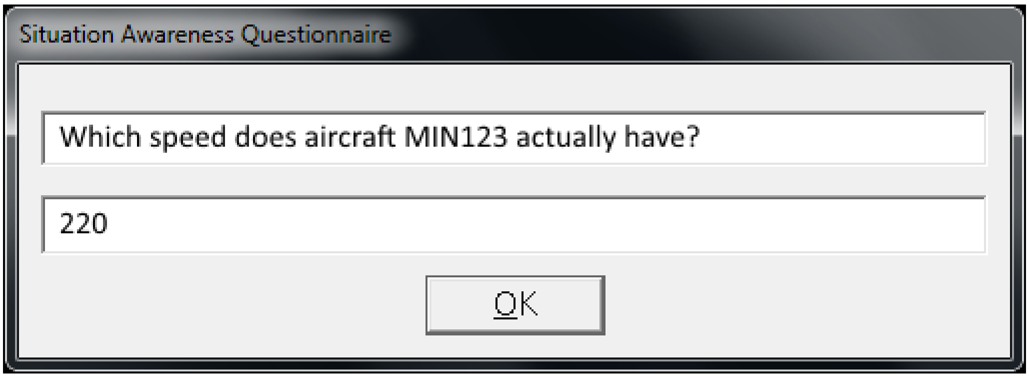

Fig. 5: Example situation awareness question

4.13.2 Operational modes

1. No questions are asked
2. The Question-Module asks Situation Awareness related questions

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4.13.3 Expected Influence on the ATCO

Operational Mode	Justification	Influence
1	This is the default mode. No questions are asked.	Baseline
2	Questions are asked regularly. The frequency of the questions depends on the vigilance level.	Unclear. An increase of the ATCOs Situation Awareness could result when ATCOs prepare for the questions, or a decrease of Situation Awareness could result if ATCOs are distracted. In either case, it is expected that the effect will depend on the frequency of the questions.

4.13.4 Evaluation

The effort to implement this adaptation depends on the possibility to adapt similar tools that have been developed to measure Situation Awareness. By changing the frequency of the questions, a good scalability of the adaption is possible. This adaption should only be used if there is evidence that a positive effect on Situation Awareness can be expected. Considering the medium effort and the interesting effects that could results, it is recommended to implement this adaptation mechanism.

4.13.5 Requirements

Identifier	Requirement
REQ-MINIMA-TS-04135-0010	A Question-Module shall be able to show questions and offer the possibility to reply to the questions
REQ-MINIMA-TS-04135-0020	A Question-Module shall generates relevant questions during simulation
REQ-MINIMA-TS-04135-0030	A Question-Module shall activate questions based on the vigilance level of the ATCO

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5 Technical Implementation of Task Environment

5.1 Simulation type

The ATC scenario that controllers shall monitor in a highly automated TMA environment can have two characteristics that will also influence evaluation outcome: live or replay simulation. A live simulation may be closer to the assumed future ATC reality whereas a replay simulation eases comparability of results and preparation of the evaluation environment due to deterministic events. For MINIMA a live simulation is chosen as the target implementation with the fall-back solution of a replay simulation to cover the implementation risk.

5.1.1 Live simulation

A live simulation contains a controller who can influence aircraft behaviour (radar data) via clearances. Those clearances can be entered via mouse (or simulation pilots connected with radio telephony that is not available in MINIMA). For MINIMA the DLR radar display RadarVision (see Fig. 6) is used to enter clearances via mouse. Those clearances (e.g. click on altitude of aircraft DLH123, select value 60, press OK, for command "DLH123 DESCEND 60FL") will be forwarded to a simulator control module of the Arrival Manager. Afterwards, this command is sent to an air traffic simulator for flight movements. Such scenario integrates arrivals and departures (as well as overflights if needed). However, live simulations demand greater effort regarding simulation staff, hardware, software, and testing.

5.1.2 Replay simulation

A pre-recorded scenario is shown to the controller. Deterministic situations such as conflicts or dense traffic can be included for the controller's monitoring task. If the controller detects a situation in which he/she normally gives clearances, he/she can use a special software dialogue (activated by space bar in RadarVision display) to document his hypothetical action. The affected aircraft will be marked with a symbol, but will not behave different (due to the replay character). The replay simulation can run on two laptops (one Windows and one Linux) just connected to a bigger screen.

Forced situation can be integrated into the scenario at specific times. The need for an initial contact or handover to the next controller position can be linked to certain simulation timetick and may either be executed automatically or "manually" depending on the automation level.

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5.2 Simulation environment

The DLR radar display RadarVision (see Fig. 6) will be used as human machine interface (HMI) in the MINIMA trials. RadarVision visualizes static airspace dependent data as well as calculation results from an AMAN. Is also serves as the graphical user interface to steer the support systems. The central view consists of the Situation Data Display (SDD) that displays runways, TMA borders, routes, points, and aircraft. The Centerline Separation Range (Fig. 3) can be shown at the bottom of the SDD.

By using the "mouse over"-functionality on an aircraft icon corresponding data like the planned 4D-trajectory or weight category can be visualized in an extended label. The standard label as shown in Fig. 6 shows the sequence number (e.g. 2) and callsign (e.g. MIN123) of an aircraft in the first line, the aircraft type (e.g. B737) in the second line, and altitude (e.g. 70 for FL70 or 40 for 4000 ft), last cleared altitude (e.g. 60), speed (e.g. 45 for 450 knots ground speed), last cleared speed (e.g. 30 for 300 knots indicated airspeed) in the third line. A timeline is shown right of the SDD. Each aircraft has a label dedicated to a certain time and runway. All dynamic elements will move downwards as time goes on.

