

## Deliverable 3.1

# Human-AI Teaming Framework and Design Document

**Authors:** Magnus Bång, Jonas Lundberg (LiU), Brian Hilburn (CHPR), Elizabeth Humm, Gianmaria Mallozzi, Vanessa Arrigoni (DBL)

## **Abstract**

HAIKU's WP3 'Human-AI Teaming' aims to develop Human Factors design guidance and methods for HAT, by:

- Reviewing state of the art in sensor technology, Human Factors constructs, ongoing research, current (and developmental) applications, and frameworks / models for HAT, with potential relevance to m HAiku UC developments; and by
- Making a preliminary mapping of projects, sensor technologies, and HF constructs to particular UCs.

This review focused on 29 applications, 17 projects, 16 sensor technology categories, and hundreds of publications across scientific and popular press. Direct lessons are drawn to help guide the development and validation of the six Use Case prototypes.

Note: this deliverable does not discuss the direct link between existing solutions to HAiku Intelligent Assistants, as the final concepts are still being refined. The link will be documented in later WP4 deliverables, documenting the finalised list of requirements. The starting baseline for the Intelligent Assistants will be described in WP6 deliverables, namely in validation strategy and validation reports.

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## List of Acronyms

Acronym	Definition
<b>AI</b>	Artificial Intelligence
<b>AOI</b>	Areas of Interest
<b>Bdx INP</b>	Institut Polytechnique de Bordeaux
<b>CU</b>	Computation Unit
<b>DOT</b>	Diffuse Optical Tomography
<b>ECG</b>	Electrocardiogram
<b>EDA</b>	Electrodermal activity
<b>EDF</b>	European Data Format
<b>EEG</b>	Electroencephalogram
<b>EMG</b>	Electromyography
<b>ENAC</b>	Ecole Nationale de l'Aviation Civile
<b>EOG</b>	Electrooculogram
<b>fNIR</b>	Functional near-infrared spectroscopy

<b>GLONASS</b>	Global Navigation Satellite System
<b>GPS</b>	Global Positioning System
<b>HAIKU</b>	Human AI Knowledge and Understanding
<b>HAIT</b>	Human AI Teaming
<b>HAT</b>	Human Autonomy Teaming
<b>HRV</b>	Heart Rate variability
<b>Hz</b>	Hertz
<b>IA</b>	Intelligent Assistant
<b>IAI</b>	Israel Aerospace Industries Ltd.
<b>IR</b>	Infrared
<b>LIDAR</b>	Light detection and ranging
<b>LOA</b>	Levels-of-automation.
<b>LACC</b>	Levels-of-autonomy-in-cognitive-control
<b>LACC-LOA</b>	A matrix combining LOA and LACC, for the identification of critical areas of Human-AI teaming.

<b>nm</b>	Nanometres
<b>PPG</b>	Photoplethysmography
<b>PTSD</b>	Post Traumatic Stress Disorder
<b>REPS</b>	Real Life Environment with Pilot State Monitoring Systems
<b>SA</b>	Situation Awareness
<b>SDK</b>	Software development kit
<b>SoA</b>	State of Art
<b>UC</b>	Use Case

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## Executive Summary

The HAIKU project aims to generate knowledge on intelligent assistants, and to develop AI enabled prototypes for six aviation-related Use Cases (UCs).

**In support of these broader aims, WP3 ‘Human-AI Teaming’** WP3 developed Human Factors design guidance and methods for appropriate human-AI partnering. It did this by:

- Conducting a state-of-the art-review (SOAR) of theoretical and empirical literature on human-AI teaming, including applications, constructs, related research, and applicable models.
- Refining a model and taxonomy of HAIT concepts,
- Developing HAIT development guidelines, and
- Developing preliminary validation framework, by identifying measures, metrics, and methods for WP6 use case trials.

D3.1 represents the first deliverable in the Human-AI teaming work package (WP3) of HAIKU. It provides a state of the art review of theoretical and empirical literature on human-AI teaming with a focus on the aviation industry. This review covered a total of 28 applications (from prototypes to commercially-available products), 19 research projects and other efforts, and over 100 scientific articles.

The document provides, additionally, an in-depth review of the state of the art in Human Monitoring in aviation and other industrial domains. This includes neurophysiological, behavioural and performance indicators of human performance - information needed for selecting sensors and approaches that are relevant for the different HAIKU use cases. This review covered a total of 16 (sixteen) categories of sensors and resulted in a preliminary mapping of these sensor categories with the six HAIKU use cases.

The remainder of the document describes LACC-LOA - a general *joint cognitive framework* for Human-AI teaming. This integrative framework uses one light-weight technique/method - the LACC-LOA matrix - to establish an overarching frame with a focus on cognitive control tasks in relation to levels of automation. After review, it was decided to move forward with the use of LACC-LOA in HAIKU. This is because 1) the framework is light and nimble enough to allow us to structure development and validation efforts around (notice that the LACC-LOA is not intended to replace other HAIT frameworks, only to serve as a structuring tool for HAIKU; and 2) the framework compares the various HAIKU Use Cases, showing the different types of Human-AI teaming being explored in the project.

The LACC-LOA framework provides firstly, a starting point for mapping out two core dimensions for human teaming with digital assistants: a) the human versus digital assistant roles (levels-of-automation), b) autonomy, in terms of the kind of cognitive work being done by the assistant (levels-of-autonomy-in-cognitive-control). At the intersection between human role and autonomy, we find areas and issues of human-AI teaming.

# 1 Introduction

## 1.1 Objective and scope of the document

The objective of D3.1 is to provide partners with a blueprint and starting point in their design efforts with the goal to ensure that HAIT principles are adequately addressed. D3.1 provides (1) an overview and state of the art report on digital assistants and related research, (2) review of psychophysiological sensing approaches and technologies available in the market, and (3) a HAIT framework - the LACC-LOA method - for guiding the design of digital assistants the different HAIKU use cases.

## 1.2 Document structure

The document is structured in three sections:

- Section 2 describes the State-of-the-Art review;
- Section 3 presents and analyses the selected sensors and technologies;
- Section 4 presents the LACC-LOA framework which is an overarching approach to identify issues and drive design for Human-AI teaming developed within HAIKU.

## 2 State of the Art Review (SOAR)

*Human-AI teaming refers to the use of artificial intelligence (AI) to augment and enhance the capabilities of human workers, rather than replacing them. In a human-AI teaming arrangement, humans and AI work together to achieve a common goal, with the AI providing support or assistance to the humans.*

*There are many potential benefits to human-AI teaming, including increased efficiency, improved accuracy, and the ability to handle tasks that would be tedious or time-consuming for humans to perform on their own. By leveraging the strengths of both humans and AI, it is possible to achieve better outcomes than either could achieve alone.*

The preceding two paragraphs were not generated by a human, but by OpenAI’s recently released ChatGPT natural language chatbot, in response to the question “What is Human-AI Teaming?” ChatGPT represents the state of the art in generative AI and since its release in December 2022 it has become the fastest growing consumer application in history (Hu, 2023). Before exploring the state of the art in Human-AI Teaming it is perhaps instructive to look backward and quickly recap the history of AI itself.

### o 2.1 A brief history of AI

The term “Artificial Intelligence” (AI) was first used in 1955 by a small group of Dartmouth College computer scientists, mathematicians and cognitive scientists who defined AI as

*“...making a machine behave in ways that would be called intelligent if a human were so behaving.”*

Press (2021) has charted the history of AI and identified over 100 milestones along its timeline, which he traces back roughly to Jonathan Swift’s Gulliver’s Travels in 1726 (See Table 1). Swift envisioned a mechanical engine capable of extending human knowledge, thereby allowing “...the most ignorant person...” to “...write books in philosophy, poetry, law, mathematics, politics, and theology...” It seems that ChatGPT has just made real the vision of Swift, some 296 years later. Press (2021) noted some interesting landmarks along the timeline. Consider these milestones that predated the 1955 introduction of the term AI:

Table 1. Some milestones along the way to the term “AI” (adapted from Press (2021)).

1763	Bayes develops his probability framework
1854	Boole introduces the symbology of logic
1898	Tesla creates a radio controlled boat equipped with ‘a borrowed mind.’
1914	Spanish engineer Torres y Queveo demonstrates the first chance playing machine
1921	Czech writer Čapek introduces the word <i>robot</i>
1927	Science fiction film Metropolis features a robot
1937	H.G. Wells predicts that the whole of human memory will be made available to every individual and that ‘any student, in any part of the world, will be able to sit with his projector in his own study at his or her convenience to examine any book, any document, and an exact replica.’
1947	Statistician J.W. Tukey introduces the term <i>bit</i> to represent a binary unit of storage

1949	Edmund Berkeley publishes <i>Giant Brains: Or Machines that Think</i>
1950	Shannon publishes an article titled <i>Programming a Computer for Playing Chess</i>
1950	Alan Turing publishes <i>Computing Machinery and Intelligence</i>
1951	Minsky and Edmonds build the first artificial neural network using 3000 vacuum tubes simulating 40 neurons
1952	Samuel develops the first checkers – playing computer program (and the first program to learn on its own)
1955	Simon and Newell develop the first artificial intelligence program.

Early AI technology, dating back to the 1950s, was based on the concept of serial expert systems that used “if-then” procedures and look-up tables to solve narrowly focused problems. Although they often showed impressive performance in tightly constrained applications (e.g. medical diagnosis, stock market trading) expert systems proved very brittle and unable to handle novel inputs, and have fallen out of favour in recent years.

▪ **2.1.1 Machine Learning (ML)**

The AI subset domain of Machine Learning (ML) seems to have been first mentioned in 1959, when Arthur Samuel wrote about its use in playing the simple game of checkers (Samuel, 1959). ML refers to a group of methods (many biologically inspired) that allow a system to improve its performance through experience and training. Mitchell (1997) defined Machine Learning as follows:

*“A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E....”*

A popular subset of ML methods are ‘deep learning’ methods that just add additional ‘hidden layers’ to the typical neural net architecture, thereby making certain advanced functions possible. Recent advances in the areas of big data, advanced algorithms and architectures (e.g. deep learning, convolutional neural nets, LSTMs), computing power and storage have resulted in an explosion of R&D into ML. Popular applications include natural language processing (freeware apps now commonly feature voice recognition, speech-to-text, etc), and visual image recognition (e.g. Google lens, and various handwriting recognition apps).

The field of ML generally distinguishes three broad approaches, which are sometimes used in combination:

- Supervised Learning (SL) – in which labelled datasets of associated input and output pairs are used to train the SL model in classification (or, less commonly, regression), so as to approximate the relationship between input and output. Common current applications often rely (at least in part) on SL models, in particular the neural network approach and its extensions (e.g. deep learning, recurrent neural networks, convolutional neural networks, long short term memory);
- Unsupervised Learning (USL)- uses unlabelled datasets, and aims to infer the natural structure present in a dataset;

- Reinforcement Learning (RL) – a rule-based agent exploration of the environment, so as to maximise a reward function. RL is particularly powerful in cases of large solution space, in which clear predictor / criterion classifications are not practical.

A simple graphic (adapted from EASA, 2020) shows a high level taxonomy of AI methods is shown in Figure 1.

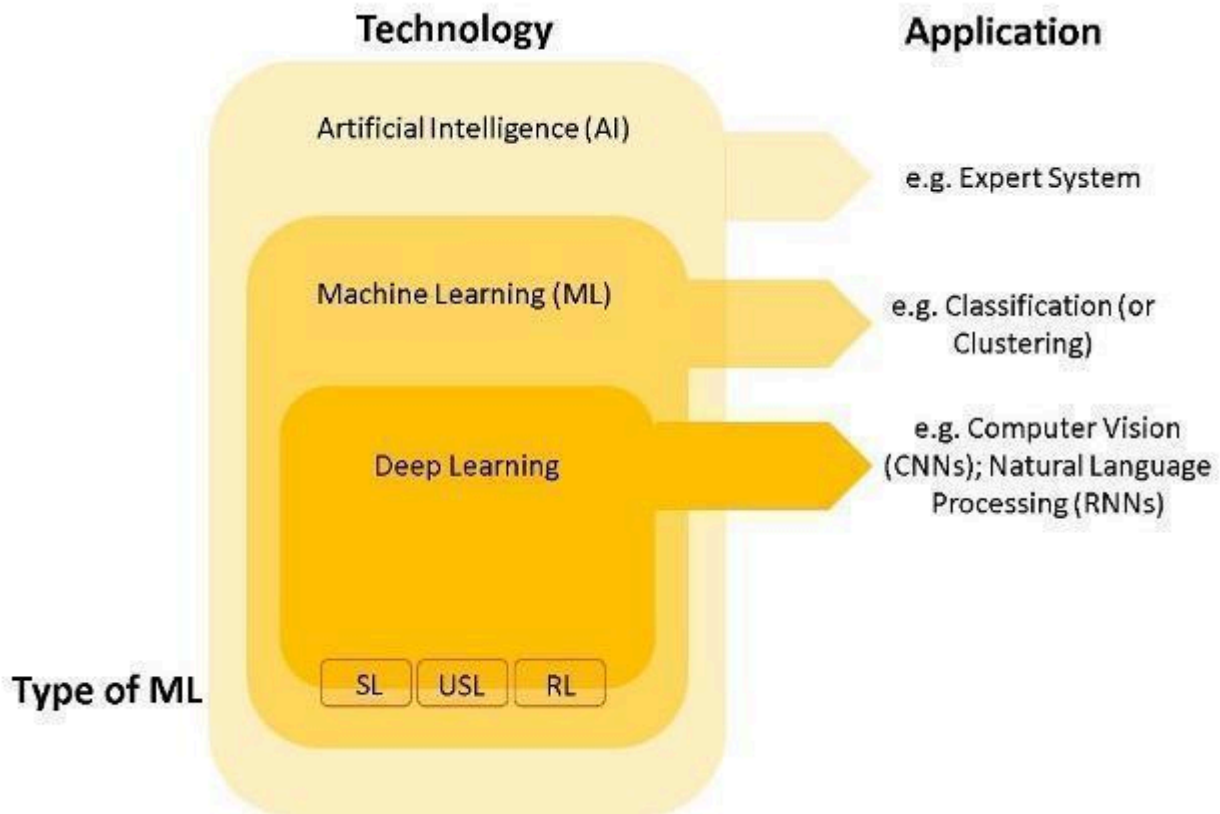


Figure 1. A high level taxonomy of AI methods (adapted from EASA, 2020).

### ▪ 2.1.2 From AI to Human-AI Teaming

An emerging concept within the AI research community is that of Human-AI Teaming (HAIT), in which AI is no longer seen as a tool but as a teammate, that can be entrusted with elements of information processing, decision making, task selection, task execution, supervisory control, etc. In the near term, this would likely mean that AI provides advisory support in the context of non- critical operations. In the longer term, however, this could mean that AI would assume more autonomy in decision-making and task execution, quite possibly even under time pressure and in the most safety critical tasks. Wojton et al (2021) captured the difference between machine tools and teammates in the following way (see Table 2).

