# Final Project Results Report


| | |
|---|---|
| Deliverable ID: | [D5.2] |
| Dissemination Level: | [PU] |
| Project Acronym: | [MINIMA] |
| Grant: | [699282] |
| Call: | [H2020-SESAR-2015-1] |
| Topic: | [Automation in ATM] |
| Consortium Coordinator: | [DLR] |
| Edition date: | [11 May 2018] |
| Edition: | [00.02.00] |
| Template Edition: | 02.00.02 |

## Authoring & Approval

### Authors of the document

| Name/Beneficiary | Position/Title | Date |
|---|---|---|
| **Jan Kraemer JK/DLR** | Project Coordinator | 2018-03-05 |
| **Francesca De Crescenzio FC/UNIBO** | WP3 Lead | 2018-03-27 |
| **Bruno Berberian BB/ONERA** | WP1 Lead | 2018-03-27 |
| **Oliver Ohneiser OO/DLR** | WP2 Lead, Project Coordinator Alternate | 2018-03-25 |
| **Gianluca Di Flumeri GDF/BS** | Third Party | 2018-03-28 |

### Reviewers internal to the project

| Name/Beneficiary | Position/Title | Date |
|---|---|---|
| Marcus Biella MB/DLR | Reviewer | 2018-03-12 |
| Oliver Ohneiser OO/DLR | WP2 Lead | 2018-03-12 |
| Jürgen Rataj JR/DLR | Reviewer | 2018-03-28 |

### Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

| Name/Beneficiary | Position/Title | Date |
|---|---|---|
| Jan Kraemer JK/DLR | Project Coordinator | 2018-05-07 |
| Oliver Ohneiser OO/DLR | WP2 Lead | 2018-05-08 |
| Francesca De Crescenzio FC/UNIBO | WP3 Lead | 2018-05-11 |
| Bruno Berberian BB/ONERA | WP1 Lead | 2018-05-09 |
| Gianluca Di Flumeri GDF/BS | Third Party | 2018-05-10 |

### Rejected By - Representatives of beneficiaries involved in the project

| Name/Beneficiary | Position/Title | Date |
|---|---|---|
| | | |
| | | |



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

## Document History

| Edition | Date | Status | Author | Justification |
|---|---|---|---|---|
| 00.00.01 | 05 March 2018 | draft | JK | First draft |
| 00.00.02 | 13 March 2018 | draft | JK | - WP3 description added<br>- Maturity Assessment added |
| 00.00.03 | 15 March 2018 | draft | OO | - Complete review<br>- Started Glossary |
| 00.00.04 | 16 March 2018 | draft | JK | - Completed 2.3 (Work Performed)<br>- Started Chapter 4 |
| 00.00.05 | 16 March 2018 | draft | OO | - Review of chapter 2<br>- Glossary completed |
| 00.00.06 | 27 March 2018 | draft | FC | - WP4 description added<br>- Chapter 4 Completed |
| 00.00.07 | 28 March 2018 | draft | OO | - Chapter 4.3 added<br>- Complete review |
| 00.00.08 | 28 March 2018 | draft | GDF/BB/FC | - Completion of 2.1 & 2.4.<br>- Complete Review |
| 00.01.00 | 29 March 2018 | final | JK | Final Review |
| 00.01.01 | 20 April 2018 | draft | JK, JR, MB | - added "(Edition 2015)" to ATM Master Plan reference (#24)<br>- removed ref. #26 (Consortium Agreement)<br>- Rephrased sec 3.1<br>- Removed count of "achieved" criteria from section 3.2 |
| 00.01.01 | 30 April 2018 | draft | GDF | - Complete review<br>- Additions to 4.3 |
| 00.01.02 | 07 May 2018 | draft | FC | - Complete review |
| 00.01.03 | 07 May 2018 | draft | JK | - Complete review<br>- Changes to Maturity Assessment<br>- Inserted section on planned publications (5.2.1) |
| 00.01.04 | 08 May 2018 | draft | BB | Complete review |



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

| | | | | |
|---|---|---|---|---|
| 00.02.00 | 11 May 2018 | final | OO | Final version for resubmission |

## Copyright Statement

© - 2018 – German Aerospace Center (DLR), Università di Bologna (UNIBO), Office National d'Études et de Recherches Aérospatiales (ONERA), BrainSigns (BS). All rights reserved. Licensed to the SESAR Joint Undertaking under conditions.

# [MINIMA]

[MITIGATING NEGATIVE IMPACTS OF MONITORING HIGH LEVELS OF AUTOMATION]

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699282[25] under European Union's Horizon 2020 research and innovation programme.

## Abstract

An increase of automation in air traffic control (ATC) can have negative effects on the air traffic controllers' (ATCo) performance. The effects are known as out-of-the-loop (OOTL) phenomenon. The MINIMA Project developed a Vigilance and Attention Controller (VAC) to mitigate these effects. A highly automated arrival management task served as a case study. Psychophysiological measurements were used to identify the state of the ATCo and combined with adaptive task activation. This allowed for activating tasks based on the ATCos' mental state to keep their performance on a high level and to ensure safe operations at all times.

This *Final Project Results Report* (D5.2) gives evidence on the overall MINIMA project with respect to the work done from 01 May 2015 to 30 April 2018. It includes reports about the work done in each of the work packages, the outcome of the project's empirical evaluation study, and its further impact on ATM research in general.



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

# Table of Contents





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

# List of Tables





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

# 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 was to improve our comprehension of the OOTL performance problem especially according to a future air traffic scenario. Further, MINIMA developed 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 Manoeuvring Area (TMA).

## 1.2 Description of Work

This deliverable serves as a general overview of the MINIMA project in total. As such, it serves as starting point for interested stakeholders to get an insight into the project. MINIMA is a collaborative project executed by the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt e. V.; DLR), the University of Bologna (Università di Bologna; UNIBO), and the French National Aerospace Research Centre (Office National d''Etudes et de Recherches Aérospatiales; ONERA). BrainSigns (BS) cooperated as a third-party. MINIMA began on 1st May 2016 and will end after April 2018. Whoever may find interest in MINIMA may refer to the Deliverables reported herein (see section 2.5).

First, an overview of the project is given. This overview includes MINIMA's operational/technical context, its scope and objectives, the work performed in each of the work packages (WP) and the key project results achieved through that. The overview concludes with a list of the technical Deliverables to which interested stakeholders may refer afterwards.


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

# 2 Project Overview

## 2.1 Operational/Technical Context

Over the past few years the global air traffic growth has exhibited a fairly stable positive trend. Further, according to the 'Free Flight' and the '4D Trajectory Management' concepts, different types of aircraft, such as manned, unmanned, and autonomous aircraft, as well as all kinds of rotorcrafts, will operate simultaneously in a 'structure-less' and 'time based' environment allowing for much more direct and continuous trajectories to be used. Also, brand new airspace designs, possibly dynamic, may be required. Within this picture, traffic flow patterns will become more complex, making conflicts and situations harder to identify for a human operator, putting immense pressure on the air traffic control system. To meet the demands for enhanced capacity, efficiency, and safety, several solutions have been proposed. As envisaged by both SESAR JU and HALA! Research Network, higher levels of automation will help ATCos to deal with increasingly complex airspace scenarios, enabling them to manage complex situations in a safe and efficient way. While high levels of automation will reduce human operator workload and increase the level of productivity, increasing the automation of Air Traffic Management (ATM) will also result in new roles for ATCos. As a matter of fact, the role of the ATCo will tend to evolve from active managing of aircraft to passive monitoring. They will mainly monitor highly automated system and only intervene if an aircraft deviates from its scheduled plan.

Such change (from manual to supervisory control) is far from trivial as empirical data suggest that traditional automation has many potential negative outcomes and safety consequences associated with it stemming from the human Out-of-the-Loop (OOTL) performance problem. As a major consequence, the OOTL performance problem leaves operators of automated systems handicapped in their ability to take over manual operations in the case of automation failure. Particularly, the OOTL performance problem causes a set of difficulties including a longer latency to determine what has failed, to decide if an intervention is necessary and to find the adequate course of action. This so called OOTL performance problem represents a key challenge for both systems designers and human factors society. However, after decades of research, this phenomenon remains difficult to grasp and treat. In the following section, we aim to provide a better understanding of this crucial phenomenon.