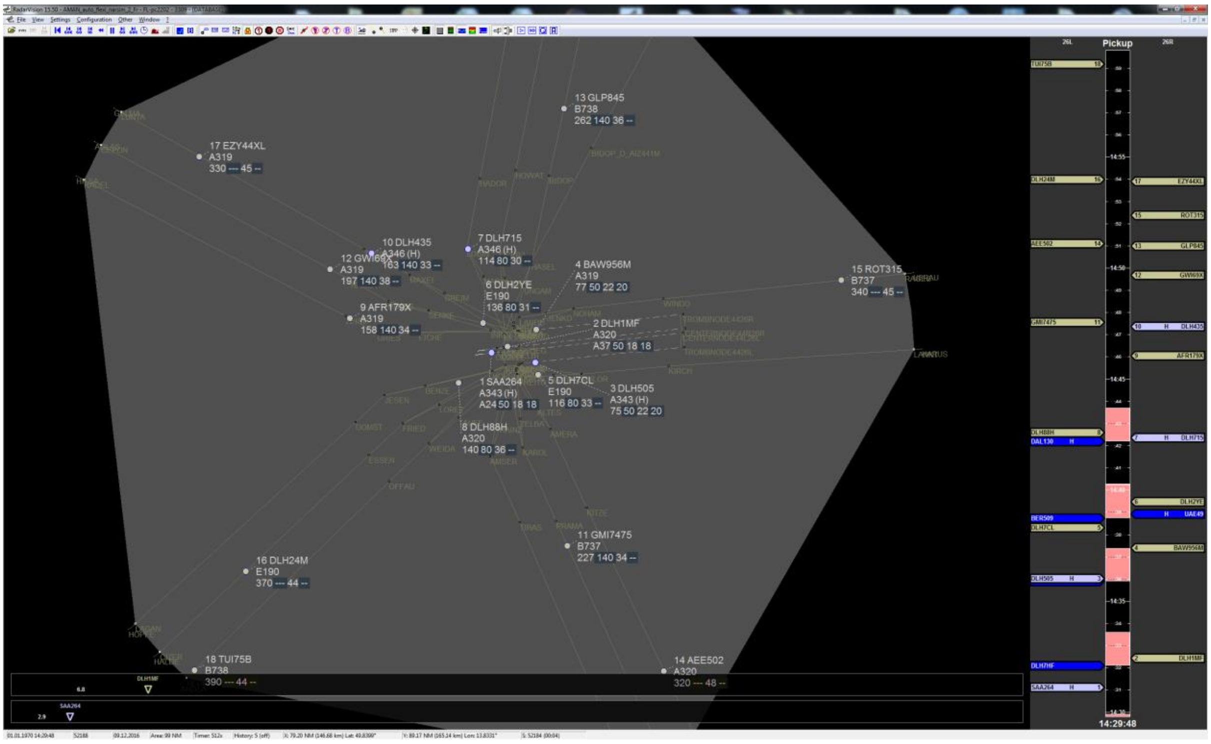

Fig. 6: DLR radar display RadarVision with timeline and centerline separation range

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5.3 Validation setup

Fig. 7 shows the scheme of hardware devices (with its main software) as well as connections between them for the MINIMA evaluation trials. The final trials will take place in Forli (Italy) at the end of year 2017.

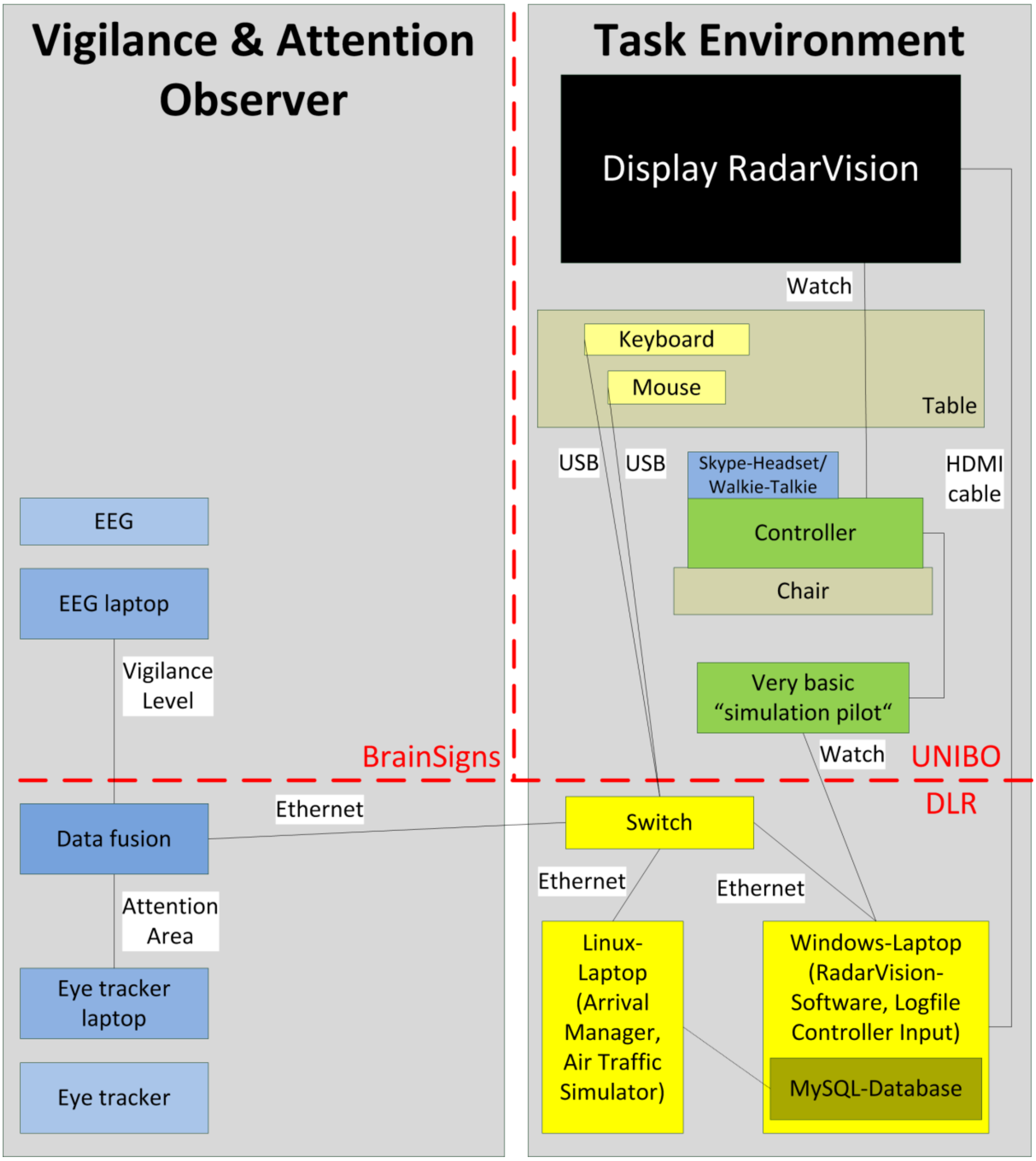

Fig. 7: Setup of simulation environment for evaluation at university Bologna site (Forli) with partner's contribution

The Vigilance and Attention Observer consists of an electroencephalographic (EEG) device and laptop responsible for vigilance level measurement (BrainSigns), an eye tracking device and laptop for attention area as well as a simple data fusion module (DLR). Details will be given in chapter 7.

The task environment comprises two laptops with various Ethernet cables and a switch to connect the simulation driving software with the infrastructure of University Bologna and BrainSigns. University Bologna (UNIBO) provides following basic hardware: table, chair, monitor with HDMI cable, keyboard (with USB cable), mouse (with USB cable), and a headset to use Skype/Walkie-Talkie. UNIBO is also responsible for organizing a controller and a very basic simulation pilot.

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6 Concept for Vigilance and Attention Measurement

One of the main goals of the MINIMA project is to provide solutions to compensate the negative impact of the OOTL performance problem and improve human performance in monitoring task. Particularly, we aim to design a module, called the adaptive task activation module, able to modify both the level of automation and the feedback sent by the automation technology in order to maintain the ATCOs in the loop of control and improve their performance in monitoring task.

However, before implementing such adaptation, an important concern is how to detect OOTL episodes. In the deliverable 1.1, we have discussed at length the characteristics and the origins of the OOTL phenomenon. From this analysis, we have identified the **vigilance decrement** as one of the major indexes of OOTL phenomenon.

6.1 Vigilance decrement as a marker of OOTL episodes

When the inclusion of automation appears critical to increase safety and efficiency for the future ATM systems, such highly automated environments will require maintaining high levels of vigilance during a long period of time. However, basic research on vigilance indicates that the discriminability of unpredictable and infrequent signals from a noisy background of “non-signals” decreases significantly with time on task. Together with this incapacity to maintain high level of vigilance over hours, vigilance decrement could also result from the complacency phenomenon.