Table 2: Difference between machine tools and teammates.

Machines as a tool	Machines as a teammate
Handle inputs, not goals	Pursue the same goal

Require direct instruction for action	Affect the current state
Only complete assigned functions	Coordinate action

HAIT is a broad concept, and its definitional boundaries do not always seem clear from the literature. This review found that distinctions between terms like human – machine teaming, human – automation teaming, and human – AI teaming can be sometimes blurred (Lyons et al, 2021). Boy & Morel (2022) recently suggested that HMT is equivalent to HAT and HAIT. Kaliardos (2022) pragmatically argues for simplifying and clarifying some of the terms we use in the field.

Moreover, given the breadth of the HAIT concept, realizing its potential will require an interdisciplinary focus likely involving computer science, human performance, mathematics, decision making, behavioral sciences, even law and ethics. Of the many challenges we face in realizing effective HAIT systems, some of the greatest are those involving Human Factors.

▪ **2.1.3 State of the Art Review (SOAR) - method and approach**

HAIKU WP3 aims to develop Human Factors guidance for appropriate HAIT. The overall aims of WP3 are to: Identify the constructs underlying effective HAIT performance; Refine a model and preliminary framework for validating HAIKU prototypes; and develop HAIT development guidelines. Within this context, the present State of the Art Review (SOAR, WP3.1) was conducted to explore the following areas:

- Applications of AI — Examples of intelligent assistant technologies, ranging from developmental systems to commercially available products, with implications for human-AI teaming and the HAIKU project;
- Related research — Recent or ongoing research projects with potential lessons for HAIKU;
- Constructs and challenges in HAIT— review of the increasing body of theoretical and empirical research into the constructs underlying effective human-AI teaming;
- Models and frameworks— potential models for characterizing human-AI teaming processes, that seem applicable to the HAIKU project.

This review dovetailed with parallel HAIKU efforts aimed at: exploring the monitoring and measurement of human performance (WP3.2), and developing preliminary design guidance for Intelligent Assistants (WP3.3).

This state-of-the-art review relied primarily on literature review, supplemented by interviews with researchers, academics, and management staff to help fill in knowledge gaps. Literature retrieval was driven by keyword search (using terms such as artificial intelligence, human – AI teaming, etc). Literature search focused on the domains of human factors, artificial intelligence, and computer science, but also picked up various HAIT-adjacent domains, including Human-Robotic Interaction, Human-Robotic Teaming, Social Robotics, Human Automation Teaming, Human Machine Teaming, Autonomous Systems, and Hybrid Intelligent Systems. Priority was given to sources from the last five years, but important pre-2018 works were also included.

In all, over 200 references were reviewed from scientific, industry, and popular press publications, as well as corporate and agency websites. As will be discussed in later sections, several references were especially notable. This was because of either their

comprehensiveness, unique subject coverage, recency, pedigree, and/or apparent relevance to HAIKU. A few of the more notable references include:

- National Academy of Sciences (2022)-- the US National Research Council recently commissioned this NAS study into the state-of-the-art and research needs around human – AI teaming. The research committee included experts from human factors, human-computer interaction, AI, cognitive engineering, and industrial – organizational psychology. Although the primary context for their investigation was ‘multi-domain operations’ (MDO) in defense, the assembled panel of experts dealt more broadly with the factors driving human – AI team effectiveness, and the significant research gaps that still exist in achieving HAIT.
- EASA (2020, 2021)—The European Union Aviation Safety Agency released its 2020 AI roadmap for ‘human-centric’ AI, followed in 2021 with its First Usable Guidance for Level 1 Machine Learning Applications. The authors acknowledged that this does not represent detailed guidance at this point, but a basis for refining the EASA AI roadmap as regulatory guidance evolves. EASA’s guidelines for developing AI rely on four ‘building blocks’ of: trustworthiness analysis; learning assurance; explainability; and safety risk mitigation. EASA released version 2.0 on the 24th of February, too late to be included in this report.
- European Commission (2019, 2020) – The EC’s AI High Level Expert Group (AI-HLEG) released in 2019 its ethics guidelines for developing trustworthy AI. A year later it released its Assessment List for Trustworthy AI (ALTAI) as a checklist driven approach that organizations can use during AI development. Given the increasing focus on ‘ethical’ AI, and the need for conceptual clarity, this pragmatic work is commendable.
- O’Neill, McNeese, Barron & Schelbe (2022)—This review traces the history of the HAT concept, examines a total of 76 experimental research articles, categorizes their experimental designs (independent- and dependent variables, etc), and draws conclusions about remaining research gaps in the study of HAT.
- Lyons, Sycara, Lewis, and Capiola (2021) – In their paper Human–Autonomy Teaming: Definitions, Debates, and Directions, the authors distinguish the (sometimes conflated) terms of automation and autonomy, review literature on human-human teaming, identify key factors relevant to HAT, and identify research gaps. Their conclusions focus largely on ‘social’ aspects such as communication, shared mental models, agency, and goal sharing.

The remaining chapters of this SOAR are structured as follows: Section 2.2 reviews state-of-the-art in current AI applications across several domains, ranging from early-stage developments to commercially available products. Although the focus is on the aviation flight deck, other domains include air traffic control, manufacturing, automobiles, and smart home (“domotic”) technology. Section 2.3 covers related research projects with potential applicability to HAIKU. Section 2.4 covers the range of human performance constructs and challenges underlying HAIT, based on review of the human factors and AI literature. Section 2.5 outlines potential models and frameworks for capturing HAIT that seem to have particular relevance to HAIKU. The final section draws general conclusions and lessons for the HAIKU Use Cases (UCs) based on this overall state-of-the-art review.

Technical details from this review are found in the attached annexes, which cover: the ALTAI checklist; Microsoft’s AI Impact Assessment Template; related research projects; glossary of technical definitions across several sources; details of example applications; structured table of human performance constructs and potential methods; details of related models and frameworks; and a summary of the LACC-LOA Joint Control Framework.

## ○ 2.2 Applications of AI and Digital Assistant Technology

AI capabilities are clearly developing at a breathtaking pace and impacting each of our lives daily. But these capabilities are not entering all domains with the same pace. Aviation is a case in point. Aviation has historically relied on its credo of ‘evolution not revolution’ to justify a measured, strategic pace of innovation. In aviation, both on the flight deck and on the ground, regulatory change generally only comes after new equipment or procedures have proven themselves ‘safe.’ In other areas such as gaming or consumer-electronics, the safety bar is clearly lower and the regulatory hurdles are not the same. Technological change can be much faster in the automobile or home electronics domains than in aviation. As a result, some of the most commonplace applications—many available on our mobile phones--feature some of the most advanced AI technology of the day.

This review of example applications relied on a combination of desk research and interviews of representatives from academia, research, and industry, and identified a total of 28 example applications. This search does not claim to have been exhaustive, only to have achieved a reasonable overview of the range of HAiku relevant applications currently available. These 28 applications were distributed across domains as follows:

Flight deck	9
ATM/ground/airport	3
Manufacturing	5
Smart home technology/ Domotics	5
Automotive	6
Total	28

This section will first broadly review some past and present AI innovations as they impact aviation. It will then review some specific Digital Assistant (DA) applications across a handful of different domains. Technical details of these showcased applications can be found in Annex D, which provides for each application some general information (designer and year), interface features including input/output modalities, system features and potential benefits, underlying HAIT concepts, graphical images, and reference links to further details.

### 2.2.1 AI in aviation

The drive to introduce AI in aviation is not new. Early efforts to develop pilot – robot teaming fancied images of the Star Wars characters Luke Skywalker and R2D2 teaming up to destroy the Death Star (Emerson et al, 1988). Most of this early work seems to have focused on the single seater fighter aircraft (Small, 1988; Nilsson, 2010, Svenmarckt & Dekker, 2022). The Co-pilote Electronique, the Mission Management Aid (MMA), and the CASSY cockpit assistant systems are examples dating back to the 1980s. The US Navy’s Pilot’s Associate (PA) Program, also of the 1980s, aimed to develop a smart copilot capability using six linked expert systems:

- Mission planner for route calculations;
- Tactics Planner for suggesting actions;
- Situation assessment for gathering data and prioritizing threats and targets;

- System status for monitoring internal aircraft subsystems;
- Pilot-vehicle interface for AI-pilot interaction and communication that included explanation functionalities and system inferencing of pilot intentions; and
- Mission executive for overseeing all expert systems and assuring a smooth operation.

Developers quickly realized that to successfully provide pilots real time advice, to support pilot understanding and avoid workload penalties, it was critical that the system be able to explain its advice to the pilot. This drove the PA program to embrace the concept of individualized AI that would tailor its advice and interactive behavior to the individual pilot.

More recently, development of flight deck digital assistants has trended toward the concept of dynamic task allocation and its subcategories of Adaptable / Adaptive automation. Under a dynamic task allocation scheme, tasks can be shared between human and machine on the basis of the human's explicit command (i.e. adaptable) or on the basis of some inferred need for reallocation (adaptive) (see the Honeywell / TU Delft CAMMI crew workload manager (2011)).

Other recent innovations have incorporated pilot neurophysiological monitoring (typically using eye tracking, EEG, heart rate, and/or electrodermal measures), intention inference, strategic advisory functions, adaptive visual support systems, decision aiding support, natural language processing, and conflict detection / resolution advisory capabilities.

Advanced technologies are also being applied on the ground side, with technologies like deep learning (neural networks), natural language processing, computer vision, biometric data, data fusion, and advanced display capabilities being applied to various aspects of ground-based operations, including airport surface movement, enroute and terminal operations, and passenger airport traffic flow.

## 2.2.2 Flightdeck applications

On the flight deck side, this review identified the following nine example applications:

- Digital assistant for non-stabilized approaches in single pilot operations (2022) - an assistant that provides decisional support to the flying pilot, replacing the monitoring pilot. It can support single pilot operators for non-stabilised approaches in the final approach phase. It analyses flight parameters, determines when a go-around is indicated, and alerts the pilot accordingly.
- Dynamic rerouting assistant for Single Pilot Operations (2022) — a system to support the flying pilot in trajectory reroutes, it calculates trajectory to approximate airports and presents landing options to the pilot. Interestingly, the system provides not only landing options but also ranks these options and presents relative advantages and disadvantages associated with each, thereby theoretically keeping the pilot better in the loop and able to make an informed decision.
- Adaptive visual information support system (2021)—this is a new adaptive system that also relies on physiological measures, namely pilot eye scan patterns (eye gaze movements and fixation sequences). In this example, the emphasis is on adaptive reconfiguration of the visual display elements to facilitate scanning.
- Mission+ (2021)—an electronic flight assistant accessed via touchscreen interface that allows flight crews to gather all relevant information concerning flight schedule and performance. Behind this interface is a powerful data integration capability (incorporating navigation charts, checklist items, real-time weather, aircraft performance data, etc.).
- Tracing Pilots' Situation Assessment by Neuroadaptive Cognitive Modelling (2020)—this system monitors pilot brain activity (EEG and derived ERPs) and an inference

engine assesses pilot cognitive state by distinguishing processed and missed alerts, and can trigger pilot assistance.

- Pilot Assist System (2019)—offered as a ‘holographic checklist assistant for the single pilot,’ this is a voice-driven tool that provides visual and spatial cues about action to perform while completing operation checklists. The pilot loads a checklist through voice command and the PAS guides the pilot’s visual attention through visual elements of the checklist and monitors progress through the checklist items.
- Aero Glass (2014)—a ‘smart glasses’ navigation technology that combines elements of the head up display (HUD) and augmented reality (AR) concepts that presents a ‘mixed reality’ representation of terrain visualization and key flight information.
- The Cognitive Adaptive Man Machine Interface (CAMMI) (2011)— a crew workload manager that, on the basis of measured EEG and ECG (i.e. heart rate-derived) inputs, infers pilot workload in a multi crew environment, and displays this information for sharing between pilots. It also can address workload imbalances by suggesting reallocations of current task sharing structure.
- CAMA (Crew Assistant Military Aircraft) (2001)—a prototype cognitive assistant for military transport aircraft cockpit that works under extended operational conditions including Instrument Flight Rules (IFR). Pilots interact with the system by speech or tactile input to request and modify flight plans, and access relevant information.

### ▪ 2.2.3 Ground (ATM / Airport) applications

The review identified the following three ground-side applications:

Fly to Gate (2022)-- A system for streamlining passenger movements through the airport, the system integrates biometric (iris and facial recognition) data with passenger path prediction, and provides airport operators an overview display to help manage passenger traffic fluctuations.

AIMEE (2017)—an integrated capability combining computer vision, deep learning, and natural language processing to process flight data and ‘backstop’ pilot-controller communications for reasons of clearance checking, but also conflict prediction and strategic oversight more broadly.

Airport Surface Display (2014)— a system for enhancing airport surface surveillance by coupling integrated data (including SWIM, ADS-B, even vehicle transponder data) with displays to provide real-time overview of the airport environment, thereby providing both airport and operators an integrated surface management system.

### ▪ 2.2.4 Manufacturing applications

In the manufacturing domain technologies like natural language processing, chat bots, personalisable automation, deep learning, wearable technologies, and augmented reality are being applied in the areas of inspection and quality control, industrial machine optimization, remote assistance, and production management. These are aiming for benefits in terms of: optimising production and reducing costs; accelerating operator learning; and providing a unified conversational platform across purposes. Our review identified the following five applications in the manufacturing domain with potential relevance for HAiku:

- Oracle Digital Assistant (2021)— chatbot technology, natural language processing, and personalized digital assistants are being applied to various business sector skills, from human resources to consumer experience. These capabilities are integrated

with analytics to identify conversational bottlenecks and usage patterns and streamline the process flow.

- Google Visual Inspection AI (2021)— deep learning trains models to detect, classify, and precisely locate multiple defect types in a single image, to automate the quality control process.
- MindSphere Smart Machine Assistant (2018)— a self-learning application for determining the optimal settings of an industrial machine in a complex environment, and advising operators via intuitive visualisations regarding suggested reconfigurations.
- SenseCore— the universal AI infrastructure technology that underlies various SenseCore applications, including “Smart City” and “Smart Life.”
- Remote Eye—Smart-glasses based technology that incorporates hands free operation with AR visualisations, enabling shared visualisation and real time communication between operators.