## 2.2 Project Scope and Objectives

The general objective of this research project was to improve the comprehension of the Out-of-the-loop (OOTL) performance problem with respect to future air traffic scenarios. Furthermore, MINIMA aimed to develop tools capable of (1) detecting the negative impact of OOTL and (2) compensating for them through a carefully selected distribution of tasks between the human agent and the automated system. A highly automated Terminal Manoeuvring Area (TMA) was selected as the use case. Specific tools and a reasonable task distribution were used to exploit performance increases resulting from higher levels of automation while keeping the ATCo vigilance on a high level to ensure safe and secure operations. MINIMA developed a dynamic task allocation which is considered as a major requirement to keep the human operator 'in-the-loop', i.e. properly aware of the traffic situation. Thus, it is a core aspect of the MINIMA concept



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

that not all tasks, which could be automated, are automated at all times. Together with this function allocation approach, designing more cooperative artificial agents is also considered as a major requirement to avoid the OOTL performance problem. In this sense, the MINIMA project has identified the minimal information required to be provided to operators to support the coordination between human operators and automation. A real-time vigilance monitoring system was developed in MINIMA to trigger the adaptive automation. Finally a new set of procedures was developed to cope with the new and dynamic task distribution and, most importantly, with possible automation failures or the misinterpretation of the situation by the system. These fall-back procedures are crucial as higher levels of automation will go along with procedures that cannot be followed by operators without the support of automation even when they are kept in the loop.

## 2.3 Work Performed

Work carried out in MINIMA was split into six WPs of which the first four WPs covered the scientific work from exploration to dissemination. The two remaining WPs covered project management issues (WP5) and Ethics Requirements (WP6). In this section, a summary of each WP along with references to their respective deliverables is given. An overview of all deliverables is presented in Table 1: Project Deliverables. A GANTT chart visualising all tasks and their temporal relations can be found in chapter 4 of D5.1 (*Project Management Plan*).

### 2.3.1 WP1: Review and Concept Development

WP1 comprised two tasks: *Review State of the Art* (T1.1) and *Concept Development for Vigilance and Attention Controller (VAC) in Highly Automated TMA* (T1.2). Results of both tasks were reported in one deliverable each (*State of the Art Report*[1], D1.1; *Concept Description*[2], D1.2).

#### 2.3.1.1 T1.1: Review State of the Art

Reviewing the state of the art refers to the extensive literature review done at the beginning of MINIMA. The review aimed to provide a clear picture of three key aspects. First, how the OOTL phenomenon can be characterised. Second, what measures have already been developed and/or applied to detect and compensate the OOTL phenomenon. Finally, physiological markers which are potentially related to OOTL occurrences were identified.

The results of T1.1 are documented in D1.1[1] (*State of the Art Report)*. It was found that decrements in human operators' vigilance and attention are one of the main sources of performance losses associated with OOTL occurrences. Hence, it was concluded that such decrements can be utilised as indicators to predict ATCos getting OOTL. Out of different possible approaches to assess vigilance and attention data presented in D1.1[1] (*State of the Art Report*), neurophysiological methods were identified as the most robust ones. Out of the potentially interesting methods, electroencephalography (EEG) and oculometric measures were later selected for implementation (see D1.2 *Concept Development*[2]).

#### 2.3.1.2 T1.2: Concept Development

During T1.2, the MINIMA concept was developed based on the results of T1.1 (*Review State of the Art*). This concept based on two key aspects. First, to assess robust and valid data on the operator's mental state in terms of vigilance and attention. Second, to identify feasible ways to guide the



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

operator's attention through means of adaptive automation to keep vigilance (and therefore attention) on a high level at all times.

The results of T1.2 are documented in D1.2[2] (*Concept Description*). Therein, the proposed ways to realise the two main aspects of the MINIMA concept are reported. EEG was proposed to assess objective vigilance data online, i.e. in parallel with the main task carried out by the ATCOs. D1.2[2] (*Concept Description*) contains detailed information on EEG assessment, including (1) EEG acquisition and amplifying, (2) data pre-processing, (3) feature extraction and (4) pattern classification. Visual attention was proposed to be assessed through an eye tracking system aimed to record data on ATCos' monitoring behaviour.

Attention guidance was proposed to be realised through different technical solutions along with recommendations for their implementation. Together with subject matter experts, during 1st Advisory Board Meeting at the SESAR Innovation Days 2016, 11 different solutions were elaborated along with 43 requirements. The former can be roughly grouped into (1) artificial tasks assigned to the human operator, and (2) an attention guidance support system which would highlight certain aspects of the *Task Environment*[4] (D2.2). Out of these 11 proposed solutions, nine would later be realised in the finalised *Task Environment*[4] (D2.2).

The work carried out in WP1 was the first important step towards MINIMA's objective to keep ATCOs in-the-loop in highly-automated task environments. The extensive literature review ensured that the MINIMA concept would base on the most recent scientific insights on that topic. Furthermore, development of the MINIMA concept was the starting point of the technical implementation carried out during WP2 (*Implementation*).

### 2.3.2 WP2: Implementation

WP2 comprised three tasks: *Implementation of Vigilance and Attention Controller* (T2.1), *Implementation of Task Environment* (T2.2), and *Implementation of Adaptive Task and Support Activation and Integration of Vigilance and Attention Controller* (T2.3). Results of these tasks were reported in two deliverables (*Vigilance and Attention Controller*[3], D2.1; *Task Environment*[4], D2.2). All work done in WP2 based on the results of WP1 (*Review and Concept Development*).

#### 2.3.2.1 T2.1: Implementation of Vigilance and Attention Controller

Implementation of the VAC required development of two sub systems: the EEG-based *Vigilance Observer* developed by BrainSigns and the Attention Controller developed by DLR. The latter comprises two sub-components: first, an eye tracking system used to record ATCos' visual attention through their monitoring behaviour during an ATC task. Second, the attention guidance solutions developed within T1.2 (*Concept Development*).

Results of T2.1 are documented in D2.1[3] (*Vigilance and Attention Controller*). Vigilance observance was implemented using the EEG-based *BrainSigns Recorder*, a system capable of assessing and processing EEG data, and extracting vigilance-specific EEG features. Using those features, the *BrainSigns Recorder* produced a real-time index representing the respective subject's current vigilance level. This index triggered the adaptive automation within the *Task Environment* (D2.2[4]).

Visual attention was assessed using the Tobii EyeX Controller, a touchless eye tracking system attached to a common PC monitor. A normative model of attention guidance for ATCos was developed to provide a reference for the interpretation of gazing behaviour. It based on three premises. First, gaze area equals focus of visual attention and therefore represents which part of the


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

TMA is actively processed. Second, need for (controller) attention correlates with dynamic traffic activity. More precisely, areas with high traffic density must be monitored more actively and frequently. Finally, a collision prevention rule was implemented, stating that an aircraft should be attended "each 1.5 Nautical Miles".

#### 2.3.2.2 T2.2: Implementation of Task Environment

The *Task Environment*[4] (D2.2) developed for MINIMA consists of a TMA approach traffic simulation. The simulated TMA was similar to that of Munich airport's with two parallel runways. Furthermore, the TMA consisted of five arrival sectors and two late merging points. High traffic load was simulated at an arrival-to-departure-ratio of 60:40. Aircraft trajectories were planned through a software-based Arrival Manager (AMAN[28]). Several components connected through a common MySQL database took over different aspects of the simulation environment. More detailed information on the technical components have been reported in D2.2[4] (*Task Environment*).

#### 2.3.2.3 T2.3: Implementation of Adaptive Task and Support Activation and Integration of Vigilance and Attention Controller

Implementation of the attention guidance solutions was done through newly developed features for the RadarVision[27] (RV) display, the Human-Machine-Interface (HMI) used within the *Task Environment*[4] (D2.2). For instance, using visual attention data assessed through the eye tracking system, aircraft unattended by the ATCo within his/her TMA could be visually highlighted to draw attention to them. This solution implemented the third premise of the normative model described in section 2.3.2.1. Detailed descriptions of each of the nine attention guidance solutions are given in chapter 4 of D2.2[4] (*Task Environment*). Integration of the *Vigilance and Attention Controller*[3] (D2.1), and the *Task Environment*[4] (D2.2) was realised through a network interface. The vigilance index determined by the vigilance observer was sent to the Task Environment's MySQL database every 30 seconds, making the vigilance index available to the adaptive automation system as a trigger.

### 2.3.3 WP3: Evaluation

WP3 comprised four tasks: *Implementation of Evaluation Plan* (T3.1), *Preparation of Test Scenarios* (T3.2), *Conduction of Study* (T3.3), and *Analysis of Study and Overall Evaluation* (T3.4). Results of these tasks were reported in two deliverables (*Evaluation Plan*[5], D3.1; *Evaluation Results*[6], D3.2).

#### 2.3.3.1 T3.1: Implementation of Evaluation Plan

Naturally, the *Evaluation Plan*[5] (D3.1) was designed to allow for a standardised examination of (1) the impact of passively monitoring a TMA with a high-level of automation on controller vigilance and (2) the *Vigilance and Attention Controller's*[3] (D2.1) utility to mitigate the expected decrease in controller vigilance. As the *Task Environment*[4] (D2.2) and the *VAC*[3] (D2.1) required expertise in ATC, it was necessary to recruit expert subjects and thus professional ATCos. It was decided to have 15 subjects to compromise with demands on sample sizes and available resources.