Nowadays, there is some consensus for the existence of a decrease of human operator vigilance in case of interaction with highly automated system. This vigilance decrement ultimately can affect system performance if operators miss or respond late to critical events, in fact different works have reported the largest contributor to human error to be failures of vigilance. In a next future, vigilance decrement could cause degradation of the monitoring process involved in supervisory task and decrease performance of ATCOs in failure detection and system understanding.

In this context, the aim of the operator’s *Vigilance and Attention Observer* is to measure both the current vigilance and attention levels of the human operator in view to quantify the OOTL phenomenon. Monitoring vigilance and attention is a hot field since it is extremely useful to prevent some accident in performing attention-demanding and monotonous tasks. Several approaches have been proposed, from the analysis of system parameter to physiological signal. We will here focus on psychophysiological measure for different reasons previously discussed [13].

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6.2 How detect change in vigilance and attention level?

"*Knowing what is going on around you*" is the definition of Situational Awareness (SA) provided by Federal Aviation Administration [13]. In fact, SA is a critical factor in those fields where the operator has to make quickly a decision, such as in the field of aviation with pilots and ATCOs, but also in the field of primary emergency intervention and in everyday activities like driving in the traffic. Besides, on the SA, performance of a human operator interacting with an automated system is established [14]. In particular, in highly automated environments, such as the Air Traffic Control domain, human operator has primarily the role of supervisor, so he/she is asked to be aware about "*what is going around him*" and eventually to intervene if necessary, that is, to be *vigilant* and ready to respond to an event. The operator can easily incur in a loss of contact with what is happening because of his passive role in the automated system, so resulting and feeling himself "*out of loop*" [15]. SA is organised in three levels: perception, comprehension, and projection in the future. The role of *Attention* is decisive in the first step: wide pre-attentive processing of environmental features delivers cues for further focalised attention [16]. Both pre-attentive and attentive stages are important to have better performances and facilitate decision making in a human-automation system.

According to the current theories, attention is a multifaceted concept. First, it was defined as a set of cognitive processes that lead to discriminate useful information in a framework of distractors (James, 2013 [17]), but this is only one of the characterizing aspects. In general, it is widely shared the theory that attention could be divided in two main domains, in particular one related to intensity and another one related to selective aspects [18][19].

The intensity aspect of attention embraces alertness and sustained attention, also called vigilance [20]: executing a task with an optimal level of performance is possible when, for the entire duration of the task, there is an appropriate level of arousal managing resources involved in, orienting them and selecting information to mentally process [21]. At this point, this capacity of controlling the focus represents the second main aspect of attention, that involves the selective and the divided attention. Therefore, arousal becomes a prerequisite for ensuring the existence of an attentive state during any task, but it is also important that such a kind of attentive state is oriented towards the right targets, i.e., the instrumentation or the display or any kind of activities composing the task itself. Consistently, there are evidences in literature linking the attentive intensity with brain and other neurophysiological features, whilst the attentive selectivity with ocular movements [22].

In order to investigate properly these two domains of attention, hereafter the intensive aspect, called *Vigilance*, and the selective one, called *Visual Attention*, will be discussed separately.

Defining a relevant index of alertness and sustained attention level in an operational context could be considered as the first step required for the development of such an inference system. Our literature review point several biopsychometrics sensitive to changes in vigilance/sustained attention suggesting them as potential candidates for triggering adaptive automation such as electroencephalographic (EEG), near-infrared spectroscopy (NIRS), transcranial Doppler sonography (TCD), oculometrics, electrocardiogram (ECG) or skin electric potential (GSR).

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However, we must be cautious with the limitations of the device we will choose. Is the signal-to-noise ratio sufficient for what they intend to measure? What artefacts could pollute our data? Could we control the algorithms producing measures from raw signals? Could we use such techniques in operational context (obtrusive nature, lack of comfort, inability to be worn for a long duration of time, and interference of bodily fluid with the devices)?

In the following part, we will review the different bio-behavioural signatures developed and their relevance regarding these different points.

6.2.1 Relevance of the different techniques and signals available

fMRI, PET, MEG

A first category of techniques corresponds to “large” brain imaging techniques: fMRI, PET and MEG. These techniques are used for diagnoses, assistance in medical procedures, and as part of neuroscientific research. They evaluate brain function safely, noninvasively and effectively. FMRI and PET measure hemodynamic changes induced by regional changes in neuronal activity. They are easy to use, and the images they produce have very high spatial resolution (as detailed as 1 millimeter) but a poor temporal resolution (a few seconds to several minutes). In contrast, MEG measures the neuronal magnetic activity with a high temporal resolution (i.e., milliseconds) albeit with a poorer spatial resolution (i.e., a few millimeters to one centimeter). Together with the resolution, these techniques present the advantage to have a specific response to change in vigilance.

Even if some studies have tried to use these techniques for real world monitoring of mental states, some major limitations make them hardly manageable for uses in HCI contexts. First, such equipment is extremely expensive to purchase and use. Second, they correspond to large device which completely surrounds subjects and their procedures feature restrictive environments in which observers need to remain almost motionless to not to compromise the quality of the brain images. This obtrusive nature (e.g., interfering or restricting natural body movement) make them not suitable for our purpose.

EEG

Related studies in recent decades have demonstrated that electroencephalography (EEG), i.e., the electric fields produced by brain activity, is a highly effective physiological indicator for assessing vigilance states. EEG measures electrical current onto the scalp by placing electro-skin-sensors across various positions on the skull (currently the skin-sensors are embedded in a wearable headset). It collects real-time data of the brain’s electrical activity in various regions to the nearest millisecond. EEG is the only brain imaging modality with a high temporal and fine spatial resolution that is sufficiently lightweight to be worn in operational settings. It is also a relatively cheap equipment for a laboratory. Recent efforts to improve usability issues such as comfort and non-restraint have led to embedding wireless electro-skin-sensors in caps, glasses or goggles. Because it is portable and non-invasive, it interferes little with HCI setting.

There is one more, not so evident, but very valuable advantage of EEG studies. In fact, PET, fMRI or fNIRS are based on the measurement of secondary metabolic changes in brain tissue, but not of primary, i.e., electrical, effects of neural excitation. This is the case in EEG recording. EEG can thus reveal one of main parameters of the neural activity - its rhythmic property, which reflects the essence of neural excitation. Therefore, by recording electrical (as well as magnetic) field patterns, the physiologist has access to the actual mechanisms of the brain information processing.

As disadvantage, we can point that EEG is a noisy signal. It is a non-stationary and extremely sensitive signal (particularly to electrical noise); even a small movement from eyes or body can contaminate it. However, while artefacts attributed to movement, eye blinks, and physiological interference accompany EEG data, several algorithms have been developed to allow for the removal of noise in the EEG signal in real time or during post processing of the data. Moreover, it sometimes takes a while for an individual to connect to an EEG machine with electrodes and various pastes to keep them in place. Recent developments in making "field-friendly" EEG systems include "dry" electrode caps, which do not need extensive participant preparation time, as well as wireless systems that do not require the participant to be tethered to cables. These technical developments have enhanced the relevance and value of EEG for mobile applications. Finally, EEG does not measure activity below the cortex and cannot pinpoint neural activation of regions within the brain nor determine neurotransmission.

fNIRS

Functional near-infrared spectroscopy (fNIRS) is another lightweight (It is comparable in size to EEG) and affordable device. It corresponds to an optical brain imaging method that measures cortical hemodynamic response. FNIRS provides good spatial localization compared to EEG, on the order of $1cm^2$ but poor temporal resolution. With latency reaching up to several seconds it is difficult to observe fast and short responses.