### ▪ 2.3.5 Smart home Domotics applications

Advanced chatbot capabilities, along with natural language processing, data pull technology, deep learning, Internet of Things (IoT) functionality, smart phone access, video recording and storage enhancements, and even drone technology are playing an ever-greater role in the ‘smart home’ of today. Such capabilities are becoming so ubiquitous that we all probably use them every day without fully considering the advances they have brought in terms of home systems control, security monitoring, information acquisition, and agenda scheduling. These are expected to provide benefits in terms of: increasing property protection and control; customised home appliance management; and customised task management. Our review identified the following five Domotics applications:

- ADT Command (2022)— a new smart home security system that integrates various home systems (e.g. doorbell cameras, smart lights, locks, thermostats) via smartphone app or voice control.
- Home Connect Plus (2021)— another platform for connecting, automating, and centrally controlling various smart home devices via smartphone app or smart speaker.
- Ring Always Home Cam (2021)— the first flying home security camera, it flies from its fixed docking station on user-defined flight paths. The system provides live in-flight footage, and can be controlled via app and or triggered through interaction with other home devices (such as an alarm system).
- Nest Learning Thermostat (2020)— the wifi-enabled learning thermostat incorporates occupancy sensing and outside data sensing, to calibrate trigger timing.
- Amazon Alexa (2014)— the ubiquitous voice-controlled virtual assistant technology developed by Amazon and available on millions of devices (e.g., Smart speakers or smart display). Beyond its immediate uses for query, Alexa also allows integration with various smart home technologies.

### ▪ 2.2.6 Automotive applications

The motorway of the future seems certain to include greater use of driver monitoring and information presentation technologies, as well as higher levels of automated driver control, and networking both among roadway users and the infrastructure itself. Applications seem focused on the following areas: Route planning and traffic updating; Hazard detection and

warning; networked connectivity; driver monitoring; automated control; and logistical optimisation. Ultimately, these efforts are aimed at benefiting traffic, driver cognitive load, and ultimately safety, Our review identified the following six applications as potentially relevant:

- AR Head-up Display 2.0 with Eye-Tracking (2021 / in progress)— this system combines HUD technology with eye tracking and AR to: project useful driving information within the driver's field of view; and infer driver drowsiness/incapacitation.
- T-One (2018)— Toyota's automation software for fleet management, which includes functionalities for path optimisation, autopilot management and distributed synchronisation, and task flow (delivery) scheduling.
- Qualcomm C-V2X (2016 / in progress)— this technology is focused on expanding the possibilities of 'vehicle-to-vehicle' wireless networking, to also link vehicles to pedestrians and infrastructure.
- PRYSTINE (2018-2021)— a European research project on vehicle automation that addressed the transition to level 3 (i.e. Conditional driving automation) and the provision of failsafe mechanisms for the return to manual (driver) operation.
- Waze (2010)— the free road navigation application that integrates GPS mapping and guidance, AI trajectory calculation, and aspects of social media, to provide real-time updates on traffic conditions and related information.
- SenseAuto— an application platform suite of various AI applications aimed at integrating driver monitoring, environmental sensing, autopilot, and cloud networking functionalities.

### ○ 2.3 Related Research Projects

Given the pace of research into AI, ML and related concepts, it was essential to survey the research landscape to identify other research activities with potential relevance to HAiku. This search was conducted via literature review and interviews with affiliated researchers. A total of 16 recent EU technical projects was identified. Also shown below is the ongoing non-technical HumanE-AI-Net project, which is playing a guidance and oversight role. The projects are as follows:

- AICHAIN (-2022)— explored the combination of federated machine learning (i.e. decentralised training) and blockchain technologies to predict (1) take-off-time and (2) flight path, using potentially sensitive commercial data. This is an important consideration in encouraging airlines to share proprietary data.
- AISA AI Situational Awareness Foundation for Advancing Automation (-2022)— addressed SA challenges in ATM automation through the domain-specific application of transparent and generalizable AI methods. The project aimed to develop an intelligent situation-aware system that enables the same team SA to be shared between controllers and AI.
- ALARM multi-hazard monitoring and early warning system (-2022)—aimed to develop a prototype multi-hazard alert system to integrate satellite-measured, ground-measured, and forecast meteo data, and produce early warnings / forecasts of multiple weather hazards.
- ARTIMATION Transparent Artificial Intelligence and Automation to ATM Systems (-2022)— assessed the impact of different visualisation techniques for ATM CD&R and delay prediction algorithms, and explored the differential human performance impacts on expert and student controllers.

- FARO safety And Resilience guidelines for aviatiOn (-2022)— developed a set of methodologies and guidelines for assessing ATM safety and resilience. It also produced a Bayesian Belief Networks computer model to display the relationship between different variables and their impact on safety.
- HAAWAII Highly Automated Air Traffic Controller Workstations with Artificial Intelligence Integration (-2022)— developed new speech recognition software to transcribe pilot-controller communications, and developed a Readback Error Detection Assistant (REDA).
- HumanE-AI-Net (2020-2024)— a non-technical project that is building a network of European research centres, universities and industrial partners, and aims to help guide development of robust, trustworthy AI systems that can ‘understand’ humans, adapt to complex real-world environments, and interact appropriately in complex social settings.
- IMHOTEP Integrated Multimodal Airport Operations for Efficient Passenger Flow Management (-2022)— used data collected from personal mobile devices and digital sensors to reconstruct passenger flows, to facilitate real time collaboration between airports and ground transportation. The project developed a predictive model of passenger behaviour via case studies at two airports.
- ISOBAR Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning (-2022)— combined ML models to predict weather-caused airspace capacity limitations, and select mitigations at both local and network levels.
- MAHALO Modern ATM via Human/Automation Learning Optimisation (-2022)— developed a ML capability for enroute CD&R, and explored via realtime simulations the impacts of advisory automation, using experimental manipulations of system conformance and transparency.
- SafeOPS Strengthening Safe and Scalable ATM Services through Automated Risk Analytics based on Operational Data from Aviation Stakeholders (-2022)— explored the utility of AI prediction in ATM security and resilience, and developed an AI-model to predict go-arounds, based on publicly available data sources.
- SAFETEAM Safe Human-Digital Assistant teaming for higher levels of automation in aviation (2022)— a recently started project in the HAIKU call, SAFETEAM focuses on HF aspects of DAs. It aims to propose methodologies for assessing safety / resilience, and plans three UCs (enroute ATC, Unstable approaches, and DAs for evidence-based training (EBT)).
- SIMBAD Combining Simulation Models and Big Data Analytics for ATM Performance Analysis (-2022)— aimed to develop and evaluate ML approaches to ATM microsimulation models. Specifically it explored: 1) estimating hidden variables in historical air traffic data, 2) algorithms for classifying traffic patterns, and 3) development of simple performance metamodels for simulation.
- SINAPSE Software defined networking architecture augmented with Artificial Intelligence to improve aeronautical communications performance, security and efficiency (-2022)— Used ML to analyse network traffic data and predict cyberattack. Strengths of the approach were 1) its ability to provide 10 minute prediction, and 2) do so by sharing only AI models not underlying data.
- TAPAS Towards an Automated and exPLAINable ATM System (-2022)— developed XAI methods and experimentally assessed ML explainability in two use cases: tactical ATC CD&R, and pre-tactical ATFM.
- TEAMING.AI (-2022)— concerns the manufacturing sector, especially the role of the human in the future industry. The project developed a HAIT framework to optimise manufacturing through greater customisation of AI technologies. It

emphasised Human Factors, ethical, and legal aspects, as well as developing trust in a distributed multi-agent HAT.

- TRANSIT Travel Information Management for Seamless Intermodal Transport (-2022)— developed multimodal KPIs, analysis methods, and simulation tools, to assess intermodal transport solutions. The project developed an open-source tool for simulating long-distance travel demand, and a timetable synchronisation tool to help design synchronised multimodal (air + rail) timetables.

### ▪ 2.3.1 Applicability to HAIKU WPs and UCs

A preliminary mapping was made between the 16 technical research projects and the HAIKU WPs and UCs, as shown in Table 3.

Table 3: Mapping was made between the 16 technical research projects and the HAIKU WPs.

Project	WP2	WP3	WP4	WP5	WP6	UC1	UC2	UC3	UC4	UC5	UC6	WP7	WP8
AICHAIN	X	X (3.2)	X										
AISA		X			X	X						Safety	X
ALARM					X					X	X		
ARTIMATION		X		X	X				X				
FARO					X					X		Safety	
HAAWAI					X		X		X				
IMHOTEP					X						X		
ISOBAR													
MAHALO		X											X
SafeOps	X	X			X				X			Safety	
SAFETEAM		X			X	X	X					Safety & Legal	X
SIMBAD			X		X								
SINAPSE												Cybersecurity	
TAPAS		X		X	X	X	X	X	X	X	X		
TEAMING.AI	X				X				X			Legal	X
TRANSIT					X						X	Security	

### ○ 2.4 HF Constructs

Automation has long been used to handle tasks that are too ‘dangerous, dirty, demanding, or dull’ for the human operator. Although automation has provided many benefits (e.g. workload management, system efficiency, safety) over the years, Human Factors (HF) has long recognized the potential costs (Bainbridge, 1983). Such costs include workload extremes, situation awareness degradation, out-of-the-loop and return-to-manual concerns, etc. As the mechanisms and processes of ‘automation’ evolved into symbolic AI into ML, additional (or modified) concerns emerged, including the heightened challenges of explainability and transparency. The opacity of ML systems (think of a neural net that generates an output without explicit logic) can defy human analysis (AVSI, 2020; Kaliardos, 2022). As ML evolves from a tool to a teammate (HAIT), it in turn challenges existing methods and models for teamwork processes (team decision making, communication, shared situation awareness, etc. (NAS, 2022)), see Figure 2.

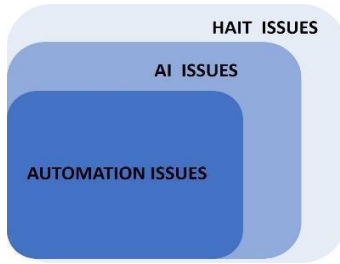


Figure 2. The evolution toward HAIT has brought new or changed HF concerns.

Schneiderman (2021) argues that the teaming metaphor in AI design risks unrealistic expectations and prefers an extended definition of AI tools. This seems to be a minority view (cf NAS, 2022) and brings its own risks such as failing to adequately consider uniquely team – related skills around teambuilding, communication and coordination.

NAS (2022) sees HAIT as a fundamental step beyond human – AI interaction that extends human capabilities and system performance beyond the individual capability of either individual agent. The authors see the social component of teambuilding as a critical and underacknowledged concern. They use the concepts of *social intelligence* and *theory of mind* to describe the necessary process whereby team members infer the processes underlying task performance.

The current review acknowledges the debate over the line between Human / AI- interaction and teaming (after all, a team can consist of only two members). The consensus view appears to be that HAIT brings unique team – related considerations. There is a long history of research into team effectiveness (Salas et al, 1992) and has focused on such issues as team composition, complementarity, shared cognition (mental models and situation awareness), coordination and communication, function allocation, task sharing, and team training skills (Wojton et al, 2021).

NAS (2022) noted that HAIT challenges current HF models and methods in seven main areas:

- Team biases
- Teamwork processes
- Team situation awareness
- Team trust
- Human-AI interaction methods
- Interfaces
- Team training

Additionally, **ethical** concerns (which run through several of the above areas) are increasingly recognised as critical (Hauptman et al, 2022; European Commission, 2019; Bryson & Winfield, 2017; Luetge, 2017), but there is debate over whether policy guidelines and principles are running ahead of scientific understanding in this area (Munn, 2022).

Literature review identified over 100 (interrelated) constructs relevant to HAIT, and these are mapped in Annex D. Based on this review, the following areas seem to be the richest ones in terms of current research: Trust; Transparency/ Explainability; Situation awareness; Teamwork processes; and Ethic.

### 2.4.1 Trust

Trust is generally recognized as a critical precursor of automation use and acceptance. Trust is a multidimensional concept (Malle & Ullman, 2021; Hancock et al, 2011; Hoffff & Bashir, 2015), encompassing both dispositional trust (the persistent tendency to dis/trust (Dzindolet et al, 2003)) and dynamically calibrated trust (Ezer et al, 2019; Lee & See, 2004). Calibration is the process by which the human learns in which situations the AI can be relied upon and when it cannot (McDermott et al 2018), and miscalibration can be associated either misuse (overuse) or disuse (Parasuraman & Riley, 1997).

Current trust models and methods still rely heavily on Lee & See's (2004) view that dynamic trust is calibrated through ongoing assessment of an agent's **performance**, **process**, and ultimate **purpose**. In this regard, it makes no difference whether that agent is human or machine—on the basis of observable performance, the operator infers underlying process and purpose.

For details on the **measurement of Trust**, see Annex H.

#### ▪ 2.4.2 Transparency and Explainability

There seems broad consensus on the need for AI transparency in the development of effective HAIT. The notion of automation transparency (and the related concept of explainability) has been researched broadly across many domains, including AI. The concern seems especially critical when one considers that some of the most powerful supervised learning ML approaches (like various neural net models) are also the most opaque in their inner workings. Across domains, a number of related terms have been used: automation transparency, interpretability, explainability and XAI, intelligibility, observability, understandability, automation visibility, and comprehensibility.

Transparency is a multifaceted construct that ultimately is shaped by what is sought to be understood. As such, the aspect that the human is trying to understand governs what should be made transparent, or explained. It can be to explain abnormal automation behavior (Kim & Hinds, 2006) or why the automation might err (McDermott et al., 2018). It can be to explain the behavior of intelligent agents and autonomous robots (Selkowitz et al., 2017; Core 2006), indicate the reliability of the automation (Jamieson et al, 2008), or the proximity of the automation is to its performance envelope (Helldin et al, 2013). There is currently very little empirical research that has explored automation transparency. While research has shown some benefits of automation transparency to acceptance, trust, situation awareness, workload, and response time, there are simply not enough results to form stable conclusions (Bhaskara, 2017). Research on transparency in the AI domains has been criticized for focusing primarily on XAI and tools like SHAP and LIME that focus on internal explainability, rather than on operator understanding and other psychological impacts (Abdul et al., 2018)

What information is required to achieve transparency? NAS (2022) recently conducted a literature review to identify specific information requirements associated with automation transparency. The team categorized these information requirements according to Endsley's (1995) three – part model of situational awareness and these can be summarized as follows:

#### System status information (stage 1 SA):

- raw data used by automation
- current system state

- Factors considered by the operator
- Performance
- Purpose and goals
- environmental constraints

System understandability (stage 2 SA):

- reasoning,
- trade-offs
- capabilities and limitations (e.g. types of error, ability to handle corrupt situations)

System predictability (stage 3 SA):

- planned actions
- predictability of future actions
- predicted consequences
- uncertainty

In the human factors and cognitive engineering domains, two models of agent transparency have been proposed for autonomous systems: Lyon's (2013) model for human-robot teaming approaches transparency from the requirement of establishing a shared intent and awareness between robot/autonomous systems and humans, and Chen et al.'s (2018, 2014) situation awareness-based agent transparency (SAT) model for human-agent teaming. The SAT model specifies three levels of transparency, paralleling the SA levels of perception, comprehension, and prediction.