Two experimental conditions were set up to examine both questions: (1) A BASELINE condition in which subjects would monitor the TMA while the *Task Environment* (*TE*[4]) (D2.2) would be set to a constantly high level of automation. The lack of involvement was expected to cause a continuous decrease of controller vigilance over time. Such decrease serves as an indicator of impending OOTL occurrences. (2) A SOLUTION scenario in which the *VAC*[3] (D2.1) would be used to dynamically adapt the *TE's*[4] (D2.2) automation level based on controller vigilance as assessed through the Vigilance


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

Observer. It was expected that decreases in vigilance, if any, would be mitigated through the *VAC*[3] (D2.1). In addition to the experimental condition, it was decided to let subjects familiarise with the system through a dedicated TRAINING session prior to the actual experimental session. Finally, individual EEG REFERENCE data for each subject would be recorded prior to the experimental session.

The experiment followed a within-subject-design. This way, subjects would directly experience the differences in the *TE*[4] (D2.2) triggered through the automation level. Furthermore, as each subject completed each experimental condition, data on both the vigilance decrease and its mitigation through the *VAC*[3] (D2.1) could be collected from all subjects. To control for training effects, the order of both conditions was randomised.

In addition to the objective measures, subjective measures were included in the *Evaluation Plan*[5] (D3.1) to get an insight into how subjects would perceive the differences between BASELINE and SOLUTION. Thus, questionnaires were used to measure Workload (NASA Task Load Index, NASA-TLX [29]) and Mind Wandering (Dundee Stress Test Questionnaires, DSSQ[30]).

#### 2.3.3.2 T3.2: Preparation of Test Scenarios

The four scenarios described above (section 2.3.3.1) were prepared in time for the Technical Integration Meetings, necessary calibration experiments for the *Vigilance Observer*, pre-tests and the *Evaluation Study* (T3.3).

All scenarios were designed to be comparable with each other in terms of TMA layout or traffic intensity. Changes were made to aircraft call signs and the direction from which they entered the TMA. This way, subjects were encountered with different traffic in each scenario.

The BASELINE and SOLUTION scenarios each lasted 45 minutes. While during the former the *TE's*[4] (D2.2) automation level was set to the highest level at all times, automation level was adapted, i.e. decreased or increased, based on controllers' current level of vigilance during the latter. During the TRAINING scenario (45 minutes), the automation level was manually changed from "High" to "Low" and "High" again (15 minutes each) to familiarise subjects with the adaptive automation solutions implemented into the *TE*. Finally, during the EEG REFERENCE scenario (15 minutes), a high level of vigilance was induced by asking standardised questions to subjects during the first five minutes. After that, subjects were left with monitoring the TMA for ten minutes, therefore inducing a low level of vigilance. This data was used to calibrate the EEG based *Vigilance Observer* individually for each subject.

#### 2.3.3.3 T3.3: Conduction of Study

The *Evaluation Study* (T3.3) was conducted at UNIBO's Virtual Reality Laboratory in Forlì, Italy from 06 – 17 November, 2017. Fifteen professional ATCOs from ENAV voluntarily participated in the experiments.

Each subject completed the experiment in two days in separate sessions. On the first day – the Training Session – subjects were briefed about the study's general procedure (but not its purpose). Then, they were introduced with the experimental setup and the *TE*[4] (D2.2) in particular through a standardised procedure. After that, they completed the TRAINING scenario (see section 2.3.3.2 above). The first day of the experiment was closed by a debriefing.

The second day – Experimental Session – started with another short briefing to clarify potential questions and address any doubts. After, the EEG and the Tobii EyeX system were installed and


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

calibrated. Following that, first the EEG REFERENCE scenario was completed. Then, the BASELINE and SOLUTION scenarios have been performed in randomised order. Finally, subjects completed the NASA TLX and DSSQ questionnaires. The Experimental Session was closed by a debriefing during which the *Evaluation Study*'s (T3.3) purpose was revealed to the subjects.

#### 2.3.3.4 T3.4: Analysis of Study and Overall Evaluation

Using the data collected during the *Evaluation Study* (T3.3), it was examined if (1) the expected continuous vigilance decrease did occur during the BASELINE scenario in which task involvement was constantly low, and (2) if the *VAC*[3] (D2.1) used during the SOLUTION scenario was capable of mitigating this decrease. Furthermore, it was examined if differences in monitoring behaviour and performance could be found between scenarios and vigilance levels. Finally, the questionnaire data was used to analyse Workload and Mind Wandering differences in both scenarios.

The results of these analyses have been reported in the *Evaluation Results*[6] (D3.2). To summarise, the following could be shown from the results: (1) Controller vigilance did indeed decrease when the *TE*[4] (D2.2) was operating on a high level of automation in both experimental scenarios. (2) If no change to the automation level was made, vigilance continuously decreased. (3) Using the *VAC*[3] (D2.1) to lower the automation level during periods of low controller's vigilance, the vigilance decrease was reversed, e.g. controllers showed higher levels of vigilance. (3) Usage of the *VAC*[3] (D2.1) caused controllers to recognise incoming aircraft earlier and to more carefully process information. (4) Regarding their workload, controllers reported their task to be more demanding and effortful in the SOLUTION scenario as they were more actively involved with it. At the same time, they reported it to be less frustrating and easier to achieve good performance in. Finally, mind wandering results show that controllers were less likely to get distracted or think about other things unrelated to their task.

These results show that the *VAC*[3] (D2.1) developed within MINIMA is capable of fulfilling its objective, namely to mitigate the negative impacts of monitoring high levels of automation. Not only did neurophysiological data show controllers to be more vigilant when working with the *VAC*[3] (D2.1), but eye tracking data show that this activation resulted in more careful monitoring of the TMA. Also, the subjective measures show better controller ratings of workload and mind wandering when the *VAC*[3] (D2.1) was used.

### 2.3.4 WP4: Dissemination

WP4 comprised one task: *Dissemination and Exploitation* (T4.1). Dissemination activities have been planned and documented in one deliverable, the *Dissemination Plan*[7] (D4.1). In total, eight publications were produced and/or presented at the relative Conferences during MINIMA, not including deliverables. All publications other than the deliverables are listed in section 5.2.

A dedicated website was installed for the MINIMA project as an additional dissemination channel (http://www.minima-project.eu[22]). On this website, information on important events and activities was published. The link to the homepage was included in all MINIMA publications. All publishable deliverables of MINIMA are available on this website.

In addition to the scientific publications listed in section 5.2, a number of periodic newsletters have been published to keep interested stakeholders updated on MINIMA's progress. Newsletters included reports on important activities, upcoming events and publications. In total, four such newsletters were published. They were send directly to interested stakeholders and published on the MINIMA website[22].


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

Moreover, the MINIMA project team has organised two Advisory Board Meetings. In these meetings, the MINIMA team met with subject matter experts to present their work and receive feedback on how to progress with project and exploit its outcomes. The first meeting was held during the SESAR Innovation Days in November 2016. During this meeting, attendees provided crucial input on the MINIMA concept and the automation solutions to implement in particular. The second meeting was held during the World ATM Congress in March 2018. During this meeting, the MINIMA concept and the outcome of its evaluation were presented to the attendees. This meeting aimed to collect feedback on (1) to which extent MINIMA aimed to achieve its objectives, and (2) possible areas of exploitation and their significance to future research.

Finally, coordination activities with other SESAR projects dealing with automation have been conducted. On **March 9th 2017** MINIMA has been presented at the Workshop: **SESAR 2020 Exploratory Research: Human Factors supporting Automation in ATM**. Several SESAR 2020 Exploratory Research dealing with Human factors in automation (AUTOPACE, STRESS, MINIMA, TaCo, AGENT, RETINA, MOTO and PACAS) discussed together on the commonalities and on the challenges on this topic. In addition, a transversal working group with members from MINIMA, from AUTOPACE and from STRESS has been working on a shared document on commonalities, complementarities and exploitation opportunities among these three projects.

### 2.3.5 WP5: Management

WP5 comprised one task: *Project Management and Coordination* (T5.1). Two deliverables were prepared for this WP (*Project Management Plan*[8], D5.1; *Final Project Results Report*, D5.2). In addition, four biannual Periodic Reports (PR) were prepared in which the work carried out in each WP during each period were documented along with additional information, e. g. resources spent and dissemination activities. Note that the fourth PR will not have been completed before May 2018.