As EEG, NIRS has the substantial benefits of low-costs, portability, easiness to handle, and mobility. Sensors are fixed on a cap; hence subjects are free to interact with a computer while wearing it. This makes it a suitable device for both laboratory and field experiments like flight simulators. Interestingly, its signal is less sensitive to head motion or environment noise regarding EEG signal. Particularly, its data are not much susceptible to electrical noise, since it is an optical imaging modality.

Despite these numerous advantages, this technique has been less explored than EEG by the Brain Computer Interface (BCI) community mainly because slow hemodynamic response prevents real-time interaction with an apparatus. Moreover, this technique suffers from depth sensitivity (limited to the upper layer of the cortex). Finally, regarding its recent development, we know few about the relevance of such technique. Some on-line BCI have been implemented and the processing of fNIRS data in real-time to provide good classification accuracy remains a challenge.

TCD

TCD is a totally non-invasive ultrasound technique used for real-time evaluation of blood flow velocities in the major basal cerebral arteries on a beat-to-beat basis. TCD offers good temporal resolution and can track rapid changes in blood flow dynamics that can be followed in real time. It is relatively inexpensive, non-invasive, portable, and fairly easy to use. It offers less restrictive and invasive conditions compared to PET and fMRI. Further, TCD technique provides a very economical way to assess cerebral flow. Owing to its excellent temporal resolution, TCD is a powerful tool for functional and dynamic studies.

Amongst other, TCD presents two major disadvantages. First, the application of this almost 'blind', free hand, and non-imaging technique requires high level of experience and knowledge about the three-dimensional cerebrovascular anatomy. Second, TCD signal present a certain level of variability

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caused by status of the intracranial distal and extracranial proximal arteries as well as systemic and cardiac physiology and abnormalities. These all are required for correct interpretation of the TCD sonograms.

Oculometric measure

Literature has shown that eye activity (both pupillary response and blinking) can be used as a relevant index of cognitive resource allocation and vigilance. Advances in eye-tracking technology have resulted in increased availability of less expensive, easier-to-use equipment. There are a variety of eye-tracking camera options available (i.e., glasses, light eye-trackers, and computer monitor eye-trackers) with different advantages and disadvantages related to weight, portability, and durability. Depending on the system used, an eye tracker can easily be embedded onto a computer monitor or display with no physical contact to participant, thus not limiting natural behaviour making it the less intrusive techniques.

However, eye tracking algorithms could deteriorate over time due to the drift effect caused by changes in eye characteristic over time. Also, the presence of glasses can affect the efficiency of the computer vision algorithms. Finally, eye properties are highly sensitive to the change in the environment (i.e., pupillometry and change in brightness) and could be impacted by many different factors (emotion, workload, fatigue …).

More interestingly, tracking eye movements has the potential to provide a more direct measure of where attention is deployed since the direction of gaze is generally considered to be tightly coupled to the orienting of attention — at least, under normal circumstances. Uncoupling of gaze direction and attention can, of course, occur as Posner’s task clearly demonstrates. The value of eye tracking is that in natural scene viewing — where the visual environment is complex compared to many simple experimental situations — it should provide a good guide to the locus of attention. In recent years, researchers have capitalized on this possibility, seeking eventually to understand how attention and gaze are deployed to make sense of the visual world.

GSR and Hear Rate

Other signals have been proved to be sensitive to decrease in vigilance, namely galvanic skin response and heart rate (particularly, heart rate variability). The main interest of these two measures is that they are non-invasive, not expensive, time-efficient and can be applied routinely and simultaneously in a large number of operators. While their collection was initially only possible with expensive laboratory-based recorders, the recent availability of valid and portable recorders or smart phone applications have substantially boosted the use of these measures for monitoring application.

However, the stimuli to which skin conductance and heart rate are sensitive are manifold, including events of a novel, significant, or intense nature, workload, emotion, fatigue and so on. Because many different kinds of events can modify these measures, it is difficult to clearly link them to the level of vigilance unless you participate in a highly controlled experiment.

Which signals used in Minima?

Regarding both advantages and disadvantages of the different techniques described, EEG appears as the most relevant technique to monitor change in vigilance. Compared to others neuroimaging devices, EEG offers the best compromise between spatial and temporal resolution, practical use and cost. Together with the use of EEG for vigilance monitoring, we propose to use eye tracking techniques to take into account how the available attentional resources is used by ATCO.

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6.2.2 Neurophysiological evidences of Vigilance in EEG

Vigilance level, also indicated as alertness, is the readiness of brain to elicit such behavioural and cognitive functions to reach high levels of performance. Because of the strict dependence on brain activity, vigilance has been deeply investigated by using EEG features: both amplitude of specific event related potential (ERP) and change in power spectrum density (PSD) are shown to be highly sensitive to change in vigilance.

Interestingly, several studies show the relation between the amplitudes of the N100 and P300 components of the event-related potential (ERP) and change in vigilance state. However, the use of the ERP for operational applications currently has several limitations including the requirement for introducing "probe" stimuli into real-world tasks to elicit the potentials and the need for averaging of single trials across scalp sites or over time.

The most reliable indicator of vigilance remains computation of the power spectral densities (PSD) within the classically defined frequency bands (alpha, beta, theta, delta, and gamma) or ratios between these frequency bands. The EEG consists of a spectrum of frequencies between 0.5 Hz to 35 Hz. Interestingly, studies show that the changes in EEG spectrum are related to the vigilance state and a number of methods have been proposed to make accurate judgments of vigilance levels. Nowadays, there is a very large literature concerning the relationship of oscillatory activity and attention/vigilance and brain dynamics associated to vigilance are well known. The general evidence is that lower levels of vigilance are related to increases in lower frequencies (theta and alpha) in EEG spectrum [23].

Continuous Performance Test (CPT) based on Go/No go paradigm, and the *Psychomotor Vigilance Task* (PVT) are two of the main used paradigms to evaluate Vigilance.

The CPT consists in rapid presentation of continuously changing stimuli with a low frequency target stimulus. It will be develop in different versions: visual or auditory, more than one stimulus target, more features target (i.e.: colour + letter), two consecutive same stimuli. Frequency and duration of target and no target stimuli are the two main parameters than can be varied in order to achieve different task difficulty in stimuli presentation. Using a low rate of target stimuli (30%) and varying the inter-stimulus interval (ISI), this task maintains a high demand on vigilance but minimizes the involvement of other cognitive factors [24]. Correct detection, reaction time, accuracy, omission and commission errors are performance parameters used to measure vigilance, assuming that better performance is synonymous of a greater vigilance level during the task.

Several groups measured brain activity using EEG during CPT task [25][26] obtaining:

- negative correlation between score/accuracy and alpha power on the whole scalp (alpha decreases when accuracy increases);
- beta activity at F3 F4 and theta activity at P3 P4 increase in CPT than rest;
- increased frontal, frontotemporal and parietal beta activity, more in right than in left hemisphere, suggesting increased alertness;
- increased theta frontal and frontotemporal is associated with increased omission errors.