*Research on automation transparency*

Empirical data have shown that automation transparency can benefit humans' understanding, trust, and acceptance of automation, while also improving performance (e.g. EAAIHLG, 2020). Consequently, transparency has been considered for many different reasons, such as to explain abnormal automation behavior (Kim & Hinds, 2006), why the automation might err (Dzindolet, 2003; McDermott, 2018), the behavior of intelligent agents and autonomous robots (Core et al., 2016; Selkowitz et al., 2015), as an indication of the automation's reliability (Jamieson et al., 2008), and the automation's proximity to its performance envelope (Helldin et al., 2013).

In a literature review on agent transparency, Bhaskara et al. (2020) investigated the effects of transparency on performance, response time, subjective workload, situation awareness, trust, and usability. Five studies were reviewed, all of which explored military applications and most of which operationalised transparency on the SAT model.

Bhaskara et al. (2020) distinguished between four levels of transparency: low (supporting perception in terms of basic information or advice), medium (supporting comprehension in terms of adding information about the agent's reasoning), high (supporting prediction in terms of adding information on either expected outcome/consequence or added reasoning for a recommendation), and very high (supported prediction by adding more information in the high transparency level (e.g., both an outcome prediction and uncertainty information). While findings show some benefits of increased (levels of) agent transparency on acceptance, trust, situation awareness, workload, and response time, the authors noted that results so far are inconclusive and that there are simply not enough results to form stable conclusions (Bhaskara et al., 2020).

Researchers have explored transparency of intelligent agents (e.g., robots) by providing explanations based on the agent's decision-making processes. Frameworks such as the Belief-Desire-Intention (BDI) (Rao and Georgeff, 1995), Partially Observable Markov Decision Process (POMDP) (Wang et al. 2016), and Parallel-rooted, Ordered, Slip-stack Hierarchical

(POSH) frameworks (Theodorou et al., 2017) have been used for modelling the decision-making processes and actions of agents. The framework used to model the mental process of the agent can also be used to provide explanations of the agent's behaviour. Generalized, all three frameworks model the agent's behaviour against three components: *goals* for which *actions* are accomplished based on an understanding of the current *state*. For increasing the user's understanding of the agent and its conduct, transparency of each component can be afforded. In experiments with an agent, built on the POMDP framework, explanations of the agent's inferred state (based on its sensors) and associated uncertainty were shown to benefit understanding, trust, mission success, and percentage correct decisions made, particularly when the agent's reliability was low.

For details on the **measurement of Transparency and Explainability** see Annex H.

### ▪ 2.4.3 Situation awareness

When pilots talk about 'getting behind the plane', or air traffic controllers speak of 'losing the picture' the concept they are both invoking is Situation Awareness (SA). SA has long been recognised across various domains as a key construct underlying cognitive performance and decision-making (see Figure 8). The study of SA seems to have grown out of the fighter cockpit domain.

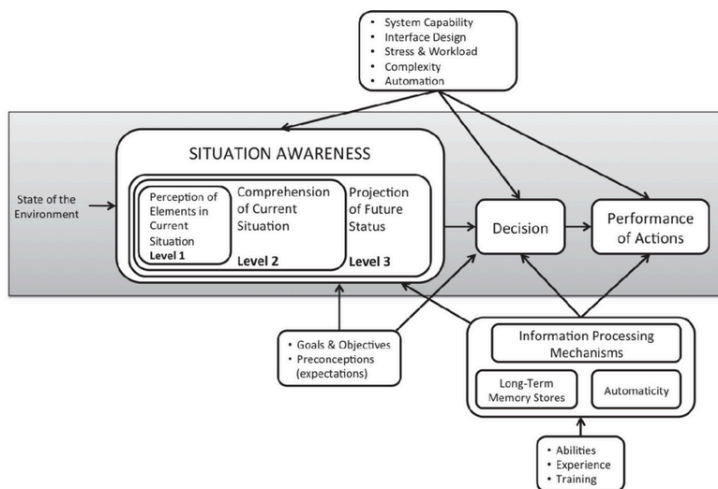


Figure 8. Endsley's (1995) three-level model of Situation Awareness (SA).

The most popular model of situation awareness has long been Endsley's (1988;1995) three level model. These three levels are perception, comprehension, and projection. Basically, situation awareness maintenance is a cyclical process by which the human perceives the state of the environment (level 1), comprehends the current situation (level 2), and is then able to project to the future status of the environment.

There have been some criticisms of the SA construct. For example, the relationship between SA and individual differences, and also its utility as a predictor of safety, have both been questioned (Thurston, 2016). Also, there is debate over whether SA refers to the process of acquisition, or the product of the three hierarchical levels.

Over the years the SA construct has been extended to the concepts of shared SA, distributed SA, and team SA (Yiu et al.,2022; Shively et al.,2017; Selkowitz, Lakhami & Chen, 2017). One interesting development for HAIT is Chen's extension of SA, into the SAT model (Chen 2018 includes bi-directional communication), suggesting a link between earlier SA assessment and HAIT relevant schemes.

For details on the **measurement of Situation Awareness** see Annex H.

#### 2.4.4 Teamwork

There is a decades-long history of research into human–human teamwork (Salas et al., 1993; Cooke et al., 2000) and much of this can be extended to the HAIT context. According to NAS (2022) heterogeneity is the single defining feature of teams, and heterogeneity can refer to either differences in **task work** - (e.g. one pilot flies while one navigates) or **teamwork** levels (e.g. one is in command and has decision-making authority). Applying this view to HAIT design means that AI and human will each do what they are best at. But this is not the ‘men are better at, machines are better at’ (MABA MABA) function allocation scheme of the 1950s. NAS (2020) argue for some overlapping roles and responsibilities for reasons of backstopping. Moreover, team control structure is not necessarily fixed and might vary by context.

Teamwork is a fairly high level emergent property and measurement is not always straightforward. For example, task performance measures (e.g. quality or correctness of outcome ) or an intuitively appealing criterion for team performance. But task performance measures can be something of a double-edged sword. As Bansa et al (2019) showed, increases in AI performance if they are not compatible with operator experience can actually decrease task performance.

Some proxy concepts that lend themselves to measurement include the following: **communication and coordination** measures (Cooke et al, 2013); Shared and **team mental models** (Cannon-Bowers & Salas, 1990), and **team cognition** (McNeese et al, 2021). Cooke Salas Kickel & Bell (2004) noted that team cognition is important for at least a few reasons:

- First, team cognition provide some window into factors underlying team performance,
- it helps target the cognitive underpinnings of team performance, and
- it can help design technical aids to bolster team performance at the actual task.

Several researchers suggest that **trust** is a closely related proxy measure of teamwork. Trust can be seen as a measure of mental model validity in the AI’s output reliability (Bansai 2019; Hasse et al, 2014)

In conclusion, a few researchers noted that teamwork measurement still requires better validated measures, and automated/embedded measures to reduce task intrusion.

Cooke et al (2004) noted that additional work was needed in

- making broader use of knowledge elicitation methods
- need for automated and embedded measures to stop intruding on task performance
- need validated measures

What Cooke et al (2017) proposed was:

- collaborative queries-- knowledge assessment via team collaboration on their responses to queries, which would otherwise have been administered individually
- performance of heterogeneous teams-- in a distributed task with multiple roles knowledge accuracy metrics should be keyed to individual role or position.
- Individual query responses are then scored not only against overall knowledge, but also against role specific knowledge.
- Aggregation and joint statistical analysis of team performance data, rather than analysis of individual data across team members
- automating and embedding measures, to minimize intrusiveness
- validating new measures of team cognition

Ma et al. (2022) propose either hierarchical task analysis (HTA), cognitive work analysis (CWA) or the Work Models that Compute framework (Pritchett et al., 2014) to implement several different categories of teamwork metrics as follows

1. Teamwork metrics of shared ecology-- include
  - a. information coherency i.e. the degree to which information is readily available to that agent and remains predictable and accessible to them
  - b. physical coherency – spatial proximity that – the degree to which agents work on separate physical elements of the work environment
2. teamwork metrics of shared cognition—include
  - a. agent capability mismatch
  - b. authority – responsibility mismatches
  - c. team cognitive coherence
3. interaction of teamwork and traditional metrics

Cooke et al. (2017) conclude the following from their review of team performance measures

1. task work knowledge is predictive of team performance
2. team knowledge changes with experience
3. communication consistency predicts team performance

#### 2.4.5 Ethics

Unlike the preceding constructs, **ethics** concerns and guidance grow more out of legal frameworks (such as various articles of the *Charter of Fundamental Rights of the EU*) than out of scientific research. As regulatory frameworks for **Ethical AI** compliance come further into focus, industry and various agencies have begun offering their own guidance (self-assessment checklists, roadmaps, etc-- often freely distributed) for ensuring ethical AI. This section presents the three guidance resources we uncovered, all of which are in the form of self-assessment tools for AI developers.

**Digital Dubai, AI System Ethics Self-Assessment Tool** – a high-level interactive tool (out in beta) to be used at the organizational level. This free self-assessment inventory outputs three simple ratings: scope estimate, overall impact risk, and decision classification significance. Although this is intended for industry management decision making at the enterprise level, there might be some limited applicability to the HAIKU UCs.  
<https://www.digitaldubai.ae/self-assessment>

**European Commission's Assessment List for Trustworthy AI (ALTAI) checklist** – The EC's AI High Level Expert Group (AI HLAG) released their Ethics Guidelines for Trustworthy AI in 2019, to help ensure that AI developments safeguard: Privacy; Transparency (in the public sense); Fairness; Human agency and oversight; Technical robustness and safety; Societal and environmental well-being; Accountability; and Fairness. These 2019 guidelines were followed by the 2020 release of the ALTAI assessment checklist, which is presented in Annex E and also available online at  
<https://digital-strategy.ec.europa.eu/en/library/assessment-list-trustworthy-artificial-intelligence-altai-self-assessment>

**Microsoft Responsible AI Impact Assessment Template**—to help ensure that AI is: Fair; Reliable; Safe; Private and secure; Inclusive; Transparent; and Accountable. This and other tools (e.g. AI fairness checklist, guidelines, and various opensource tools) are available at their website. The checklist is reproduced in Annex F and online at  
<https://www.microsoft.com/en-us/ai/responsible-ai-resources>

One additional set of tools, from **KOSA.AI**, seems worth mentioning. KOSI is a commercial company selling a suite of tools that claims to guide AI development end-to-end, including compliance checking. The extent of this functionality, and pricing, are unverified.

## 2.5 Models

Stramler (2019) defines a *model* as:

*...a system for providing quantitative estimates of results under specified conditions, [which] may be physical, graphical, computer / electric, or theoretical / abstract.*

Modelling involves constructing a simplified representation (i.e. abstraction) of some broader domain, process, construct, or system, in sufficient detail that this abstraction can help describe system performance and/or make predictions about specific underlying processes and outputs. For this discussion we distinguish models from frameworks, a less granular, higher-level abstraction. In this chapter we discuss both integrated high-level frameworks for HAIT, and more granular models of underlying constructs (e.g. trust).

This search for HAIT-applicable models started from a Human Factors (HF) perspective, and expanded to encompass other domains such as system engineering and software development. HF has a long history of descriptive- and predictive modelling to help drive system design, development and evaluation in such domains as automobile driving (Park & Zahabi, 2022), aviation (Foyle & Hooley, 2007; Johnson & Maddox, 2007), process control, and nuclear power generation (O'Hara, 2009). This review did not initially consider ergonomic modelling (and the fitting of interface to operator) but tried to focus on cognitive and team specific aspects that would be more immediately applicable to the HAIT context. Model approaches over the last half century seem to have evolved in step with technology: from early control theory models (in which the human is seen as a mere 'meat servo' controller); to task network models; to cognitive architecture-based models grown out of cognitive science and information processing perspectives.

In this section, acknowledging that there are no or few mature and developed Human AI teaming frameworks available at present (NAS, 2022), we present a set of high-level approaches that are suitable candidates to use in the analysis and design of Human AI teaming systems. Of these, most have been established before the emergence of HAIT, and have been applied more broadly in Human Systems Integration (HSI), sometimes in HAT applications. A few explicitly address HAT and HAIT, at different levels of granularity.

This chapter is presented in two sections. The first (2.5.1) identifies candidate high-level integrated frameworks for HAIT and LOA models (2.5.2). The second section, 2.5.3., identifies some component models that seem promising for underlying aspects of HAIT performance. Again, modeling has a long and rich history in Human Factors and System Engineering, and there are many long-accepted models. The following summary focuses on those that are either new, or extensions of long accepted models now adapted to specifically address HAIT or similar areas.

### 2.5.1 Integrated (high-level) frameworks

#### Cognitive work analysis

Cognitive work analysis (CWA) (Rasmussen 1994, Vicente 1999) is a larger framework that considers the constraints in the external environment/system that the operator needs to consider achieving goals and system fulfilment (ecological approach, behavior

constraining). A full CWA analysis is comprehensive and encompasses five phases starting from the ecological perspective (constraints) and subsequently analyzing support needed to the human operator at its later stages. We discuss here the first stage: work domain analysis and the Abstraction Hierarchy.

The work domain analysis comprises the first stage of CWA and it involves identifying the constraints of the system independent of tasks and goals. The identified constraints are placed on a scale called the Abstraction Hierarchy where the highest level represents the overall purpose of the work and system, and the lowest level describes the physical components of the system. Next highest is the value-level related to priorities and the system's ability to meet its purpose. The mid-level describes the functions/constraints that must be met to approach the needed values/priorities. In the next lowest level are the object-related processes represented and these describe the function of system's components, that are described at the lowest physical level in the Abstraction Hierarchy.

### *Cognitive Systems Engineering*

Cognitive Systems Engineering (CSE) is an approach to model and understand complex human-machine systems on a systems cognitive level (i.e., cognitive functions) and modeled as an adaptive system that reacts to feedback inputs to adapt to and act to maintain control of a process. Cognitive systems, according to Hollnagel (2000), can be modeled as joint systems – the human and the artefact - that together maintain control in a dynamic environment. The joint system has a goal as well as knowledge about itself and the environment in the planning and execution of a task to maintain control.

CSE does not model cognition as information processing transformations, or provides structural components, but rather emphasising the cognitive functions as results from underlying cognitive processes and utilising constructs from cybernetic control theory (goals, feedback). The contextual control model (COCOM) describes basic properties of the joint system:

### *COCOM and ECOM*

Three basic concepts are central in COCOM: competence, control, and constructs.

Competence represents the set of possible actions or responses that the joint system can take to a situation according to the recognised needs and demands. Control characterises the orderliness of performance and the way in which competence is applied in relation to the immediate and long term goals, and this is time-dependent. Constructs refer to what the system knows or assumes about the situation in which the action takes place (Hollnagel, 2000).