### 2.3.6 WP6: Ethics Requirements

WP6 did not explicitly comprise a task. Work carried out in this WP included everything necessary to receive an Ethics Approval required for the *Evaluation Study* (T3.3) to be conducted. Six Ethics requirements were identified, encompassing two main aspects: Humans (i.e. subject recruitment) and Protection of Personal Data (POPD). The means taken to ensure that each of these requirements were met have been documented in six deliverables (D6.1[9] to D6.6[14]), each dedicated to one of the Ethics Requirements (2x Humans, 4x POPD; see Table 1: Project Deliverables for details). Finally, an Ethical Approval was requested from UNIBO's Bioethics Committee (Comitato di Bioetica) and granted by the same by the end of May 2017.

## 2.4 Key Project Results

MINIMA has achieved three key results during its two years of work: (1) characterisation, of the OOTL phenomenon and identification of actions to compensate it, (2) development of tools for online detection of vigilance decrease and mitigation of the OOTL phenomenon, and (3) validation of the developed tools in a high-fidelity environment.



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

### 2.4.1 OOTL characterization, detection and compensation

First, the OOTL performance problem, its characteristics, and its significance in terms of safety and operability in highly automated work environments have thoroughly been elaborated and documented in the *State of the Art Report*[1] (D1.1). It was shown what comprises the OOTL problem, what causes it and how it negatively affects human operator performance and therefore safety. Further, several biopsychometrics sensitive to changes in vigilance/sustained attention were identified, making them potential candidates for triggering adaptive automation. Finally, currently applied solutions used to compensate this degraded state were identified.

Based on the literature review, the vigilance/attention decrement was identified as one of the main sources of the performance decrements observed in OOTL phenomenon. It was concluded that current vigilance and attention levels of the human operator could be used as a measure of the OOTL phenomenon. Further, it was decided to use EEG (power spectrum density) and oculometrics measures as physiological markers of decrease in vigilance. Finally, adaptive automation has been assumed as the most relevant solution to compensate the OOTL phenomenon (D1.2[2]).

### 2.4.2 – Development and implementation of Tools for OOTL measurement and mitigation

Second, an effective tool to mitigate the OOTL was conceptualised based on the *State of the Art Report*[1] (D1.1). This tool developed has been called the *VAC*[3] (D2.1). It aims to keep human operators in-the-loop through adaptive automation based on neurophysiological data.

First, a *Task Environment* (*TE*, D2.2[4]) was developed to explore the impact of automation on ATCo performance and the relevance of the tools developed. This TE integrates various processing modules to provide a high-fidelity real-time simulation of expected future air traffic control scenarios. An AMAN was used for trajectory planning within high-density traffic scenarios in a generic TMA. Trajectory planning was optimised for safe and efficient traffic flow, reducing potential violations against any safety regulations to a minimum. With RadarVision, the TE contains a high-end human-machine-interface for controller working positions, which is also highly adaptable.

Then, the *VAC*[3] (D2.1) was developed. The *VAC* integrates two different modules: an EEG based *Vigilance Observer* to assess objective vigilance data in real-time and, based on its results, trigger adaptive automation solutions to keep vigilance (and therefore attention) at an adequate level at all times.

The vigilance observer aims to propose a solution to track changes in vigilance and attention based on physiological markers. Particularly, Power Spectral Densities (PSD) extracted from the EEG signal were used as an informative feature. The Vigilance Observer encompasses four functions: EEG acquisition and amplifying, noise and artefact elimination, feature extraction and pattern classification algorithms. To perform online classification of the ATCo mental state, the BrainSigns Recorder was used, a piece of software developed by BrainSigns. It allows recording, processing and visualisation of bio signals, in particular EEG. Moreover, the computation and online classification of neuro indexes of the investigated mental state and its dispatching (i.e. the online index) through a specific network protocol (TCP/IP) are also implemented (see D2.1[3] for more details).



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

Further, an adaptive task and support activation module was developed. This module enabled the modification of both the level of automation and the feedback sent by the automation technology. This aimed to serve ATCos to remain in the loop of control and improve their performance in a monitoring task. Several adaptations were developed and implemented from adaptation of sector size to attention guidance to separation conflicts or to actual trajectory deviations and losses of separation. Additional features implemented into the module included, sequence optimisation, a visualised Centerline separation range, and provision of additional information to increase service or advisories. Amongst other, real and artificial tasks were selected which can be (re-)assigned to the human operators to increase their engagement in the monitoring task. Also, an innovative concept of attention guidance support was developed, which highlighted unattained aircraft within the TMA to guide the operator attention. These different adaptations were identified and specified with the cooperation of subject matter experts. The different adaptation proposed and their specifications are described in detail in D2.2[4].

### 2.4.3 MINIMA's tool Evaluation

Third, through an E*valuation Study* (T3.3) with 15 professional ATCos, it was examined how the tools developed for MINIMA fit with its initial objectives. This evaluation showed that the *VAC*[3] (D2.1) was actually capable of mitigating decreases in controller vigilance caused by lack of involvement by adjusting the level of automation accordingly (see D3.2 *Evaluation Results*[6]). This included a data-based demonstration of (1) vigilance decrease when controllers were not actively involved in the task, and (2) how such decrease could successfully be mitigated through the *VAC*[3] (D2.1).

Particularly, EEG data indicated that vigilance decreased over time when controllers were not actively involved in the task. This supports the hypothesis on the impact of high automation levels on controller vigilance. Interestingly, the results indicated that the *VAC* tool successfully mitigated this negative impact of automation. First, it was observed that *VAC* tool moderated the decreasing trend, indicating that it worked as intended. Second, the results in terms of scenario time percentage classified as "Low vigilance" supported these conclusions since EEG data showed that overall vigilance was higher when the *VAC* was used. This result indicates that the *VAC* effectively reacted to a "Low vigilance" state occurrence, re-increasing the ATCo's vigilance level. In other words, adaptive automation helped to keep the ATCo In-the-Loop.

These EEG data were corroborated by controller monitoring behaviour. Indeed, oculometric measure indicates that the *VAC* induced a more active monitoring behaviour of controllers. Although general gaze behaviour was equal among scenarios and vigilance levels, Tim-to-First-Fixation and frequency of fixations were found to be lower during the SOLUTION scenario. Therefore, incoming aircraft were recognised earlier and controllers more carefully processed information during fixations. This is consistent with the higher average level of vigilance as shown by the EEG results. Therefore, the eye-tracking data show that the neurophysiological reactions to lack of involvement also result in observable changes in controller behaviour.

In addition to the objective measures, subjective ratings on Workload and Mind Wandering given by subjects showed that the higher activation was also consciously perceived by the subjects. Particularly, using NASA TLX questionnaire, we observe that controllers found the task to be more demanding and effortful when using the VAC system. Interestingly, they also perceived the system as less frustrating and their performance as better, which are promising results in favour of the MINIMA concept. Finally, controllers reported to be less distracted by other matters beside their task when



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

VAC was used. Overall, these subjective measures support the conclusions drawn from EEG and oculometric measures.

Taken together, the results obtained show that the MINIMA concept implemented worked as intended. First, it was shown that a continuous decrease in vigilance occurs when controllers are practically uninvolved with their task. Then, it was shown that such decrease could be anticipated and reversed using the Vigilance and Attention Controller developed within MINIMA. It can therefore be concluded that the MINIMA concept of preventing OOTL through an EEG-based adaptive automation system was successfully implemented. All of these key project results and their successful achievements have been confirmed by the MINIMA Advisory Board members upon presenting it to them.

## 2.5 Technical Deliverables

| Ref. | Title – Description | Delivery Date[1] | Dissemination Level[2] |
|---|---|---|---|
| D1.1[1] | **State of the Art Report**<br>This Deliverable presents a description of the state of the art of operation concepts for monitoring high level automation tasks, task distribution including artificial tasks, attention guidance support and attention measurement using Brain Computer Interfaces (BCI). | 12 Dec 2016 | Public |
| D1.2[2] | **Concept Description**<br>This Deliverable describes the concept behind the MINIMA project. It includes five key aspects. First, the highly automated TMA used as an example for a monitoring task in ATM and the assumptions made about automation. Second, vigilance measurement of the human operator through a BCI. Third, identified real tasks and defined artificial tasks that can be assigned to the human operator to increase his engagement in the monitoring tasks. Fourth, attention guidance support, which may dynamically highlight certain aspects in the task environment. Finally, the concept for dynamic task distribution of real and artificial tasks based on the measured vigilance level. | 08 Feb 2017 | Public |
| D2.1[3] | **Vigilance and Attention Controller**<br>This deliverable describes the developed and implemented *Vigilance and Attention Controller* which combines the *Vigilance and Attention Observer* and the Task Manager. This | 31 Jul 2017 | Confidential |