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The PVT is used for the evaluation of vigilance and reaction time through performance alteration (i.e., because of sleep loss). Moreover, PVT results are generally interpreted as reflecting arousal and attentional state of the individual: low performance is related to low level of attention and arousal. The task consists in responding to a visual stimulus that can occur in a period of 2-10 seconds randomly in 10 minutes (or eventually 5 minutes [27]) duration. It is an ecological task, brief and portable, and it is not affected by learning effects.

From the EEG point of view it has been found:

- Negative correlation between alpha and theta power with performance in vigilance task [28];
- Increasing in frontal beta power for slowest trials [29].

In conclusion, summarizing the evidences in order to set a proper experimental design, vigilance could be evaluated investigating theta, alpha, and beta activity on the frontal, frontotemporal and parietal sites of the brain, thus the EEG system will be set up accordingly (see chapter 7).

6.3 Eye movements and visual attention

Often at work, it is asked to the operator to attend more than one thing at the same time. This is possible thanks to the human ability to move the attentional focus, and is essential for every multitasking activity [30]. This is the concept explained before about the selective aspects of attention. Of course, measuring only the attentive intensity aspect, i.e. the vigilance in our case, does not pledge that this amount of vigilance is properly oriented toward the tasks composing the work activity: On the contrary, other distracting activities could cause great levels of vigilance but consequently low performance on the work activity itself. For such a reason, it is crucial to monitor also which is the attentional focus of the operator, i.e. where his/her visual attention is addressed.

To evaluate the subjective level of visual attention the *Conjunction Search Task* (CST), as a selective-set task, provide the attentional component information without the influence of other cognitive aspects. It is based on recognition of target object in a pattern of similar distractor objects. The target differentiates from others for one (easy condition) or more features (conjunction condition), modulating the task difficulty but without affecting other cognitive processes, such as mental workload for example. The use of more features implies that the subject is necessary in an attentive state to recognize the object and he/she has to perform a serial visual searching (*overt attention*) of the objects [31].

The task can be highly moulded to be coherent to what an ATCO has to manage in his/her workstation: for instance, white moving triangles on the screen are subjected to events, such as colour and shape modifications, happening randomly in different rings, at different distances from the center. The subject could be asked to push a button every time he/she gets an event. The perceived visual attention level could be gathered by the subject by means of Visual Analogue Scale [32].

In this context, the use of eye tracking device can provide crucial information about the “attentional path” of the subject, revealing for example if the gaze is correctly directed and if there are particular fixation points [33].

7 Technical Implementation of Vigilance and Attention Measurement

Accordingly to the scientific literature evidences explained in chapter 6, the EEG will be used to provide a measure of *Vigilance* whilst Eye Tracking to provide information about *Visual Attention*. The technical implementation of the two measurements will be described separately.

7.1 Technical implementation of Vigilance Measurement

In MINIMA project, we propose to develop a passive-BCI system fully integrated with a high realistic ATM simulator able to trigger adaptive solutions in real-time depending on the vigilance level estimated by means of the ATCO's brain activity. In view to develop this vigilance monitoring tool, a 2-steps approach is proposed:

- Calibration in simple task with traditional laboratory equipment (implementation phase)

In this first step, we propose to define a set of relatively pure tasks that consistently elicit the targeted cognitive states to provide training data for the model and to validate the methods for cognitive monitoring. Validation of cognitive state measures generally involves experimental manipulation of task demands to induce cognitive state changes (here vigilance), objective measurement of performance metrics (e.g., accuracy, reaction time), and subjective measures that allow participants to describe their perceived level of vigilance in the given task. The cognitive state measures must also be validated across participants and adjusted to account for individual differences when required. We can use other measure of vigilance (pupil dilatation, Heart rate variability …) to find correlation in this simple setting. During this implementation phase the EEG signal will be recorded by using a high number of electrodes (between 30 and 40) in order to investigate deeply the brain sites involved in the vigilance process, that is prefrontal, frontal, frontotemporal and parietal sites (please see section 6.2.2).

- Real time assessment in ATC context with simpler EEG system (evaluation phase)

In this second step, we will evaluate the robustness of our algorithm in a high realistic ATM simulation. Thanks to the results obtained during the implementation phase, the channels number will be reduced, for example discarding those channels less informative, in order to reduce the intrusiveness and improve the wearability of the system that will be adopted in real scenarios during the validation experiments.

The vigilance monitor device proposed will be based on the power spectral density (PSD) distribution. It will encompass four functions:

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1. EEG acquisition and amplifying,
2. Data preprocessing,
3. Feature extraction,
4. Pattern Classification.

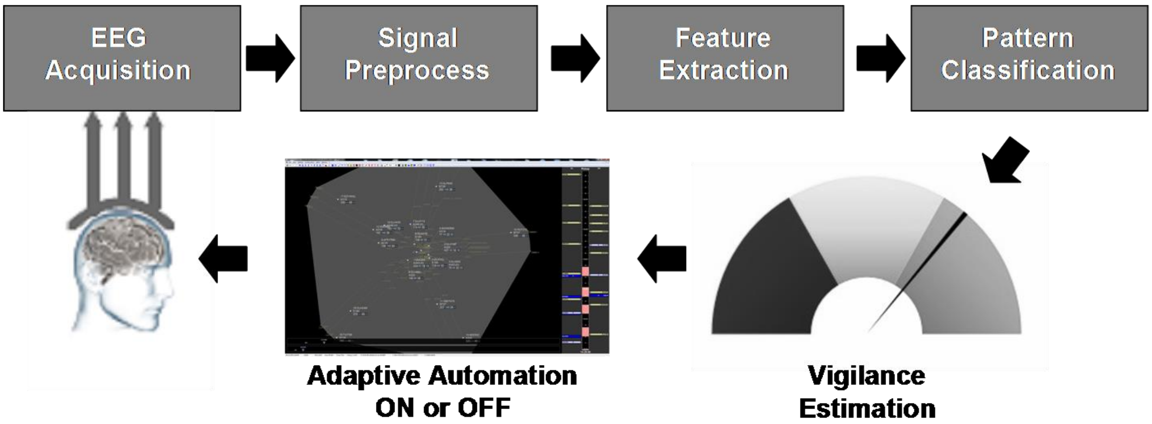

Fig. 8: General Framework of the proposed BCI system for vigilance analysis and estimate. Multi-channels raw EEG signals are first collected as inputs, and then EEG signal must be denoised and artefacts must be removed. After the pre-processing of EEG data, vigilance level would be analysed by feature extraction and pattern classification algorithms, the results would trigger the Adaptive Automation when the vigilance decrement condition occurs.

7.1.1 Function 1: Data Acquisition and amplifying

First, EEG signals have to be collected as inputs.

EEG system

BrainSigns will provide its EEG instrumentation to perform Vigilance Measurements. In particular, the EEG device will be the **Galileo BEPlus** (EB Neuro Spa, Italy), a system able to record up to 64 EEG channels with a sampling frequency up to 1024 Hz. Galileo BEPlus is a **wired EEG system**. If more intrusive than a wireless system (certainly the ultimate solution for operational context regarding ease of installation, comfort and degrees of freedom), this system presents two major advantages. First, it is highly reliable in terms of recorded signal. Second and most importantly, BrainSigns has already employed successfully this instrumentation during the SESAR WPE Project NINA (http://www.nina-wpe.eu/#overview).