In an extended version of COCOM, ECOM (Extended Control Model), Hollnagel introduces several control loops and modifies the model to include different levels of control that, basically, represent a scale from low level regulation to planning control (skill-based, rule-based and knowledge-based control actions). In characterising ECOM, Hollnagel pictures four stacked control loops. There can be interaction between control loops and each control loop can be temporarily suspended. Automation can assume control over one or more of these loops, and performance can be either open- or closed-loop. The two models are depicted in Figure 9.

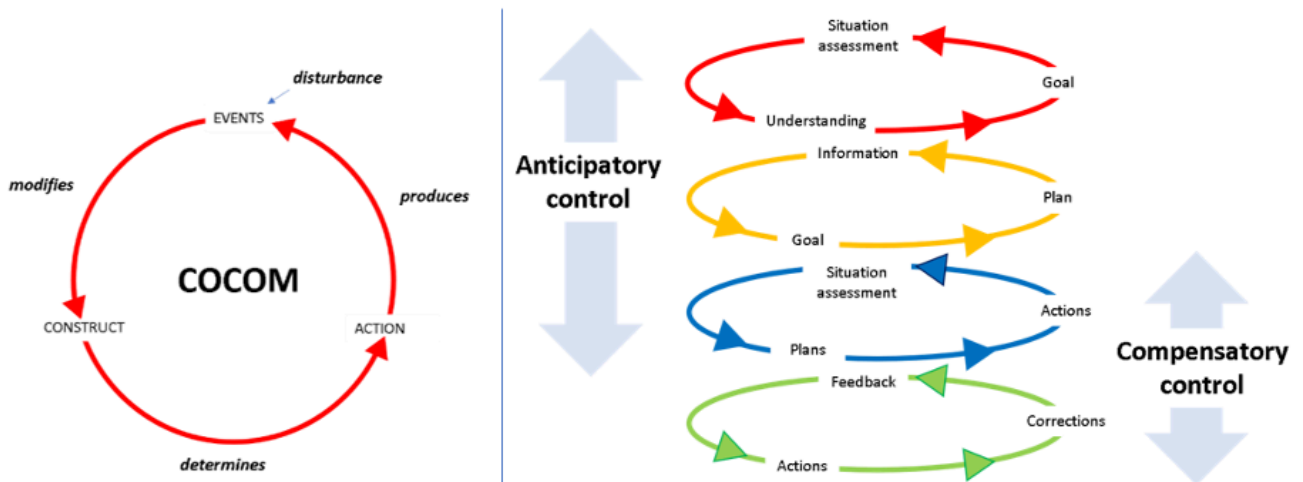


Figure 9: The Cognitive Control Model (COCOM) and Extended Control Model (ECOM) (after Hollnagel, 2000).

## PRODEC

PRODEC (Boy & Morel, 2022) is a recent (and still in-progress) framework and method for designing human machine teaming (see Figure 10). It aims to integrate Procedural and Declarative (hence the name) methods. It is one of the few frameworks to explicitly address HAIT. PRODEC was developed around projects covering intelligent assistance for fighter pilots, tele-robotics for oil and gas exploration, and remote maintenance of helicopter engines. PRODEC focuses on both procedural as well as problem-solving skills for both humans and machines. PRODEC is rooted in Scenario-Based Design (a sort of multiplayer wargaming environment to develop realistic scenarios) and its knowledge elicitation and analytic activities following general steps:

- Initial task analysis,
- Elicitation of emergent functions and structures,
- Prototype implementation using declarative representation,
- Human in the loop simulation,
- Observation and analysis, elicitation of emergent properties, and
- Modified task analysis.

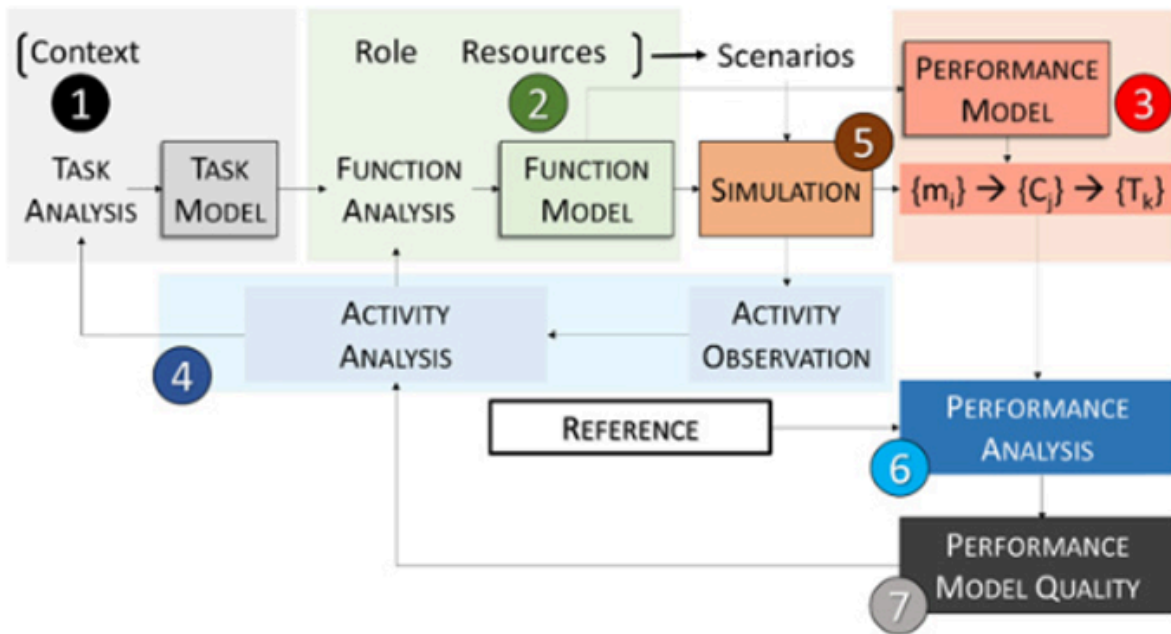


Figure 10: PRODEC method applied to a multi-agent system in the MOHICAN project (Boy & Morel, 2022).

The authors claim that PRODEC has been used and validated in the MOHICAN project on advanced fighter aircraft, and has helped develop metrics for performance, trust, collaboration in the context of this assessment. This framework and approach looks promising, but further information is required.

### *National Academy of Sciences HAIT framework*

The US National Academy of Sciences recently completed a study into research gaps and issues around Human-AI Teaming. Chaired by Mica Endsley, the expert group structured their investigation and one of their main conclusions was that better models are needed for HAIT processes (NAS, 2022). As shown in the Figure 11 below, the team created a functional flow diagram of the processes underlying human – AI team performance and identified a total of 13 underlying constructs. Of these, the authors note model gaps in seven of the HAIT related constructs:

- Team biases
- Teamwork processes
- Team situation awareness
- Team trust
- Human-AI interaction methods
- Interfaces
- Team training.

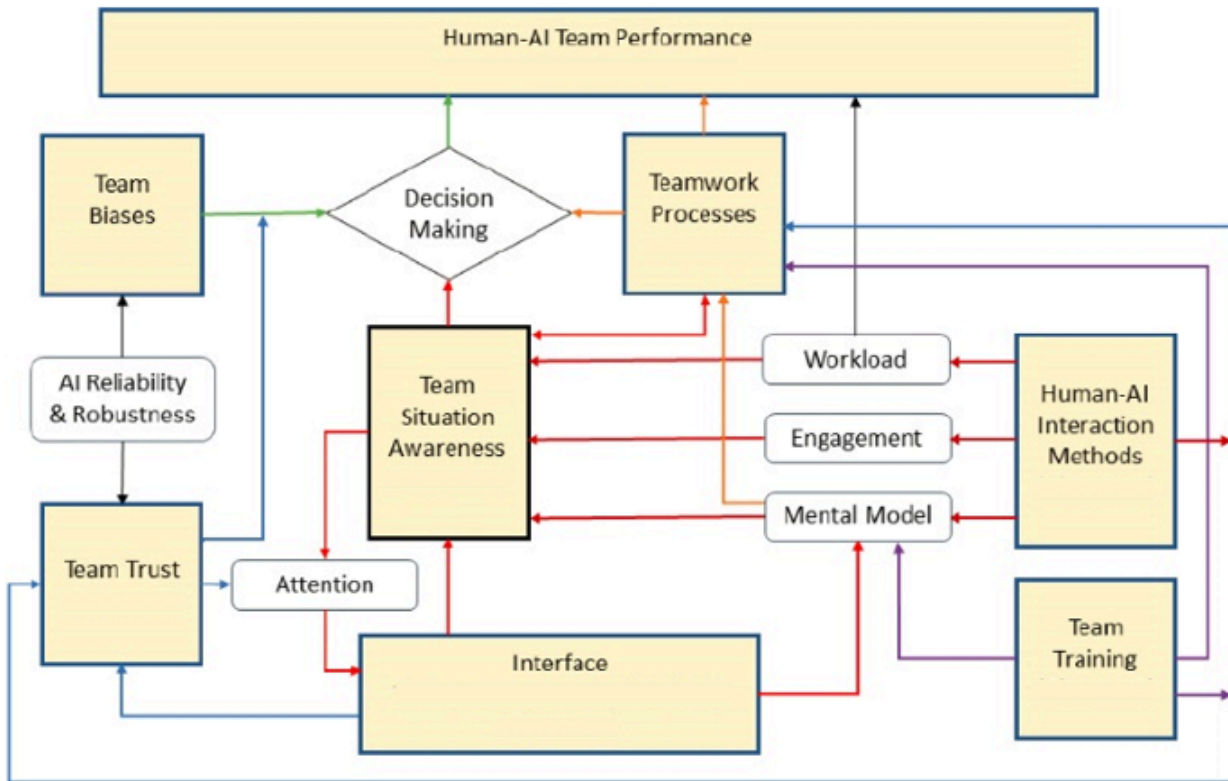


Figure 11. A framework for HAIT (after NAS, 2022).

### MITRE Framework for Designing HMT

McDermott et al. (2018) developed a set of general requirements for human – machine teaming. Their resulting guide acknowledges that one size does not fit all, and provides the system engineering methods for tailoring general requirements to specific systems. The team identified ten 'leverage points' that it organized into an HMT framework to structure the design content and design process factors (see Figure 12).

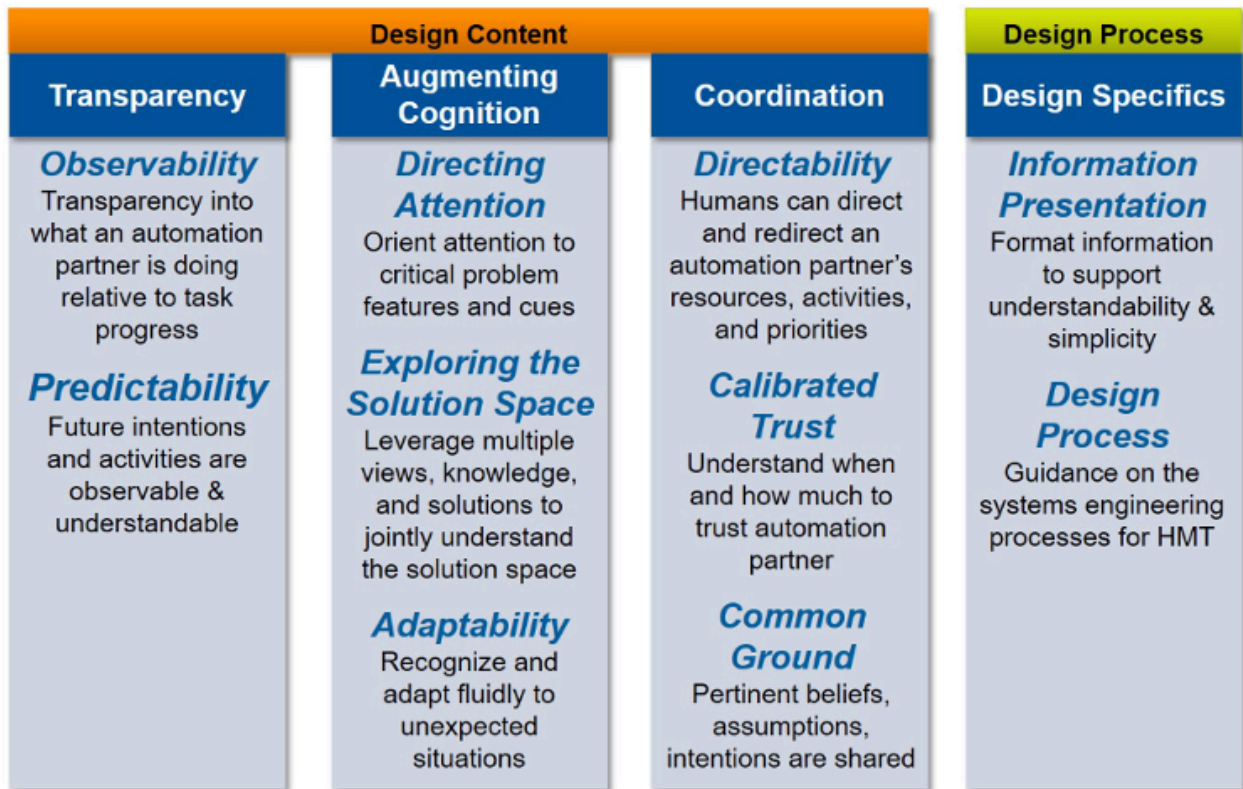


Figure 12: MITRE Framework for Designing HMT.

From this framework MITRE outlines a three step process for system development:

1. Knowledge elicitation is achieved via:
  - a. SME interviews (to describe the system and envisioned autonomy, identify top challenges, specify current state of automation and autonomy, and conduct critical decision method probes); and
  - b. Knowledge Audits (deepening discussion of domain specific knowledge)
2. Data analysis - coding interview notes and categorizing textual information into the elements of the HMT framework.
3. Writing requirements - producing actionable guidance for developers, based on the previously collected data.

### *Inputs-Mediators-Outcomes (IMO) Framework for Team Effectiveness*

The IMO framework (Ilgen et al, 2005) was adopted as an evolution of the previously predominant framework Input-Process-Output (IPO), acknowledging the relevance of mediating mechanisms other than team processes, such as cognitive, motivational, and affective states – referred to as emergent states—and the possible complexity and nonlinearity of system interactions (Sénquiz-Díaz & Ortiz-Soto, 2019), see Figure 13. Such other aspects as the temporal/cyclic dynamics and the multi-level composition of the team (organization-team-member) have been also incorporated in the framework (Mathieu et al., 2008).