[1] Delivery date of latest edition

[2] Public or Confidential



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

| | | | |
|---|---|---|---|
| | Controller assesses operator vigilance through electroencephalography and, based on that, controls the adaptive automation system. Through that system, different assistance functions can be activated or deactivated. Those functions are described in D2.2 (*Task Environment*) | | |
| D2.2[4] | **Task Environment**<br>This deliverable describes the developed and implemented *Task Environment* including the assistance functions, which can be activated and assigned. In total, nine such functions were implemented into the *Task Environment*. | 31 Jul 2017 | Confidential |
| D3.1[5] | **Evaluation Plan**<br>This deliverable represents the experimental protocol for *Evaluation Study* (T3) which was conducted later in November 2017. It contains the objectives of the evaluation study, the evaluation procedure, the measurements to be used and the scenario requirements. | 07 Nov 2017 | Public |
| D3.2[6] | **Evaluation Results**<br>This deliverable describes the *Evaluation Study's* (T3) conduction and its results. It includes a recapitulation of the *Evaluation Plan* (D3.1), along with reports and justifications of deviations from the latter. The actual results reported in this deliverable include those of the analyses regarding differences between a baseline scenario and a scenario in which the *Vigilance and Attention Controller* (D2.1) was used. Comparisons between both scenarios include impact on vigilance (EEG), monitoring behaviour (Eye-Tracking) and performance (separation losses). | 29 Mar 2018 | Public |
| D4.1[7] | **Dissemination Plan**<br>This deliverable covers the dissemination activities as originally planned for MINIMA. Activities include scientific publications and other publications. The former include journal articles, conference proceedings papers, talks/poster presented at conferences or workshops. The latter include the MINIMA homepage (http://www.minima-project.eu) setup for dissemination, periodic newsletters sent to interested stakeholders, and Advisory Board Meetings. | 26 Jan 2017 | Confidential |
| D5.1[8] | **Project Management Plan**<br>This deliverable documents the project management structure according to ER Project management guidelines and consortium agreement. It refines the project concept and the internal project infrastructure. Infrastructure also included distribution of work among partners, and resources in terms of personnel months. | 22 Nov 2016 | Public |
| D5.2 | **Project Results Final Report**<br>This deliverable serves as a general overview of the MINIMA project in total and therefore serves as a starting point for interested stakeholders. It summarises the work carried out in each of the WP from May 1st 2016 to April 30th 2018. An | to be submitted | Public |



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

| | | | |
|---|---|---|---|
| | overview of the project is given, including the topics as documented in this document's table of contents. | | |
| D6.1[9] | **H – Requirement No. 1**<br>This deliverable describes how the Ethics Requirement #1 (H – Humans: Details on the procedures and criteria that will be used to identify/recruit research participants must be provided) identified for MINIMA has been addressed within the project. Informed Consent Forms were prepared for the *Evaluation Study's* participants. Recruitment details reported in this deliverable have also been included in the Ethics Proposal given to UNIBO's Ethics Committee (Comitato di Bioetica). | 15 Sep 2016 | Confidential |
| D6.2[10] | **H – Requirement No. 2**<br>This deliverable describes how the Ethics Requirement #2 (H – Humans: Detailed information must be provided on the informed consent procedures that will be implemented.) identified for MINIMA has been addressed within the project. It includes detailed information about the preparation of the Informed Consent Forms (see D6.1 above). | 15 Sep 2016 | Confidential |
| D6.3[11] | **POPD – Requirement No. 3**<br>This deliverable describes how the Ethics Requirement #3 (POPD – Protection of Personal Data: Copies of ethical approvals for the collection of personal data by the competent University Data Protection Officer / National Data Protection authority must be submitted) identified for MINIMA has been addressed within MINIMA. It documents the kind of data assessed during the *Evaluation Study* (T3) and how data is stored. Also, it contains information about the Ethical Approval given by UNIBO's Ethical Committee (Comitato di Bioetica). | 30 Aug 2017 | Confidential |
| D6.4[12] | **POPD – Requirement No. 4**<br>This document describes how the Ethics Requirement #4 (POPD – Protection of Personal Data: Justification must be given in case of collection and/or processing of personal sensitive data) identified for MINIMA has been addressed within the project. It documents justifications on why each kind of data recorded during the *Evaluation Study* (T3) was necessary to serve the study's purpose. | 15 Sep 2016 | Confidential |
| D6.5[13] | **POPD – Requirement No. 5**<br>This document describes how the Ethics Requirement #5 (POPD – Protection of Personal Data: Detailed information must be provided on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation.) identified for MINIMA has been addressed within the project. It documents the overall handling of subjects' personal data recorded during the *Evaluation Study* (T3). This includes data | 15 Sep 2016 | Confidential |



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

| | | | |
|---|---|---|---|
| | recording, anonymization, protection, and publication. Also, it describes how individual consent is documented. Finally, compliance with UNIBO's Data Protection Officer and National and EU Legislation was guaranteed. | | |
| D6.6[14] | **POPD – Requirement No. 6**<br>This document describes how the Ethics Requirement #6 (POPD – Detailed information must be provided on the informed consent procedures that will be implemented.) identified for MINIMA has been addressed within the project. It documents how data protection is carried out throughout the project and the *Evaluation Study* (T3) in particular. Also, it documents data protection regarding dissemination activities. | 31 Aug 2017 | Confidential |

**Table 1: Project Deliverables**



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

# 3 Links to SESAR Programme

## 3.1 Contribution to the ATM Master Plan

MINIMA has made no direct contributions to the ATM Master Plan in terms of either Enablers or Operational Improvements. Still, MINIMA contributed to the ATM Master Plan through its objectives to identify possible ways of predicting, detecting and mitigating potential safety issues resulting from ATCos getting OOTL. These objectives, which were aligned to the ATM Master Plan content, have been achieved through the work performed during MINIMA. Therefore, it is reasonable to argue that MINIMA contributes to ATC safety.

## 3.2 Maturity Assessment

The results of the maturity assessment are documented in Table 3.

| ID | Criteria | Satisfaction | Rationale - Link to deliverables - Comments |
|---|---|---|---|
| TRL-1.1 | Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie? | Achieved | The OOTL phenomenon, along with its characteristics, causes and impact on human operator performance has been thoroughly researched and described in the State of the Art Report (D1.1). The phenomenon occurs when the human operator's role is reduced from active involvement to passive monitoring. This causes a decrease in vigilance, attention, and situation awareness. In long term, a decrease in manual skills must be expected. In case the automation fails, a controller in such a mental state will not be able to properly take over control. This is a major safety issue. |
| TRL-1.2 | Has the ATM problem/challenge/need(s) been quantified? | Partial – Non Blocking | Potential negative consequences of the OOTL phenomenon have thoroughly been described in the State of the Art Report (D1.1). As such, a clear picture of how the phenomenon affects human operator performance was elaborated. Still, current research |

| | | | |
|---|---|---|---|
| | | | literature does not provide clear numbers or statistics on the quantification of these consequences. Therefore, the impact on the operator's mental state cannot be measured in explicit numbers. However, as safety issues are of a very high priority, any such issues must be addressed, whether they can be quantified or not. Furthermore, it is very likely that such quantification will be possible in the future. MINIMA contributed to a preliminary quantification based on an expert sample of ATCos who have been actively involved in MINIMA's Evaluation Study. |
| TRL-1.3 | Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others. | Partial – Non Blocking | The developed VAC with EEG and adaptive automation in the TE worked well in the research environment. This environment might look different in a future operational context. Potential weaknesses and constraints include applicability to ATC domains other than Terminal Manoeuvring Areas, operational feasibility and maturity of the tools, and finally some constraints regarding the stability of the Human-Machine-Interface used within MINIMA. |
| TRL-1.4 | Has the concept/technology under research defined, described, analysed and reported? | Partial, Non-Blocking | The MINIMA Concept (D1.2) has been developed based on a scientific State of the Art Review (D1.1). Its technical implementation has been documented in two deliverables (D2.1/2, disclosed Deliverables). Finally, it was evaluated through an empirical evaluation study (D3.1). The results of this evaluation study have been reported in D3.2, on the MINIMA |



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

| | | | |
|---|---|---|---|
| | | | homepage, to the MINIMA Advisory Board, and in four project newsletters. |
| TRL-1.5 | Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level? | Partial – Non Blocking | The results of MINIMA contribute to SESAR's performance ambition as documented in the ATM Master Plan[24]. As MINIMA has developed and validated a system suited to keep ATCos "in-the-loop", e. g. able to provide safe air traffic control in highly automated task environments, MINIMA contributes to the safety aspect of SESAR's performance ambition through its reduction of risk per flight. Furthermore, MINIMA contributes to the intended improvements in automation supports, which according to the ATM Master Plan[24] are necessary to achieve the performance ambition. |
| TRL-1.6 | Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? What are these new capabilities? Can they be technically implemented? | Achieved | MINIMA produced a Vigilance and Attention Controller, a tool capable of mitigating safety risks resulting from human operators getting Out-of-the-Loop in high automation work environment (D2.1 & D2.2, disclosed Deliverables). This is achieved through adaptive automation solutions (directly implemented into the Task Environment [D2.2, disclosed Deliverable]) used to keep human operator vigilance on an adequate level at all times. The adaptive automation is controlled by an integrated electroencephalography based Vigilance Observer. This Vigilance Observer allows for a real-time assessment of objective vigilance data. After technical implementation all systems proved feasibility in an empirical |