In MINIMA, the sample frequency will be 256Hz. EEG caps of different size will allow recording correctly the signal from different subjects independently of their head size.

Dry Vs Wet electrodes

Type of Electrodes could be “dry” – no electrolyte solution – or, more frequently, “wet” – solvent is either water or gel. In the time of MINIMA, we will use **wet electrodes**. In the case of wet electrodes, data collection requires skin preparation and conductive gel application to ensure excellent electrical conductivity between a sensor and human skin. These procedures are time consuming and sometimes uncomfortable, and certainly not appropriated to operational context. However, dry

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electrodes remain not enough robust or too much painful to be a relevant solution at the moment. In a near or less future, but before ATM system will be completely automated, we can expect that mobile and wireless EEG device equipped with comfortable dry electrode will exist, and such technology should be used to design a user acceptable and feasible EEG device for real-time monitoring in operational context.

Active Vs Passive electrodes

Electrodes also could be active (amplification of the signal at the level of the electrodes) or passive. For practical reason (BrainSigns system is equipped with passive electrodes), we will use **passive electrodes** in MINIMA.

Number of electrodes

As already pointed, we will first use a high number of electrodes (between 30 and 40) in order to investigate deeply the brain sites involved in the vigilance process. Then, once relevant signal identified and algorithms trained, we will propose to decrease the number of electrodes to 16 electrodes in order to reduce the intrusiveness and improve the wearability of the system proposed.

Position of electrodes

The electrodes will be placed based on the Standard International 10-20 system, mainly on the prefrontal, frontal, frontotemporal, and parietal sites. Electrodes in mastoids will be used as reference.

7.1.2 Function 2: Noise and Artefact elimination

EEG is a non-stationary and extremely sensitive signal, even a small movement from eyes or body can contaminate it. In our case, the presence of noise will be increased by the fact that no constrains will be imposed to the subject (e.g., avoid the movements) in order to achieve a high realism and therefore to obtain neurometrics reliable also in real scenarios. So removing the polluted signal segments or contaminated channels and reducing the noise influences from EOG, EMG and other channels are all necessary in the EEG signal preprocessing work.

In the process of data preprocessing, we will first remove the EEG signals from the damaged channels. Then, the EEG signals will be band-pass filtered (5th order Butterworth filter) to eliminate the noise. Because the brain potential is generally between 1Hz and 40 Hz, so the band-pass filter cut-off frequencies are set to 1Hz and 40Hz..

At this point, artefacts elimination will be performed. The EEG signal will be segmented into epochs of 2(s), shifted of 0.125(s). The Fpz channel will be used to remove eyes-blink artefacts from the EEG data by using the regression-based algorithm REBLINCA [37]. With respect to other regressive algorithms [37], the REBLINCA algorithm has the advantages to preserve EEG information in blink free signal segments by using a specific threshold criterion that recognize automatically the occurrence of an eye-blink, and only in this case the method correct the EEG signals. If there is not any blink, the method has not any effect on the EEG signal. In addition, the REBLINCA method does not require EOG signal(s). For other sources of artefacts (i.e., ATCOs normally communicate verbally and perform several movements during their operational activity), specific procedures (Threshold

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criterion, Trend estimation, Sample-to sample difference) available in the EEGLAB toolbox [37] will be applied.

7.1.3 Function 3: Feature extraction

To make sense of the recorded EEG signal, feature extraction and data dimension reduction are needed. Due to the close relationship between the EEG spectrum and the subject's vigilance state (please see section 6.1), the rhythm activities, that is, EEG power in the three specified bands, Theta (4-8 Hz), Alpha (8-13 Hz), and Beta (13-30Hz) and their ratios, are calculated as features. Many transform techniques such as *fast Fourier transform* (FFT), short-term Fourier *transform* (STFT) or *wavelet transform* (such as Morlet wavelet function) have been utilized to describe the minute and detailed changes of the vigilance in the research based on EEG.

In MINIMA, the EEG Power Spectral Density (PSD) will be estimated by using the Fast Fourier Transform (FFT) in the EEG frequency bands. Such frequency bands will not be defined equally for all the subjects (e.g., alpha equal to the 8÷12 [Hz] band), but the Klimesch approach will be adopted by using the Individual Alpha Frequency, in order to take into account the physiological subjective aspects of brain activity [37].

7.1.4 Function 4: pattern classification algorithms

Various classifiers performing classification task have been proposed. Amongst other, support vector machine (SVM), artificial neural networks (ANN) and autoregressive (AR) are the most commonly used classifiers in the EEG research domain.
In the case of MINIMA, a machine learning approach will be thus adopted in order to compute a Vigilance index based on the selected brain features. Particularly, during the calibration scenarios (*LowVigilance* and *HighVigilance*), we calibrate the algorithm before the Testing scenarios presentation. In particular, the Power Spectral Density of EEG epochs related to each calibration scenario (*LowVigilance* and *HighVigilance*) will be calculated by using only the frequency bands directly correlated to the vigilance state. The EEG frequency bands [frequency resolution of 0.5(Hz)] of interest will be defined for each ATCO by the estimation of the Individual Alpha Frequency value, as stated previously. At this point, the classification algorithm automatic stop Stepwise Linear Discriminant Analysis (asSWLDA, [38]) will be used to identify the most relevant discriminant features among the two different experimental conditions related to the lowest and the highest level of vigilance. Once identified, the asSWLDA classifier will assigns to each significant feature specific weights plus a bias. These parameters will be used later on to compute online the vigilance level index of the user during the Testing scenarios.

During the experimental scenarios, the vigilance index will be classified online in, at least, two classes (HIGH and LOW) to trigger the Adaptive Automation (AA). In such a case for example, when the vigilance will be lower than a specific threshold, the vigilance state of the user will be classified as LOW and the adaptive solutions would be activated. On the contrary, the adaptive solutions will be disabled (HIGH class).

The BrainSigns team successfully applied such a kind of methodology with the EEG signal to evaluate online the mental workload of professional ATCOs performing realistic tasks in their workstation [38], being also able to trigger AA solutions on the basis of the workload index itself [39]. The application is quite similar to that one investigated within this project, since the main difference consists in the cognitive processes investigated (vigilance and attention instead of mental workload), therefore the

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goodness of the results of the previous studies can be considered promising, once identified the brain features more related to vigilance and attention.

7.2 Technical implementation of Visual attention Measurement

In addition to the level of vigilance, we also propose to monitor how our participant will use his available resources during the task. Particularly, we propose to use eye tracking technique to monitor the attentional focus of the ATCO. *Tracking eye* movements has the potential to provide a more direct measure of where *attention* is deployed since the direction of *gaze* is generally considered to be tightly coupled to the orienting of attention. Both decrease in vigilance and not adapted focus of attention will be used to trigger Adaptive Automation.