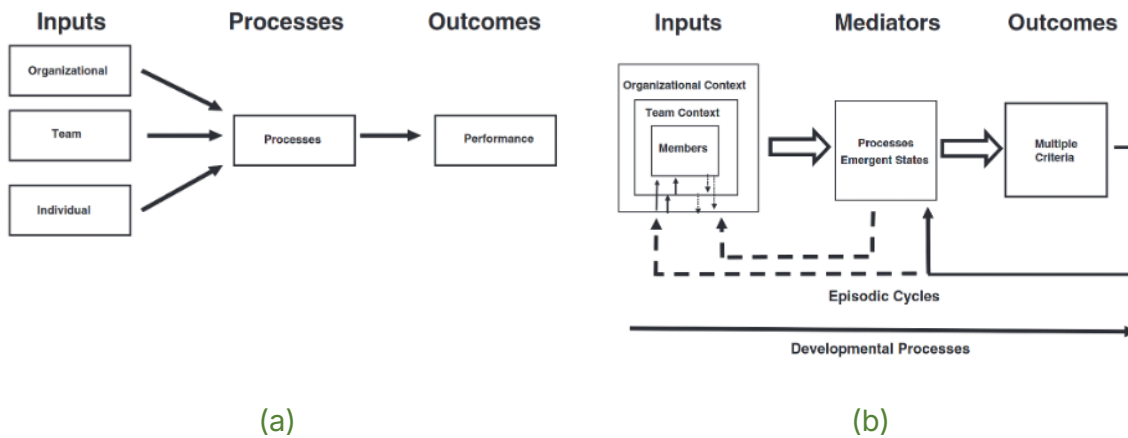


Figure 13: Team effectiveness frameworks: a) IPO; b) IMO; adapted from (Mathieu et al., 2008)

These high-level models are employed to organize the different constructs that contribute to team performance processes and outcomes, as depicted in Figure 14. Specific models are available to analyse the detailed dynamics of constructs as situation awareness, team cognition, trust, etc.

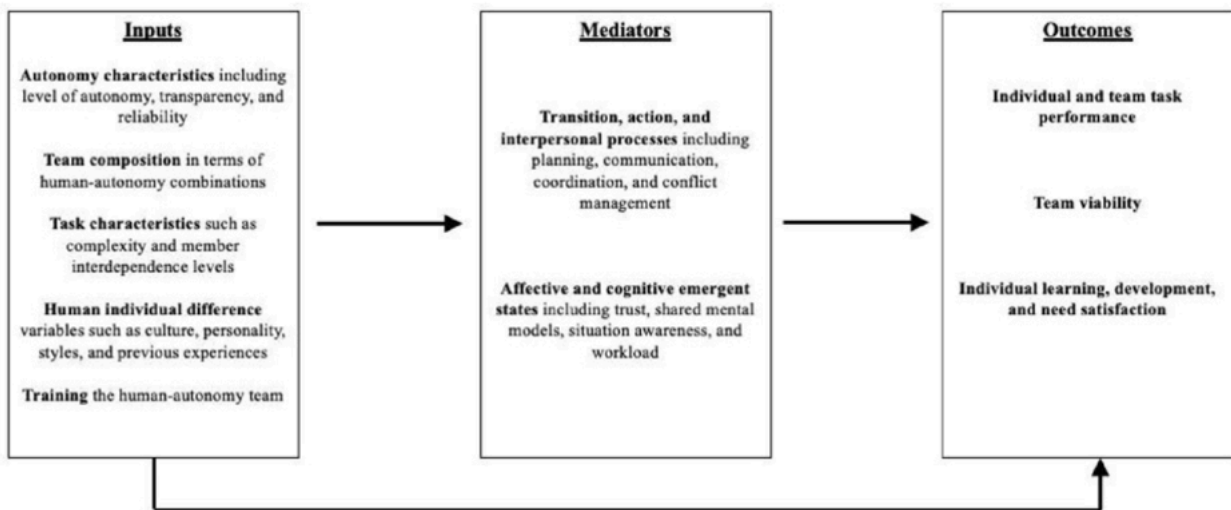


Figure 14: Examples of variables (characteristics and constructs) involved in the IMO process.

Ilgen's IMO model has become known as the Input-Mediator-Outcome-Input (IMOI) model, emphasizing the cyclical nature of the process.

### 2.5.2 LOA Models

Level of Automation (LOA) models have been around for almost 50 years (Sheridan & Verplank, 1978). Since that time, at least a dozen extensions have been proposed. One thing all LOA models have in common is that they propose a continuum of automation from fully manual to fully automated control, capturing both automation level and authority in one dimension. Parasuraman, Sheridan & Wickens (2000) proposed a model for types and levels of automation, extending the basic LOA model by suggesting that automation can be applied in four broad classes; information acquisition, information analysis, decision, and action selection; and action implementation (see Figure 15). Information acquisition refers to the

low-level positioning and orientation of sensory receptors, including preprocessing to achieve selective attention (of multiple data sources).

The secondary stage is sentient perception and conscious processing of the sensory information. This occurs prior to the point of decision making. Decisions on actions to take, as responses to demands of the situation, follows at the third stage (cognitive level). The final stage is the actual actions taken based on the prior decisions in the third stage. The authors acknowledge that the model is a simplification of human information processing but sees it as starting point for including automation in human-machine systems.

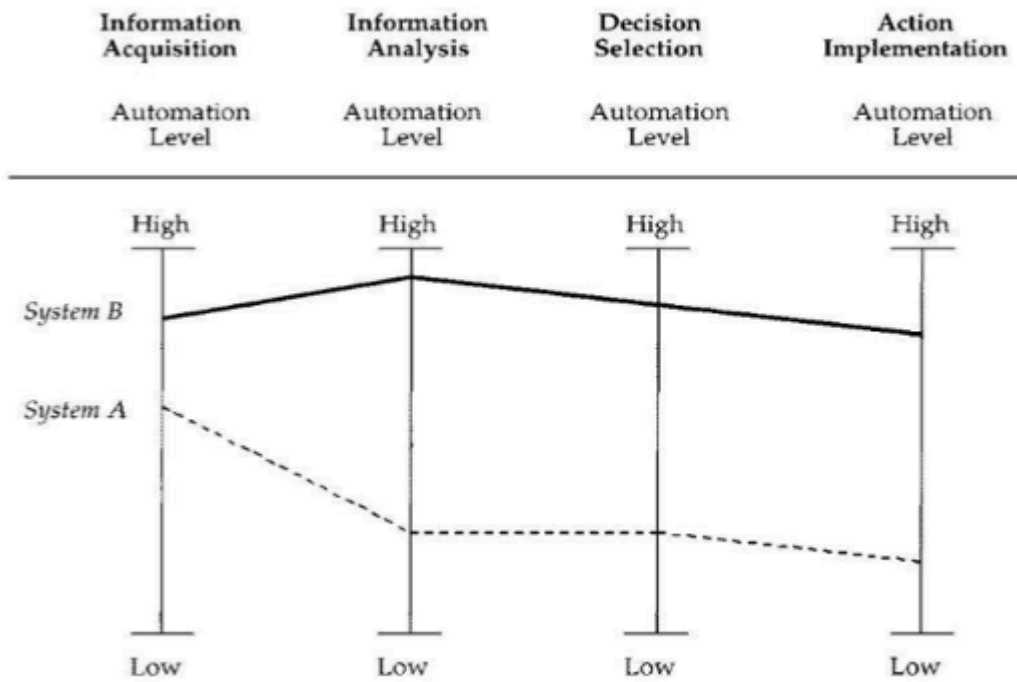


Figure 15. A model for Types and Levels of Automation (Parasuraman, Sheridan & Wickens, 2000).

As discussed in section 5 the LOA frameworks have fallen out of favor as they have become judged too simplistic and fail to consider other potential dimensions of automation, including automation type (e.g. static vs dynamic), LOA trigger mechanisms, and authority structure (how much authority does the automation have to invoke LOA changes?).

### Joint Control Framework

The Joint Control Framework (JCF) can be seen as an extension of the above theories based on abstraction layers and cognitive functions as the unit of analysis (Lundberg & Johansson, 2021). JCF adds further analysis of Levels of Autonomy in Cognitive Control (LACC), and temporal descriptions of human-machine interaction in a Score notation. The approach facilitates analyses across cases and domains, and it has been suggested as a candidate framework for analysis in the HAiku project.

The framework can be used to describe critical episodes of interaction between human operators and autonomous, automated, and manual control systems (see Figure 16). A JCF analysis considers cognitive control levels (functions), temporal aspects of control, and communication and control at the system joints. A JCF analysis typically includes process mapping (PM), analysis of Levels of Autonomy in Cognitive Control (LACC), and temporal

descriptions of human-machine interaction through the Score notation. Details of the Joint Control Framework can be found in (Lundberg and Johansson 2021).

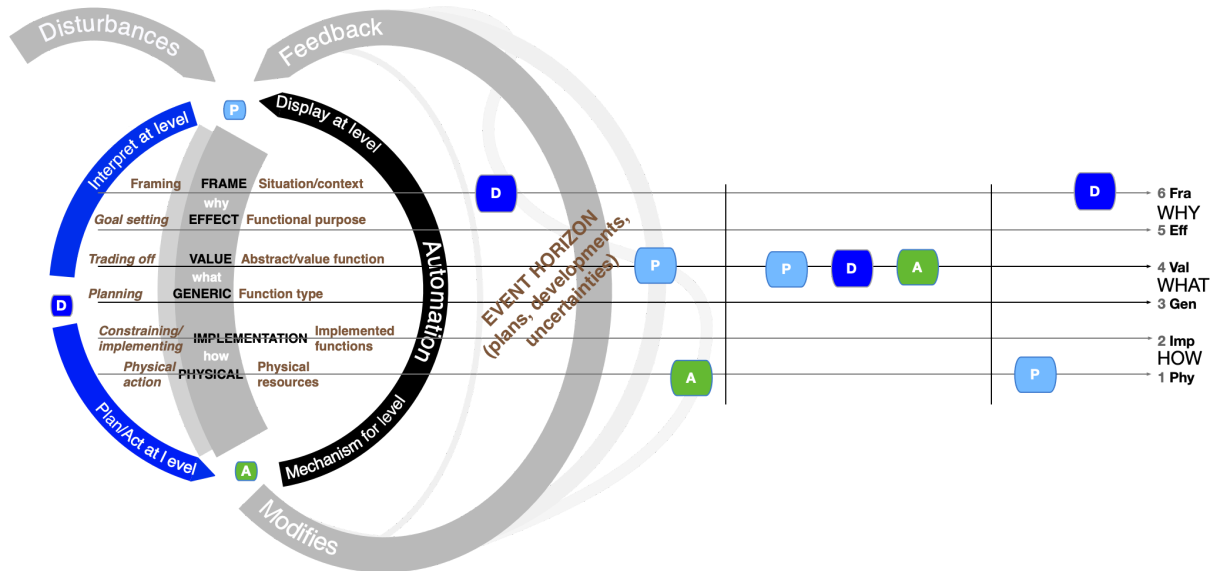


Figure 16: The Joint Control Framework (from Lundberg & Johansson, 2021).

### 2.5.3 Component models

As noted by NAS (2022), there seem to be research gaps in several of the constructs underlying HAIT (including team trust, teamwork processes, team SA, and training). Nonetheless review identified several component models that might be interesting for the HAIKU UCs. This section presents some of them.

#### *Hauptman et al's Team Ethics and Adaptive Autonomy model*

This recent two-part model proposes a dynamic ethical code for AI teammates in HAIT (Hauptman, Schelble & McNeese, 2022). In the first part of the model, an ethical code is used to adapt the AI agent's autonomy level. The second part of the model explains how the ethical code is iteratively updated. This two-part process of ethics adaptation and explanation is shown in the following schematics (Figures 17-18).

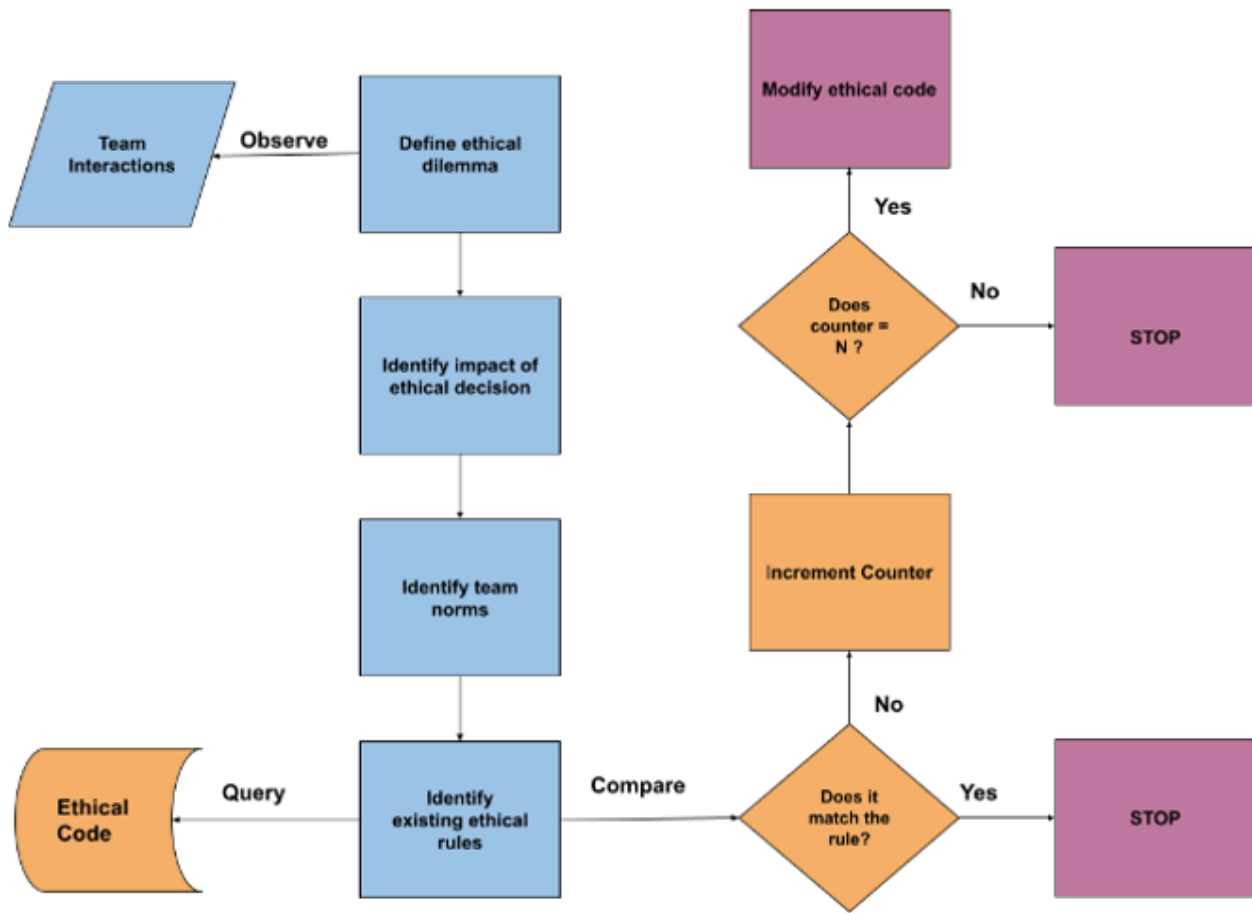


Figure 17: Ethical code adaptation (Hauptman et al, 2022).