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

| | | | |
|---|---|---|---|
| | | | Human-in-the-Loop study. |
| TRL-1.7 | Are physical laws and assumptions used in the innovative concept/technology defined? | Not Applicable | - |
| TRL-1.8 | Have the potential strengths and benefits been identified? Have the potential limitations and disbenefits been identified? Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible. | Achieved | The potential strengths of the MINIMA concept have been thoroughly documented in the respective deliverables (D1.2, D2.1/2.2 [disclosed Deliverables], D3.2). The MINIMA concept bases on the idea of using objective neurophysiological data assessed in real-time to dynamically adapt the automation level of a task environment (D2.2, disclosed Deliverable). This way, the MINIMA concepts supports human operators to stay In-The-Loop and therefore able to overlook their task environment at all times. During the evaluation study (D3.1/D3.2), it was shown that this concept is indeed able to mitigate the negative impacts of monitoring high levels of automation. When the VAC was used, mean vigilance was 20 % higher compared to the Baseline condition without the VAC.<br><br>One potential limitation of the MINIMA concept's feasibility for operational environments is the inconvenience of today's EEG systems. They are rather intrusive, and effortful in installation and calibration. However, newly developed EEG systems were presented which are much less effortful to install and more comfortable to wear. Such systems will very likely help to overcome this current |



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

| | | | |
|---|---|---|---|
| | | | limitation in the future. |
| TRL-1.9 | Have Initial scientific observations been reported in technical reports (or journals/conference papers)? | Achieved | Scientific observations have been reported in the deliverables submitted to SJU throughout the project. Furthermore, all technical aspects of the project have been disseminated at scientific conferences as papers, presentations and posters. Additional dissemination activities, including publication of two open access journal articles and participation in a workshop on automation, are planned. The latter will also be used to further deepen the collaboration between the project teams of MINIMA, AUTOPACE and STRESS. |
| TRL-1.10 | Have the research hypothesis been formulated and documented? | Achieved | The research hypotheses have been formulated and documented in the technical deliverables (D1.1/2, D2.1/2 [Disclosed Deliverables], D3.1), along with the results of the analyses conducted to examine them (D3.2).<br><br>It was hypothesized that controller vigilance would decrease significantly in a highly-automated task environment in which operators' roles would be reduced to passive monitoring. The decrease in vigilance was hypothesised to be measurable through electroencephalography. This would result in decreased safety due to the operator being at risk of becoming unable to take over control in case automation fails. Another hypothesis was that the decrease in vigilance could be mitigated through an adaptive automation system. Such system |



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

| | | | |
|---|---|---|---|
| | | | would be able to monitor controller vigilance and, in case of a decrease, activate an adaptation system designed to re-increase controller vigilance.<br><br>After the Evaluation Study, it was found that the data supported the hypotheses stated above. During a high automation scenario in which professional ATCo were required to do nothing but to monitor the system, electroencephalography showed a significant, continuous decrease of controller vigilance over time. In another scenario in which the Vigilance and Attention Controller [3] (D2.1, Disclosed Deliverable) was used, such decrease of vigilance was mitigated through the various task activation functionalities. These results have shown that (a) lack of involvement leads to a decrease in controller vigilance, constituting a potential safety issue, and (b) such decrease can be compensated through the adaptive automation system developed in MINIMA. |
| TRL-1.11 | Is there further scientific research possible and necessary in the future? | Achieved | Absolutely. The Vigilance and Attention Controller conceptualised (D1.2), developed (D2.1) and evaluated (D3.2) during MINIMA was shown to be capable of mitigating the negative impacts of monitoring high levels of automation. Therefore, it is an effective tool to keep human operators in the loop in highly automated areas. An important step for future research will be to improve its feasibility by making the electroencephalography measures less intrusive, less complex, and easier to configure. |



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

| | | | |
|---|---|---|---|
| | | | BrainSigns, a third party in MINIMA, have recently presented a prototype of a dry, six electrodes cap for electroencephalography.<br>Integrating such a system with the Vigilance and Attention Controller will significantly improve the latter's feasibility.<br><br>In a collaborative process, the project teams of the SESAR ER projects MINIMA, AUTOPACE and STRESS have come up with a white paper in which a conjoint future research activity combining the contents of each project is described. In detail, it suggests combining adaptive system automation (MINIMA) following newly developed system automation guidelines (STRESS) and apply it to ATCO training (AUTOPACE). For that, AUTOPACE provides a training techniques catalogue addressing both technical and psychological aspects. These training techniques are integrated with the neuro-based adaptive automation system developed within MINIMA, whose design will be re-worked under consideration of the system automation guidelines developed in the STRESS project. This combination will offer a possibility to further enhance human-centered automation in ATC, and ensure the conjoint exploitation of three ER projects. |
| TRL-1.12 | Are stakeholder's interested about the technology (customer, funding source, etc.)? | Partial - Blocking | The MINIMA Advisory Board confirmed the reported achievements as well as the positive feedback on the SESAR Innovation Days, the ART Workshop (“you are facing an important problem”) and other conferences. As Advisory Board members are recruited from |



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

| | | | |
|---|---|---|---|
| | | | potentially interested stakeholders, they can be considered to be preliminarily interested about the MINIMA concept at its current state, but also in its further development. As MINIMA was an exploratory research project, the developed VAC (D2.1) and TE (D2.2) are still research prototypes. As such, development of an industrial prototype will be necessary to raise commercial interest in it. |

**Table 2. ER Fund / AO Research Maturity Assessment**



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

# 4 Conclusion and Lessons Learned

## 4.1 Conclusion

In conclusion, the outcomes of the MINIMA project show that it has indeed matched its initial objectives. The results of WP1 have contributed to an increased understanding of what comprises the OOTL performance problem, its causes and how to predict mitigate it.

The *State-of-the-Art Report*[1] (D1.1) provides interested readers with an encompassing introduction to the OOTL performance problem and served as the basis of the MINIMA concept development as described in D1.2[2]. The latter, developed in cooperation with subject matter experts, describes how the OOTL performance problem can (1) be predicted using neurophysiological markers and (2) be mitigated through a vigilance-based adaptive automation system. In future research, those documents will contribute to the understanding of the OOTL performance problem and how it can be prevented. This way, they will contribute to the development of innovative systems aiming to increase safety in ATM.

The *Vigilance and Attention Controller*[3] (D2.1) and the *Task Environment*[4] (D2.2) are the products of the MINIMA concept's technical implementation. The former helps keeping ATCos in-the-loop by continuously assessing their vigilance level through objective measures and adjusting the automation level accordingly. The latter integrated the adjustment mechanisms to actually realise different levels of automation within the ATCos' work environment and served as the evaluation platform of the MINIMA concept.

The results of the *Evaluation Study* (T3.3) have shown that the MINIMA concept and its technical implementation constitute important contributions to safety in ATM. Not only was it shown that a lack of task involvement in high automation systems leads to the predicted vigilance decrease and thus reduced safety. The *VAC* (D2.1) proved to successfully identify episodes of decreasing controller vigilance, and re-increase it through its adaptive automation system. In addition to the objective measures used to find those effects, subjective controller feedback showed that it made their task more effortful and demanding, but at the same time less frustrating and easier to achieve good performance in. This indicates that ATCos are willing to use the MINIMA concept, which in turn supports its feasibility in terms of user acceptance. This is an important prerequisite for a successful (potential) implementation in operational ATC.

Finally, the feedback MINIMA has received from its dissemination activities (see section 2.3.4) show that the project addresses a crucial ATM problem and provides a meaningful and feasible approach to a technical, human-centred solution. Moreover, it was argued that the MINIMA concept, due to its generic nature, could be applied in domains other than ATM/ATC, i.e. automotive.

In sum, the exploratory research done in MINIMA was a successful step towards increasing safety in high automation work environments where human operators are required to serve as backup plan in case automation fails. It cannot be said when automation will be as elaborate as necessary to cancel out human involvement. As long as it is not, concepts such as that of MINIMA are crucial to profit from the benefits of automation without risking its ironies.