7.2.1 Eye tracking system

The measurement of eye movements has been pursued for over a century; however, only in the last thirty years have accurate, non-invasive, methods been developed [40]. Today, the most popular methods involve directing a camera and infrared light source at the participant's eye(s). By recording the surface of the eye with a video camera, the pupil can be detected by its lack of reflectance (dark pupil tracking); alternatively, with a bright light aimed at the eye, the pupil can be identified by the light reflecting through the pupil, off of the retina (light pupil tracking) [41]. While locating the pupillary reflection provides the primary indicator of eye movement, a second corneal reflection is often used to control for head movement. An alternative method of eye tracking involves electro-oculography, the use of electrodes placed near the eye to record changes in electrical potentials produced by eye movements (e.g., [42]).

Generally, eye tracking data is collected using either a remote or head-mounted 'eye tracker' connected to a computer. Each type of system has advantages and disadvantages relative to the other. Sophisticated desktop systems are unobtrusive to the participant and directly measure point of gaze on one stationary scene (for example a computer or video monitor). On the other hand, if measurement must be made as the participant turns and scans a wide field of view or multiple surfaces, a desktop system may not meet your requirements. Using free camera placement, recent remoted eye tracking system (for example, SmartEyePro 3D) has extended the usable field of view (Up to 8 cameras can give up to 360 degree continuous field). Head mounted systems can generally make a measurement no matter how the participant turns his head or what he/she holds but participants do have to wear something, and the measured quantity is eye line of gaze with respect to the head. If you need to know point of gaze on a scene, either the head must be fixed or the position and orientation of the head must also be measured. The necessary head reference can be provided by a head mounted scene camera and/or by one of several head tracking systems.

Regarding MINIMA concept, we choose to use a remoted system (Tobii EyeX) with 60 Hz sampling rate. This system can deliver information in real time (i.e., gaze direction).

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7.2.2 Interpretation of eye tracking data

In contrast to EEG signal, the interpretation of eye tracking data is relatively easy. Even if many different methods of exploring eye data exist, the eye tracking data do not require any particular skill in terms of analysis, since the software itself provides results in terms of gaze movements, fixations and so on.

For MINIMA, we propose to use eye tracking to identify in real time where, when and what people look at and what they fail to see.

Basically, we will use **fixation** and **saccades** as measures of visual attention and interest**.** Gaze points constitute the basic unit of measure – one gaze point equals one raw sample captured by the eye tracker. If a series of gaze points happens to be close in time and range, the resulting gaze cluster denotes a fixation, a period in which our eyes are locked toward a specific object. The eye movements between fixations are known as *saccades*.

Without doubt, the terms fixation and saccades are the most prominent metrics in eye tracking literature. Based on fixation position (where?) and timing information (when?), we could compute different index, like the time and the number of fixation spent on a specific area of interest (AOI) or the Time to First Fixation (or TTFF), that is the amount of time it takes a respondent to look at a specific AOI from stimulus onset. These different metrics will inform us where and when the ATCOs look at and how different events in the simulation will catch attention of the ATCO.

- ***Number of fixation and Time spend on a specific area of interest***

  Areas of Interest, also referred to as AOI, are user-defined subregions of a displayed stimulus. They could refer to specific part of our interfaces where critical information appears regarding specific event. The number of fixation refers to the number of time our participant will stop on this specific area of interest. "Time spent" quantifies the amount of time that respondents have spent on an AOI. Together, these measures can inform us about the attentional strategy used by the ATCO's (information extraction or exploration).

- ***Time to First Fixation (TTFF)***

  The time to first fixation indicates the amount of time it takes a respondent to look at a specific AOI from stimulus onset. TTFF can indicate both bottom-up stimulus driven searches (a flashy company label catching immediate attention, for example) as well as top-down attention driven searches (respondents actively decide to focus on certain elements or areas on a website, for example). TTFF is a basic yet very valuable metric in eye tracking. It could be relevant when important event appears in the simulation.

By directly and continuously measuring eye movements, eye tracking devices will enable us to parse the orientation and engagement of attention, as the locations of initial fixations indicate orientation (i.e., where one looks first), while the duration of these fixations indicate the engagement of attention (i.e., how long one looks).

Using these measures of the controller attention area, we aim to help the controller in keeping his attention at the relevant display areas. In case of critical event and whatever the current level of vigilance, three different situations could be envisaged: (1) ATCO is focused on the relevant part of the radar display regarding the current situation, (2) ATCO is focused on a non-relevant area of the

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radar display, (3) ATCO is exploring the environment without specific area of interest. Oculometric measure could help us to detect problematic situation as cases 2 or 3 and help ATCO to focus on the relevant information. To make it possible, we need (1) to evaluate which ATC event on the radar display is the most relevant for the controllers (this is called normative model of attention distribution in section 4.4), (2) to detect which radar areas the controller actually focuses his attention on, e.g. via eye-tracking, and (3) to guide the controllers' attention to the relevant radar display area if his attention is somewhere else. A similar procedure has been already proposed by DLR (see [43]).

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8 Interface between Task Environment and Vigilance & Attention Observer

The vigilance and attention observer comprises the output of two measures: the vigilance level and the controller attention area (see also Fig. 7). The automation level is connected to those values.

8.1 Basic Message including Simulation Timetick

Each message between the ATC environment and the physiological environment is send as an xml (Extensible Markup Language) string. XML with opening and closing tags has the advantage of being human readable and easily evaluable for machines. The basic message (M) always contains the simulation timetick (T). An example message looks like this: “<M><T>1235480200</T><#>*</#></M>”, where # is the tag identifier and * is the concrete information being tagged (description in section 8.2 and 8.3). Timeticks shall be in Linux timetick type starting January 1st, 1970 to make evaluation and correlation of measures and results easier.

8.2 Vigilance Level

The vigilance level of a controller is defined through an integer value between 0 and N_{MAX}. Briefly, our machine-learning approach, based on the use of a classifier, will allow to discriminate different levels (N_{MAX}+1) of the mental state investigated, i.e., vigilance, assigning them an increasing integer value. The value of N_{MAX} will depend on the number of discriminable vigilance levels, by the way a value of N_{MAX} means maximum measurable vigilance of the controller, whereas 0 indicates no vigilance at all. Of course, N_{MAX} will be equal to or greater than 1, where 1 would mean that at least two classes have been defined, a LOW (0) and a HIGH (1) class.

This integer value is send as an xml string (e.g. “<M><T>1235480201</T><V>53</V></M>”) via a TCP-connection between dedicated hosts and on defined ports. The frequency of measurements is 256 Hz, accordingly to that one of the EEG system. A combined value will only be send as a string every fifteen seconds, in order to reduce the variance of the measurement and to provide a measure that is not affected by fast physiological variations of the mental process but is strictly related with its overall evaluation. However, the “best value” of the triggering frequency will be estimated on the basis of the results, as the better compromise between the reliability of the measure and the needs of the automated system.

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8.3 Attention Area

The attention area (gaze point) of a controller is defined through a relative x- and y-coordinate between 0 and 1 regarding the extent of a monitor. The combination {0;0} indicates the left upper corner, {1;1} the lower right corner of the screen. Each value has four decimal places. These float values are send as an xml string (e.g. "<M><T>1235480202</T><A><x>0.5432</x><y>0.9</y></A></M>") via a TCP-connection between dedicated hosts and on defined ports. This string will be send with the frequency of measurements of 60 Hz.