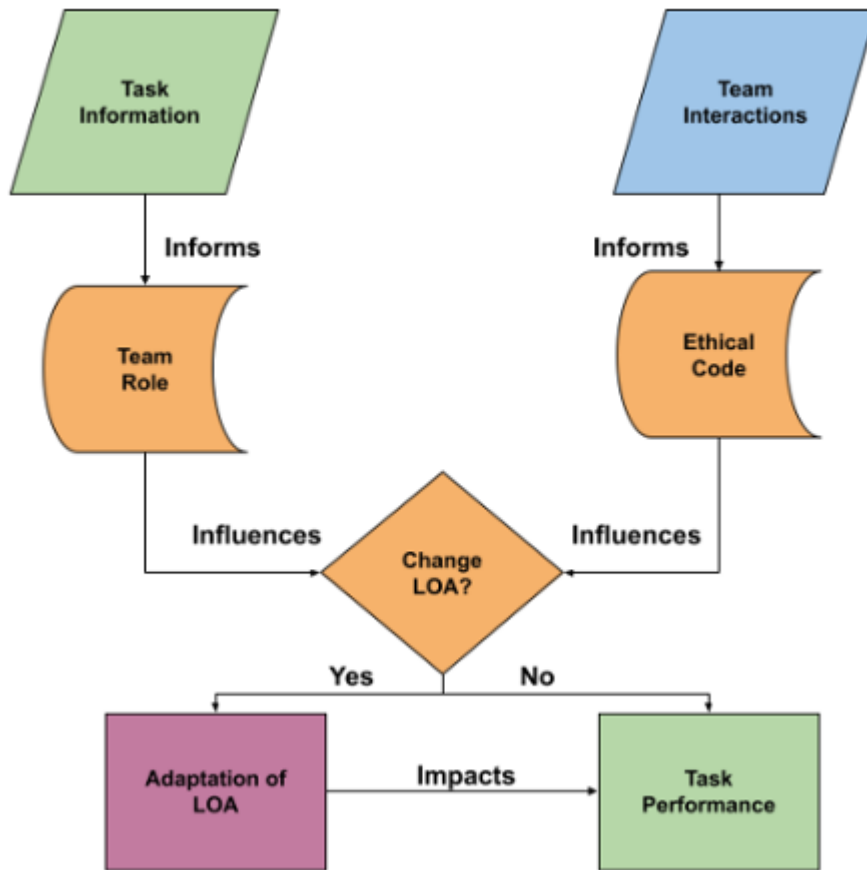


Figure 18: Ethical code [explanation](#) (Hauptman et al, 2022).

### *MUFASA Automation Use Model (MAUM)*

The MUFASA project explored air traffic controllers' use of advanced decision aiding automation, and put forward a theoretical framework for how to understand operators' decision to use or not use an intelligent aid. This view distinguishes factors both internal and external to the controller that feed into the evaluation decision. According to this model a cycle of use – feedback – assessment - trust recalibration occurs. This underscores one of the paradoxes of (optional use) intelligent aids: that an operator might only come to trust the system after using it, but might not choose to use it until they trust it.

Notice that this model also distinguishes three levels of trust, based on Lee and See's (2004) trust model. According to Lee and See, the only objective indication we get of another agent's **performance** (whether that agent is an intelligent aid, a robot, or another human) is their observable performance. On the basis of this we all infer underlying **process** and further, underlying **purpose**. Lee & See's widely accepted model of trust dimensions has been called the PPP Model.

In addition to 'calibrated trust' (via the PPP model), operator automation strategy is driven by a dispositional trust, that is a more general tendency to trust or distrust automation. It is often assumed (correctly or not) that dispositional trust toward new advanced technologies decreases with age. Finally, the interaction between external contextual factors and internal "performance shaping factors" drive the final decision of whether to rely on automation or not. Time pressure and task criticality, for example, can be important drivers of the use decision. This underscores the distinction between **acceptance of** and **agreement with**

automation. If time is tight, the operator might accept the use of automation that they would not necessarily agree with.

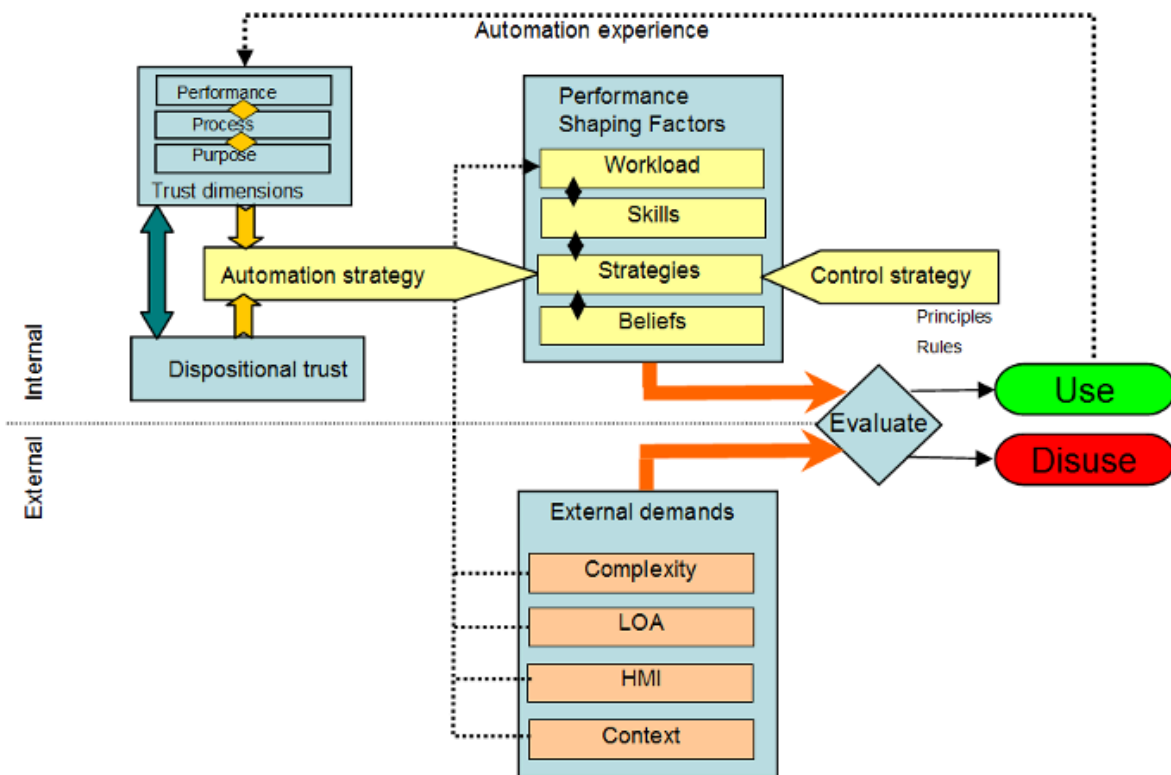


Figure 19. The MUFASA Automation Use Model (MAUM, after Westin & Hilburn, 2011)

### Chen et al's Situation Awareness Based Agent Transparency (SAT) Model

Chen and her colleagues developed the "situation awareness-based agent transparency" (SAT) model to explain human awareness of an agent's current actions and plans, reasoning process, and outcome predictions. The original SAT model (Chen et al., 2014) was expanded to incorporate teamwork and bidirectional transparency (Chen et al, 2018). See Figure 20.

The SAT model integrates a few widely accepted component models. First is Endsley's three stage model (perception, comprehension, projection) of situation awareness (Endsley, 1995). It is also built on Lee & See's (2004) PPP trust model and Rao & Georgeff's (1995) BDI (beliefs, desires, intentions) agent framework.

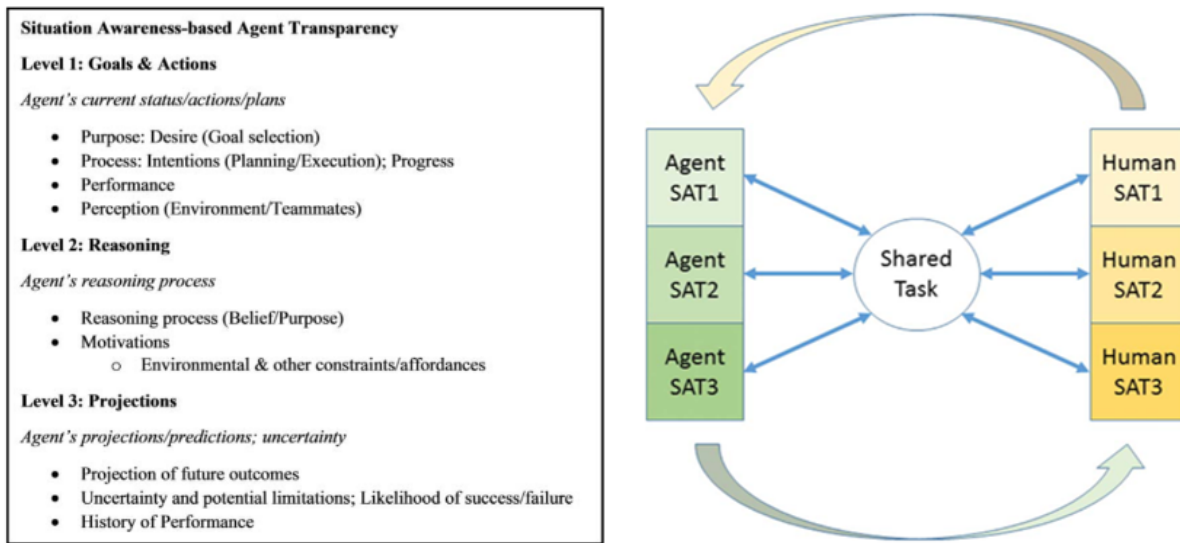


Figure 20: Chen et al's original (2014) and revised (2018) SAT model.

In 2018, four years after their original SAT model, Chen and her colleagues acknowledged the increasing role of machine learning and 'mixed initiative' teaming, and updated the SAT model by incorporating teamwork transparency and bidirectional communications aspects between human and agent.

### *The Lee & See (2004) 'PPP' Trust Model*

Although this model is almost 20 years old it deserves mention for its impact and longevity. Many of the current trust frameworks and measurement schemes incorporate Lee & See's (2004) idea that trust is calibrated through assessment of three aspects of agent behavior: overt performance, underlying process, and the deeper purpose behind the agent.

If there is one shortcoming of the PPP Model, and others that rely on it, it is that it focuses exclusively on dynamic or calibrated trust. That is, the model addresses how trust either develops or decays with the experience of interacting with automation. But there is also the potential issue of dispositional trust, or the relatively fixed willingness to accept automation (Merritt & Ilgen, 2008).

### 3 Monitoring of Human Performance

#### 3.1 Introduction

##### 3.1.1 Objectives

The main purpose of this section is to present the State-of-the-Art (SoA) in Human Performance Monitoring, in aviation and other relevant industrial domains, performed within Task 3.2 "Monitoring of Human Performance". More specifically, the goal of this task is to identify and select the most relevant sensors and technologies for the HAIKU Use Cases.

##### 3.1.2 Structure of section

The document is structured in four sub-sections:

- Sub-section 1 is the introduction;
- Sub-section 2 describes the methodology chosen to perform the State-of-the-Art;
- Sub-section 3 presents and analyses the selected sensors and technologies;
- Sub-section 4 shows a preliminary mapping of the selected sensors and technologies on the six HAIKU use cases.

#### 3.2 Methodology

The development of the State-of-the-Art is based on a 2-step methodology and mostly relies on the vast experience of consortium partners on the topic.

Step 1 consists in the definition of the SoA review criteria and the subsequent selection, through a desk review, of relevant sensors and technologies and related analysis (see the next paragraph for more details). Step 2 aims at mapping the selected systems on the HAIKU use cases, fitting them with end users' task types and relevant cognitive states.

More details on both SoA review and Selection criteria is provided in the following paragraph.

##### 3.2.1 State-of-the-Art Review Criteria

The definition of review criteria is a key first step to allow comparison across technologies and thus the identification of the most suitable ones for the HAIKU use cases. It is also relevant to provide better insight into how technologies could possibly be combined.

The criteria are presented in following Table 4.

Table 4: State-of-the-Art review criteria

Criterion	Definition
Sensor/Technology	Technology name and acronym(s)
<i>Technology</i>	
Manufacturer/s	Technology manufacturer or developer (if still in an experimental phase)
Readiness	(1) System is available on the market

	(2) System is in an experimental phase
Consortium expertise	Is a HAIKU partner familiar and knowledgeable with the technology and able to operate it?
<i>Technical</i>	
Equipment/Sensor Type	What is the technology and/or sensors being used (e.g. pressure sensor, eye tracker, accelerometer, heart rate monitor)?
Associated Software	Does the technology have an associated software to process the data output? (yes/no) Is it proprietary and the software code is locked or is it an 'in-house' (Haiku partners) software design? Does it analyse the data in real time and give an output or is it for post-hoc analysis?
<i>Human Factors concept</i>	
Data being measured	What data is being measured by the technology or sensor (e.g. blink rate, saccade length, gesture, heart rate variability, skin conductance)?
Physical and cognitive states being observed (from the data)	What psychological, physiological or behavioural parameter is being observed in the data (e.g. workload, arousal, attention tunnelling, drowsiness)?
<i>Characteristics</i>	
Invasiveness	Low: the sensor / technology is not invasive at all (e.g. no-wearable device); Medium: the sensor / technology might be invasive in specific circumstances (e.g. infrared cameras); High: the sensor / technology is invasive (e.g. wearable device).
Temporal / Spatial Resolution	Does it have high or low temporal and/or spatial resolution? What is it?
Limitations	Details of the most relevant limitations E.g. Does the technology need calibration? Does the technology require specific environmental characteristics?)

Cost	What does the technology cost (referring only to the system and not the required activities for setting it up)?
<i>Context of use</i>	
Industries	What industry(ies) is this technology currently used in?

On the basis of the selected review criteria, a template for technologies / sensors analysis was developed.