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

## 4.2 Technical Lessons Learned

This section summarizes the main recommendations to mitigate technical issues of the process and to improve technical feasibility as there were some technical difficulties during the experiments

The RadarVision software used as the human machine interface in the task environment encountered crashed eight times throughout the two weeks of the experiments (three of the crashes occurred in training runs and are of less importance). Every time such a crash occurred, RadarVision had to be restarted to continue the scenario. As the traffic simulation itself was executed by a separate system, from a technical perspective this was a minor problem. RadarVision could easily be restarted to continue the scenario with only a few seconds lost in between. However, the experimental design aimed to induce OOTL phenomena through low vigilance levels caused by a monotonous task. As software crashes were highly salient, they were able to cause an impact on the subjects' vigilance level at the time of the crash. Therefore, crashes were handled in two ways depending on the time they occurred. If they occurred early in the scenarios (less than 30 minutes into), the scenario was restarted completely if there was sufficient time to do so. If they occurred later than 30 minutes into the scenario, the scenario was not repeated and only the data obtained up to that point was included in the analysis. In the end two of the five affected baseline respectively simulation runs were up to 15 minutes shorter than intended, but could be used for data analysis nonetheless. The other two runs of a single subject had to be excluded due to the resulting time pressure at the evaluation day schedule. Thus, for the data analysis point of view there was no significant impact.

After the first crashes appeared, UNIBO informed DLR. DLR tried to understand what caused them but without success. Based on the continuous report of UNIBO, crashes occurred randomly at different scenarios and different times. No systematic errors could be found. Also, it has to be noted that during the one day full rehearsal one week before the *Evaluation Study* began, no such crashes appeared. Also in the future, it will be hard to identify non-deterministic issues. Therefore, it can only be recommended to have a cycle of sufficiently long rehearsals much prior to the actual study to have a better opportunity to figure out any technical issues.

It has been reported by the experimenters that during the *Evaluation Study*, participants sometimes found themselves in situations where their altitude and speed advisories were not properly implemented by the system. For instance, if a controller instructed a 'descend' to flight level 80 to an aircraft, the aircraft apparently did not follow the advisory. As continuous descent approaches were simulated, advisories were limited to 'descend' (altitude) and 'reduce' (speed). Continuous descent also means that aircraft continuously lost height throughout their approach to the simulated airport. Therefore, it is possible that advisories were mistakenly perceived as not being implemented because aircraft were reducing their height anyway. Another issue with the height advisories was that BASELINE and SOLUTION scenarios were designed to have one separation loss between two aircraft. One aspect of the MINIMA concept's evaluation was to see if controllers were more likely to prevent the conflict in the SOLUTION scenario as their vigilance was supposed to be higher compared to the BASELINE scenario. However, as altitude advisories influenced the planned and then flown trajectory, controller interaction might have caused only very small effects from time to time. Controllers could have perceived this as an unreliable way to prevent the separation losses and thus may have reduced their interactions. However, it is clear that advisory implementation did work as intended. For the future it might be better to give a clear feedback on the input and system's acceptance of controller's interactions to raise controller's trust in the automation.



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

In addition, one subject was a substitute subject who readily participated to replace a last minute dropout. Unfortunately, the subject did not have sufficient time to complete all of the experiment. Furthermore, the training session was omitted. Although the controller had already participated in the preliminary trials in July and underwent the training session then, it was not enough for the standardised evaluation design. Therefore, the subject's data was also excluded from the analysis.

Originally, it was planned to collect 30 data sets (15 subjects x 2 scenarios). After the reported data exclusion a total of 26 data sets were collected (from 13 subjects). Data sets had an average duration of $M$ = 43.75 minutes (30.90 minutes in the shortest scenario). The data collected resulted to be enough for the demonstration of the MINIMA concept and did not need to be integrated. Anyway, it might be reasonable in the future to plan roughly 10% more subjects to have a backup in case any subjects drop out or have unusable data.

Furthermore, the task environment in MINIMA is based on a very high automation level. However, the ATCos that were currently involved in the experiments are used to work on the systems that are operated nowadays, which are much less automated. This can provoke a decrease in trust in automation while operating the task environment. Running a familiarisation session with a smaller sample of participants within the task environment would allow collecting specific moments of the simulation in which adjustments, such as sound or visual feedbacks for commands, can be implemented in order to mitigate this issue during these transitional years.

## 4.3 Recommendations for future R&D activities (Next steps)

Based on the experience and results from the MINIMA project many recommendations for future R&D activities can be derived.

The current Vigilance Observer prototype, developed by BrainSigns and adopted during the Evaluation experiments, consists of:

- Traditional textile EEG cap, with 15 wet and wired electrodes: *wet* means that conductive gel has to be applied over all the electrodes before the experiments, *wired* means that all the electrodes are connected to the amplifier by wire;
- An EEG amplifier, to put on the desk, connected by wire to the electrodes and to the computer;
- A computer where the BS Vigilance Observer software runs online.

With respect to this configuration, the electroencephalography measures could be gathered in a less intrusive, less complex, and easier to configure way, i.e. the Vigilance Observer could be designed even more lightweight to step closer to operational use. For instance, BrainSigns is working on a prototype of a six dry electrodes EEG cap that could be integrated into a VAC for improved feasibility. Also, the amplifier is very small and light, therefore integrated directly on the cap and wireless connected to the computer where the software is running. Furthermore, the Attention Controller – especially the adaptive automation elements – could be analysed more in detail and could then be adapted to future needs and enhanced as soon as the relevant future ATC environment becomes more concrete and might differ from the MINIMA TE.

A larger sample size of system matter experts taking part of an elongated human-in-the-loop study would foster to achieve statistically significant and generalizable results. In fact, MINIMA research activity, despite its Exploratory Research status, highlighted the effectiveness of the proposed


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

approach to prevent OOTL phenomena. However, the results are related to the specific study carried on, that could be considered in some ways a pilot study. Once demonstrated the high potential of the MINIMA concept, it should be validated with a larger sample, i.e. hundreds of professional ATCOs, in order to include different ATM systems and ATCOs with different expertise (e.g. tower and en-route). In order to do this, also simulation scenarios should be very long to induce actual OOTL occurrences.

As already foreseen in SESAR2020's PJ.16-04 Attention Guidance activity, some of the adaptive automation elements triggered by eye tracking measures will be used to guide the controller's attention to the desired spots at the controller working position (CWP). Similar contents are also currently discussed as Candidate Solutions for SESAR2020 Wave 2 ("Digital HMI Improvements for ATCos") taking into account „eye movements" at the controller working position. Further research regarding vigilance and attention observance/control of controllers is recommended supported by MINIMA's results.



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

# 5 References

## 5.1 Project Deliverables


[1] MINIMA (699282), State of the Art Report, D1.1, 00.02.00, 12 Dec 2016.

[2] MINIMA (699282), Concept Description, D1.2, 00.02.00, 08 Feb 2017.

[3] MINIMA (699282), Vigilance and Attention Controller, D2.1, 00.01.00, 31 Jul 2017.

[4] MINIMA (699282), Task Environment, D2.2, 00.01.00, 31 Jul 2017.

[5] MINIMA (699282), Evaluation Plan, D3.1, 00.02.00, 07 Nov 2017.

[6] MINIMA (699282), Evaluation Results, D3.2, 00.02.00, 29 Mar 2018.

[7] MINIMA (699282), Dissemination Plan, D4.1, 00.02.00, 26 Jan 2017.

[8] MINIMA (699282), Project Management Plan, D5.1, 00.01.00, 22 Nov 2016.

[9] MINIMA (699282), H – Requirement No. 1, D6.1, 00.01.00, 13 Sep 2016.

[10] MINIMA (699282), H - Requirement No. 2, D6.2, 00.01.00, 13 Sep 2016.

[11] MINIMA (699282), POPD - Requirement No. 3, D6.3, 00.01.10, 30 Aug 2017.

[12] MINIMA (699282), POPD - Requirement No. 4, D6.4, 00.01.00, 13 Sep 2016.

[13] MINIMA (699282), POPD - Requirement No. 5, D6.5, 00.01.00, 13 Sep 2016.

[14] MINIMA (699282), POPD - Requirement No. 6, D6.6, 00.02.00, 31 Aug 2017.


## 5.2 Project Publications


[15] Ohneiser, O., Hasselberg, A., Berberian, B., De Crescenzio, F., Babiloni, F., & Schmeier, Tobias (2016). Mitigating Negative Impacts of Monitoring high levels of Automation: the MINIMA project. Poster presented at The Sixth SESAR Innovation Days 2016, November 8-10, Technical University of Delft, The Netherlands.

[16] Berberian, B., Ohneiser, O., De Crescenzio, F., Babiloni, F., & Hasselberg, A. (2017). MINIMA project: detecting and mitigating the negative impact of automation. Proceedings of HCI International 2017, Berlin: Springer.