8.4 Automation Level

The automation level (not equal to any "Level of Automation" in the literature) is given by an integer value. An automation level will be assigned to each vigilance level. A fixed set of adaption modes will be defined for each level. In order to not confuse an operator, an automation level (L) needs to be active for at least 5 minutes until switching to another automation level. However, 5 minutes after the last change of an automation level, the level directly switches to the automation level assigned to the currently measured vigilance level ignoring older inputs without influence.

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9 Conclusive remarks

In this document, a clear presentation of the task environment used in MINIMA is proposed and the identification of the different characteristics of this environment is defined. Technical implementation of this environment is detailed.

We also present different solutions for attention guidance (Sequence optimization, Sector Size modulation, Separation conflict anticipation, Radio communication, Advisories, and additional information). Amongst other, we identify real tasks and define artificial tasks that can be assigned to the human operator to increase his engagement in the monitoring task. Different kinds of attention guidance support, which may highlight certain aspects in the tasks environment dynamically to guide the attention of the operator, are also proposed. Each of these mechanisms is assessed regarding the expected influence on the ATCO and its potential to help with the reduction of situation awareness and to mitigate other problems triggered by highly automated workplace and regarding the effort required to implement this mechanism in the simulation environment. Based on that, recommendations for implementation are given.

An important part of the document is also dedicated to the presentation of the Vigilance and Attention Measurement. Vigilance and attention decrement is identified as one of the main sources of the performance decrements observed in OOTL phenomenon. In this document, we propose solution to track change in vigilance and attention based on physiological markers. The presented findings suggest that it is possible to obtain robust indices on vigilance and sustained attention state using physiological measures. However, if several biopsychometrics are presented as sensitive to changes in vigilance and sustained attention suggesting them as potential candidates for triggering adaptive automation, not all of these measures appear as relevant regarding MINIMA constraints. Regarding potential benefits of each technique, we propose to use EEG (and particularly change in power spectrum density) to provide a measure of Vigilance whilst Eye Tracking is proposed to provide information about Visual Attention. Procedure for implementing this Vigilance & Attention Observer is also detailed. Particularly, the different steps of the EEG signal processing are identified and described: (1) EEG acquisition and amplifying, (2) Data preprocessing, (3) Feature extraction, and (4) Pattern Classification.

This document represents an important step for the MINIMA project and will be used as a base for the implementation phase. It presents in detail the different elements of the MINIMA concept, how to implement, and make relation between these different components.

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11 Requirements Overview

The following table includes all requirements identified in this document

Identifier	Requirement
REQ-MINIMA-TS-04035-0010	The ATCO's User Interface (Radar screen) shall support mouse commands
REQ-MINIMA-TS-04035-0020	The Speech Communication between ATCO's and Pilots shall be simulated
REQ-MINIMA-TS-04035-0030	Simulation Pilots (Pseudo-pilots) shall have the possibility to enter commands into the simulation
REQ-MINIMA-TS-04045-0010	The eye tracking system shall be available.
REQ-MINIMA-TS-04045-0020	The eye tracking system shall be calibrated for the environment in which the experiment is conducted.
REQ-MINIMA-TS-04045-0040	The normative model of monitoring behaviour shall identify areas that require attention
REQ-MINIMA-TS-04045-0050	The normative model shall combine the live eye movement data and simulated traffic data and identify the areas that are not monitored enough.
REQ-MINIMA-TS-04045-0060	The normative model shall have an interface with the eye tracking system, the radar display and the radar simulation.
REQ-MINIMA-TS-04045-0070	Dependent on the vigilance level of the ATCO, the radar display shall select the corresponding salience level.
REQ-MINIMA-TS-04045-0080	The radar display shall have a low salience mode and present the areas delivered by the normative model as text
REQ-MINIMA-TS-04045-0090	The radar display shall have a high salience mode and visually highlighted the areas delivered by the normative model.
REQ-MINIMA-TS-04055-0010	The simulator software should predict future aircraft position and detect potential conflicts based on these positions.
REQ-MINIMA-TS-04055-0020	The Interfaces with the radar display should allow the transmission of potential separation conflicts.
REQ-MINIMA-TS-04055-0030	The radar display should visually highlight potential separation conflicts.
REQ-MINIMA-TS-04065-0010	The simulator software shall evaluate the situation and detect current separation conflicts and close aircraft

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REQ-MINIMA-TS-04065-0020	The simulator software shall evaluate the situation and detect deviations from the route
REQ-MINIMA-TS-04065-0030	The simulator software shall evaluate the situation and detect violations of altitude restrictions
REQ-MINIMA-TS-04065-0040	The Interfaces with the radar display shall allow the transmission of conflicts and close aircraft.
REQ-MINIMA-TS-04065-0050	The radar display shall visually highlight current conflicts and close aircraft
REQ-MINIMA-TS-04075-0010	The simulator software shall evaluate the situation and detect deviations of agreed from actual times
REQ-MINIMA-TS-04075-0020	The Interfaces with the radar display shall allow the transmission of target times and deviations.
REQ-MINIMA-TS-04075-0030	The radar display shall show target times and highlight deviations
REQ-MINIMA-TS-04085-0010	The CSR should be adaptable during simulation (switch it on and off)
REQ-MINIMA-TS-04095-0010	An Advisory-System may extract Advisories form Trajectories
REQ-MINIMA-TS-04095-0020	If the corresponding mode is active, the ATCo may have the possibility to veto an Advisory
REQ-MINIMA-TS-04095-0030	If the corresponding mode is active, the ATCo may have the possibility to confirm an Advisory
REQ-MINIMA-TS-04095-0040	It may be possible to change the mode of the Advisory-System during simulation
REQ-MINIMA-TS-04105-0010	The AMAN may process input from the simulation but also from the ATCO.
REQ-MINIMA-TS-04105-0020	The Interfaces with the radar display may allow the transmission of sequence.
REQ-MINIMA-TS-04105-0030	The AMAN may be able to switch between the different modes of sequence generation during simulation
REQ-MINIMA-TS-04105-0040	The radar display may visually present the AMAN sequence.
REQ-MINIMA-TS-04105-0050	The radar display may visually present the request from the airlines fitting to the current arrival sequence.
REQ-MINIMA-TS-04105-0060	The radar display may allow the ATCO to change the current AMAN sequence.
REQ-MINIMA-TS-04115-0010	The radar display may visually present additional information, e.g. in a sub menu of the label, that can be requested by pilots
REQ-MINIMA-TS-04115-0020	A list of pilot requests may be available for each scenario
REQ-MINIMA-TS-04115-0030	Information that can be requested may be defined for all aircraft in each scenario
REQ-MINIMA-TS-04115-0040	Participants may to be trained to find the requested information on their screen
REQ-MINIMA-TS-04125-0010	The position where aircraft are handed over from adjacent sectors may

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	be adaptable
REQ-MINIMA-TS-04125-0020	The responsibility for the runways may be adaptable
REQ-MINIMA-TS-04125-0030	The simulated traffic NOT controlled by the participant of the simulation may be controlled (either by automation or manually)
REQ-MINIMA-TS-04135-0010	A Question-Module shall be able to show questions and offer the possibility to reply to the questions
REQ-MINIMA-TS-04135-0020	A Question-Module shall generates relevant questions during simulation
REQ-MINIMA-TS-04135-0030	A Question-Module shall activate questions based on the vigilance level of the ATCO

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