[17] Berberian, B., Ohneiser, O., De Crescenzio, F., Babiloni, F., Di Flumeri, G., & Hasselberg, A. (2017). MINIMA project: detecting and mitigating the negative impact of automation. In D. Harris (Ed.): Engineering Psychology and Cognitive Ergonomics. Performance, Emotion and Situation Awareness (pp. 87-105). Cham, CH: Springer International Publishing. doi: 10.1007/978-3-319-58472-0_8




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

[18] De Crescenzio, F., Di Flumeri, G., Ohneiser, O., Kraemer, J., Berberian, B., Bagassi, S., Sciaraffa, N., Aricò, P., Borghini, G., Babiloni, F. (2017). Preliminary Findings on how to Mitigate Negative Impacts of Monitoring High Levels of Automation. Poster presented at the Seventh SESAR Innovation Days 2017, November 28-30, University of Belgrade, RS.

[19] Kraemer, J., Ohneiser, O., De Crescenzio, F., & Berberian, B. (2017). MINIMA. Mitigating Negative Impacts of Monitoring High Levels of Automation. Presentation at the Agency Research Team Workshop on Automation in Air Traffic Management. Vienna, AUT: FREQUENTIS headquarters.

[20] Kraemer, J., Ohneiser, O., De Crescenzio, F., & Berberian, B. (2017). MINIMA. Vigilanz und Aufmerksamkeit als Trigger für Adaptive Automatisierung. (engl. MINIMA. Vigilance and Attention as a Trigger for Adaptive Automation. Presentation at the 66th German Aerospace Congress, September 5-7. Technical University of Munich, GER.

[21] Ohneiser, O., De Crescenzio, F., Di Flumeri, G., Kraemer, J., Berberian, B., Bagassi, S., Sciaraffa, N., Aricò, P., Borghini, G., & Babiloni, F. (2018). Experimental Setup for Validating Out-Of-The-Loop Mitigation when Monitoring High Levels of Automation. Paper presented at the 20th International Conference on Air Traffic Management and Aviation, April 16-17. Lisbon, PT.

[22] http://www.minima-project.eu

### 5.2.1 Planned publications

In addition to the publications listed above, two peer-reviewed journal article publications are planned to disseminate the results of MINIMA. It is planned to publish those articles in open access journals to make them available to a broader public. The first article will cover the calibration experiments for the *Vigilance Observer* conducted in July 2017. It is intended to publish it in the *Frontiers in Neuroscience's* special issue titled: *Neuroergonomics: The Brain at Work in Everyday Settings*. The second article will cover the results of MINIMA's *Evaluation Study* (T3.3) and therefore the overall outcome of the *Vigilance & Attention Controller's*[3] (D2.1) impact on mitigating the negative impacts of monitoring high levels of automation. It is intended to publish this article in the *Aerospace* journal's topical collection titled: *Air Transportation – Operations and Management*.

## 5.3 Other

[23] Project Execution Guidelines for SESAR 2020 Exploratory Research, Edition 01.00.00, 08/02/2016.

[24] European ATM Master Plan (Edition 2015)

[25] MINIMA (699282), Grant Agreement.

[26] Ohneiser, O. (2010). RadarVision – Manual for Controllers. DLR (IB112-2010/54).

[27] Helmke, H., Hann, R., Uebbing-Rumke, M., Müller, D., & Wittkowski, D. (2009). Time-Based Arrival Management for Dual Threshold Operation and Continuous Descent Approaches. In:



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

Proceedings of the 8th USA/Europe Air Traffic Management Research and Development Seminar.

[28] NASA (1986). NASA Task Load Index (TLX) v. 1.0 Manual.

[29] Matthews, G., Szalma, J., Panganiban, A. R., Neubauer, C., & Warm, J. S. (1999). Profiling Task Stress With The Dundee Stress Test Questionnaire. In L. Cavalcanti & S. Azevedo: Psychology of Stress (pp. 49 – 91). New York City, USA: Nova Science Publishers Inc.

[30] Byrne, E. (2015). Commentary on Endsley's "situation awareness misconceptions and misunderstandings", Journal of Cognitive Engineering and Decision Making, 9, 84-86. doi:10.1177/1555343414554703

[31] Kam, J. W., Dao, E., Blinn, P., Krigolson, O. E., Boyd, L. A., & Handy, T. C. (2012). Mind wandering and motor control: off-task thinking disrupts the online adjustment of behavior. Frontiers in Human Neuroscience, 6, 329.

[32] C. Calefato, F.Tesauri & R. Montanari. (2008). The Adaptive Automation Design. INTECH Open Access Publisher.

[33] J.R. Anderson. (2015). Cognitive Psychology and its implications. Eighth Edition. Worth Publishers.

[34] M. Schiessl, S. Duda, A. Thölke, & R. Fischer. (2003). Eye tracking and its application in usability and media research. MMI Interaktiv - Eye Tracking. 1(6): 41-50.

[35] D.B. Kaber & M.R. Endsley. (1997). Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. Proc. Safety Prog. 16: 126–131.

[36] W.D. Gray, H. Neth & M.J. Schoelles. (2006). The functional task environment. Attention: From theory to practice, 100-118. Oxford University press.

[37] J. Warm, R. Parasuraman, & G. Matthews. (2008). Vigilance Requires Hard Mental Work and Is Stressful. Human factors. 50: 433-441.

[38] C.D. Wickens. (2008). Multiple resources and mental workload. Human Factors. 50(3): 449–455.



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

# Appendix A

## A.1 Glossary of terms

| Term | Definition | Source of the definition |
|---|---|---|
| Adaptive Automation | "refers to systems in which either the user or the system can modify the level of automation by shifting the control of specific functions, whenever specific conditions are met" | Calefato, Tesauri & Montanari (2008)[33] |
| Attention | "The allocation of cognitive resources among ongoing processes." | Anderson (2015)[34] |
| Eye-Tracking | "The main target of the eye tracking method is to assess the allocation of visual attention on the screen." | Schiessl et al. (2003)[35] |
| Mind Wandering | "Mind wandering episodes have been construed as periods of 'stimulus-independent' thought, where our minds are decoupled from the external sensory environment." | Kam et al. (2012)[32] |
| Out-Of-The-Loop Phenomena | "Human supervisory control and monitoring of automated systems, as well as, passive system(s) information processing can all be classified as forms of out-of-the-loop (OOTL) performance. Whether the operator's task is to decide if process control intervention is necessary, detect a critical system event, or accept or reject the actions of a computer controller, he or she is removed from direct, real-time control of the system. OOTL performance is a critical issue in overall automated systems functioning because it is associated with numerous negative consequences including: (a) operator failure to observe system parameter changes and intervene when necessary (vigilance decrements); (b) human over-trust in computer controllers (complacency); (c) operator loss of system or situation awareness; and (d) operator direct/manual control skill decay." | Kaber & Endsley (1997)[36] |



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

| | | |
|---|---|---|
| Situation Awareness | "A continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events." | Byrne, 2015[31] |
| Task Environment | "To be at all useful to understanding human cognition requires a focus on the environment from the perspective of the to-be-accomplished task" | Gray, Neth & Schoelles (2006)[37] |
| Vigilance | "Refers to the ability of organisms to maintain their focus of attention and to remain alert to stimuli over prolonged periods of time." | Warm, Parasuraman & Matthews (2008)[38] |
| Mental Workload | "characterizing the demand imposed by tasks on the human's limited mental resources, whether considered as single or multiple" | Wickens (2008)[39] |

**Table 3: Glossary**



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

## A.2 Acronyms and Terminology

| Term | Definition |
|---|---|
| **AMAN** | Arrival Manager |
| **ATC** | Air Traffic Control |
| **ATCo** | Air Traffic Controller |
| **ATM** | Air Traffic Management |
| **BCI** | Brain-Computer-Interface |
| **BS** | BrainSigns |
| **CWP** | Controller Working Position |
| **DLR** | German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt) |
| **EEG** | Electroencephalography |
| **ENAV** | Italian Air Navigation Service Provider (Ente Nazionale Di Assistenza Al Volo) |
| **HMI** | Human-Machine-Interface |
| **MySQL** | My Structured Query Language (inofficially) |
| **ONERA** | French Nation Aerospace Centre (Le Centre Français de Recherche Aérospatiale) |
| **OOTL** | Out-of-the-Loop (phenomenon) |
| **POPD** | Protection of Personal Data |
| **RV** | RadarVision |
| **SESAR** | Single European Sky ATM Research Programme |
| **SJU** | SESAR Joint Undertaking (Agency of the European Commission) |
| **TE** | Task Environment |
| **TMA** | Terminal Manoeuvring Area |
| **TRL** | Technology Readiness Level |
| **UNIBO** | University of Bologna (Università di Bologna) |
| **VAC** | Vigilance and Attention Controller |

**Table 4: Acronyms and technology**



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

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