Table 5: Technologies / sensors analysis template

<b>Technology:</b>		
Manufacturer/s:	Readiness:	Consortium expertise:
<b>Technical</b>		
Equipment/Sensor Type:	Associated Software:	
<b>Human Factors concept</b>		
Data being measured:	Physical and cognitive states being observed (from the data):	
<b>Characteristics</b>		
Invasiveness:	Temporal / Spatial resolution:	Limitations:
Cost:		
<b>Context of use</b>		
Industries:		
<b>Applicability in HAIKU Use Cases</b>		
<b>UC1:</b> Flightdeck startle response	Yes/no	Task/s:
<b>UC2:</b> Flightdeck route planning		
<b>UC3:</b> Digital Tower		
<b>UC4:</b> UAM		
<b>UC5:</b> Airport Safety Watch		
<b>UC6:</b> Virus spreading in airports		

## Image & References

### ▪ 3.2.2 Use Case Mapping Criteria

In order to find a suitable mapping between the technologies reviewed and the six HAIKU use cases, high level requirements were elicited from use case owners through a series of questions, as follows:

1. Do you envisage a purpose for monitoring human performance? (Monitoring human performance, in terms of the collection of information about the users, in a representative environment, from worn or off-body detection systems, to provide insight into their status, either in real time or post-hoc).
2. What human characteristic would you try to capture? (For example physical activity, health, fall detection, sleep, workload).
3. What data/information would you aspire to collect (if known)? (For example breathing rate, heart rate, GPS, accelerometry, ECG).
4. What other requirements do you have that need to be considered? (For example platform integration limitations, hardware/software support, time and spatial resolution, invasiveness etc.)
5. What would you use the data for? (For example to inform design, to train the AI, for test and evaluation etc.)

The responses to these questions, alongside the use case descriptions, were then used to generate recommendations for potential technologies that could complement and support the use case aspirations.

## 3.3 State of-the-Art on Human Performance sensors and technologies

The SoA was performed in the **aviation industry** as a domain of reference of HAIKU. It was also extended to the **automotive field** as a leading industry in the development of Human Performance monitoring technologies, however these technologies are not separated by originating industrial sectors as they might be applicable to either, even if they may have been validated in one. The only difference between aviation and automotive is that the technologies in the automotive sector tend to be more based not only on the driver but also encompass the status of the vehicle, and the environment, and the mapping between the three.

Sensors and technologies to monitor HP can be clustered into **16 different categories**:

1. Face reader;
2. Voice analysis;
3. Pressure sensors;
4. Wristband / Smartwatches;
5. Headset for EEG recordings or functional Near Infrared Spectroscopy (fNIR);
6. Electrodermal activity (EDA);
7. Heart rate /respiratory rate;
8. Blood oxygen sensor;
9. Eye Tracking;
10. Actigraphy;
11. Accelerometers;
12. Gyroscope;
13. Cameras;
14. Smart clothing (conductive yarns);
15. Radar;
16. Laser.

The technologies reviewed are each examples of a category of sensor type.

It should be noted that:

- Not all sensors or sensor-suites available have been reviewed, only examples from each category, in order to demonstrate the SoA for each type of sensor type but also to highlight the direction of the research and development in this field;
- Some details are not available for certain technologies, especially when the technology is particularly novel (seemingly for reasons of commercial sensitivities or that some technical aspects had not yet been fully realised);
- Commonly, sensors are combined to provide coverage of several human performance parameters, or in order to triangulate data, increasing the validity of results.

Table 6 is a summary of all reviewed technologies and the sensor type represented in each technology. The more detailed reviews follow.

*Table 6: Summary of the reviewed technologies*

Technology Name	Sensor Type
Mindtooth	Wearable EEG
Soli Gesture Recognition	Miniaturised Radar Sensor
Jacquard	Touch sensitive textiles
Tobii glasses v2	Wearable eye tracker (glasses)
Tobii Spectrum	Screen based eye tracker
Tobii Gaming	Screen based eye tracker
Pupil Labs Core	Wearable eye tracker (glasses)
Polar H10	Heart Rate Sensor

Pilot State Monitoring Systems (REPS)	Eye and head tracking cameras, Near-IR lights, a computational unit, pressure sensors on the seat and a wristband.
Neurometrics Toolbox	EDA, heart rate, EEG
HARMAN In-Cabin Monitoring Systems	Tactile sensors behind the driving wheel. A camera records fluctuations of the pupil. In-cabin radar sensor.
Fitbit	Altimeter, Haptic motor, Optical heart rate sensor, Accelerometer, Gyroscope, Ambient light sensor, Built-in microphone, Built-in speaker, GPS + GLONASS, Multipurpose electrical sensors compatible with ECG app, Bluetooth and Wifi.
B-Alert X series	Mobile EEG: 9 or 20 channels of EEG plus one optional ECG, EOG, EMG, ECG channel. On-board accelerometer.
SUEmpathy100	ECG, Skin conductance, Electromyogram (EMG) and blood pressure.
The ŌURA ring	Blood oxygen, Infrared Photoplethysmography (PPG), optical heart rate, skin temperature (negative temperature coefficient sensors) Photodiodes, 3D Accelerometer.
FaceReader	Facial Expression Identification system - Software for facial analysis through a camera. Photoplethysmography (PPG) unit optional.
Vocavio	Speech Analysis of voice recordings
NIRSIT	Functional Near Infrared Spectroscopy System. Photogrammetry for localization and 6-axis gyroscope.
Real Time Pilot Activity Monitoring (IAI)	All sensors are embedded in the pilot seat - heart rate and respiration monitor. Possible use of eye tracking.
Delphi adaptive cruise control	Radar
HDL-32E	LIDAR sensor - high definition 3-dimensional information about the surrounding environment using laser technology.
625B-Infrared camera	Infrared camera - day and night images
OMRON	ECG
MindWave Mobile	EEG

LogicOne	EOG
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Annex G presents the extended tables capturing state-of-the-art in human performance sensors and technologies.

### 3.4 Mapping of technologies on HAIKU use cases

In this section, the selected technologies are mapped on the six HAIKU use cases on the basis of the goal of each case, the envisaged end users' task types and relevant cognitive states that could be measured.

Table 7 shows the overall mapping, while a more detailed explanation is provided in the following paragraph.

Table 7: Overview on the technologies mapping on the HAIKU use cases

Technology	UC#1: Cockpit Startle response	UC#2: Cockpit Route planning	UC#3: UAM UAM	UC#4: ATM Digital Tower	UC#5: Airport Safety data	UC#6: Airport Virus spreading
Mindtooth	✓	✓		✓		
Soli Gesture Recognition			✓			
Jacquard						
Tobii glasses v2	✓		✓	✓		
Tobii Spectrum			✓	✓		
Tobii Gaming			✓	✓		
Pupil Labs Core	✓		✓	✓		
Polar H10						
Pilot State Monitoring Systems (REPS)	✓		✓			
Neurometrics Toolbox	✓	✓				
HARMAN In-Cabin Monitoring Systems					✓	

Fitbit						
B-Alert X series	✓	✓		✓		
SUEmpathy100						
The ŌURA ring					✓	
FaceReader	✓					
Vocavio					✓	
NIRSIT						
Real Time Pilot Activity Monitoring (IAI)	✓					
Delphi adaptive cruise control						
HDL-32E					✓	
625B-Infrared camera					✓	
OMRON						
MindWave Mobile	✓	✓		✓	✓	
LogicOne			✓	✓		

### 3.4.1 Use case #1

#### Digital Assistant in the cockpit to assist in 'startle response' adverse events.

HF performance monitoring is a key factor for UC#1 for capturing information on workload, the emotion of surprise, startle intensity and to evaluate characteristics of attention.

The most relevant data for this purpose are: accelerometry, ECG, EEG, pupil diameter, skin conductance, gaze path, EMG, and video of facial expression. It has to be noted that, in this case, invasiveness is a key attribute to any sensors used in an operational context and to some, but to a lesser degree in a test environment for this use case. Integration on the flight deck is another critical factor from a physical and electromagnetic point of view.

To achieve the UC#1 goal, it is recommended the usage of a combined system built primarily around EEG sensors. Of those considered in this review, the recommended systems are:

- Neurometric Toolbox (which also features galvanic skin response);

- Mindtooth, MindWave Mobile, or B-Alert X Series (which also features an optional ECG, EOG, EMG, ECG channel and on-board accelerometer);
- FaceReader to evaluate facial expression;
- Tobii systems or the Logic One system (screen-based) to trace eye movements, or other wearable systems;
- Pilot State Monitoring Systems (REPS) and the Real-Time Pilot Activity Monitoring (IAI). This would be less invasiveness options, bringing however with them a compromise on the type of data collected.

UC#1 envisages to monitor HP. The choice of the technologies to use will be made at a later stage (by the end of HAIKU Year 1), once the specific test and validation scenario will be fully defined.

### 3.4.2 Use case #2

#### **Digital Assistant in the cockpit to assist in route planning/replanning.**

Human Performance monitoring could be relevant for UC#2 for providing insight into workload and arousal(stress), in the test and evaluation part of the concept demonstration. This would be in order to demonstrate the effectiveness of the system and to ascertain how the system is impacting on workload, for example to examine:

- How the digital assistant has changed the workload profile across the flight phase;
- Any peak of arousal/stress/workload if the pilots has to engage with the solution in situations where the AI is not performing correctly;
- What workload / arousal is present when the pilot needs to understand any decision support 'advice' given by the digital assistant (e.g. is the transaction easy? Does the pilot understand why the AI is making a particular suggestion?).

For this purpose an EEG/EDA system would be useful, and thus for UC#2, the following systems are recommended:

- Neurometrics Toolbox (which includes Galvanic skin response);
- Mindtooth;
- B-Alert X series system;
- MindWave Mobile.

UC#2 acknowledges the value of objective feedback on stress and workload. However, EEG may not be used in their assessments as this kind of system can be constraining and quite demanding to set up. They suggest that it could be a solution if an easy to use, non-intrusive, effective solution became available. However, for evaluation purposes, this case study plans to recreate a well-controlled environment and a protocol that aims to be protective of the "immersion" or fidelity aspects of the scenario for the pilots, in preference to HP monitoring.

### 3.4.3 Use case #3

#### **Digital Assistant for Urban Air Mobility coordinator to assist in traffic management.**

UC#3 has considered using eye tracking technologies or less accurate head tracking, for test and evaluation, and for real-time human-AI teaming assessment.

According to this, the recommendations for this case study are:

- Wearable eye tracking, either the *Tobii* systems, or the *Pupil Labs Core* product;

- Screen based eye tracking systems for less invasiveness, including the *Tobii* solutions but also the *Logic One* screen based eye tracking;
- An integrated system like the *Pilot State Monitoring Systems (REPS)* which uses eye and head tracking cameras.

Furthermore, a technology that might become useful for UC#3 is the Google Soli Gesture recognition, which may have an application in reducing workload, by providing the opportunity for interactions that are eye-free and allow the users to continue with their primary tasks. However, this technology is radar based and so electromagnetic integration into an aviation environment would need to be considered.

Notwithstanding this, at the present time, UC#3 is not considering the inclusion of real-time HP monitoring in the concept.

#### 3.4.4 Use case #4

##### **Digital Assistant for tower (and remote tower) controllers to assist in routine and repetitive tasks for aircraft on approach.**

UC#4 may consider monitoring of HP during the test and evaluation phase in order to assess the impact of the Digital Assistant on controllers' workload. To this end, suitable technologies could be EEG systems and, in some specific environments, eye tracking.

According to this, the recommendations for this case study are:

- *Mindtooth*, the *B-Alert X series system*, or *MindWave*;
- Wearable eye tracking systems are the *Tobii* systems which have been well validated, but also the *Pupil Labs Core system*;
- Screen based eye tracking systems for less invasiveness, including *Tobii* options but also the *Logic One* screen based eye tracking system.

However, at the present time, UC#4 is not considering the inclusion of real-time HP monitoring in the concept.

#### 3.4.5 Use case #5

##### **Digital Assistant in the airport to assist safety in data analysis.**

HP monitoring technologies might be of interest for UC#5 in case of desire to capture the human component of risk in the airport safety reporting system. Moreover, it is recognised that UC#5 would benefit from real-time fatigue monitoring, if it became available as a technology.

In particular, it is noted the potential use of the risk models generated in the SAFEMODE project. For example, the taxi-way collision model where the human component of risk is largely attributed to problems with visibility (glare, darkness, weather conditions, physical obstruction), communications (loss of comms, unclear clearance, misunderstanding, inappropriate readback), application of procedure, and problem with intervention. Thus, it could be valuable to collect data on these human interaction aspects. Moreover, in the driver cabin of air-side vehicles that might be prone to collisions, driver monitoring systems could highlight some useful data on driver performance, vigilance, fatigue etc.

For this purpose the technologies recommend are as follows (noting any sensitivities of collecting data on human performance in a real-life ATC setting):

- The Oura ring (for sleep tracking and activity levels);
- Vocavio (speech analysis tool) or a more simple voice recording platform that can extract critical events;
- HARMAN In-Cabin Monitoring Systems or some of the autonomous vehicle 'spatial detection' systems e.g. HDL-32E or the 625B-Infrared camera (in ground vehicles);
- Screen-based eye tracking devices (for possible training of the AI system to know what aspects of the safety database (or Safety Dashboards) are referred to etc).

Notwithstanding this, UC#5 haven't planned on using any human sensors, as they don't use any at the moment in London Luton Airport where the data is collected.

### 3.4.6 Use case #6

#### **Digital Assistant in the airport to monitor risk factor conditions associated with indoor spread of infectious diseases.**

UC#6 does not have intentions on using HP monitoring technologies and will design the system using occupancy-based sensors.

## 4. Human-AI Teaming Framework

This section proposes a framework for Human-AI teaming that can be used for design efforts (WP4) and for evaluations (WP6). The proposed approach is an integrative framework that uses one light-weight technique/method, the LACC-LOA matrix, to establish an overarching frame for design work in HAIKU. This provides focus for other methods as well as other frameworks, and makes cases comparable with regards to the framework dimensions and core teamwork aspects.

The Human-AI teaming framework focuses on three dimensions that are critical for digital assistance. Firstly, what separate roles the human and digital assistant have, secondly, how autonomous the digital assistant is, and thirdly, the focus areas for HAIT.

In HAIKU, the framework will be used to provide 1) comparability between the digital assistants from the six cases, and 2) a checklist to prioritise what HAIT-principles/concerns are most central, tailoring it for each case. The framework can both describe the current work-as-done today and the future work-as-done-with-AI. The emphasis on current/future is another point of tailoring for each case. It will support the use cases in focusing design work and evaluations, through iterative knowledge capture on the areas of concern. The areas of concern include task time criticality, cognitive state (SKR mode, Rasmussen et al, 1981), AI autonomy level, shared situation awareness requirements, bidirectional human-AI training mechanisms, interface design, and individual differences/AI personalization.

The framework provides firstly, a starting point for mapping out two core dimensions for human teaming with a digital assistants: a) the human versus digital assistant roles (levels-of-automation), b) autonomy, in terms of the kind of cognitive work being done by the assistant (levels-of-autonomy-in-cognitive-control). At the intersection between human role and autonomy, we find areas and issues of human-AI teaming. Secondly, the framework provides guidance on how to go from the overview to more detailed in-depth analyses of human-AI teaming.

### 4.1 LACC-LOA

Before going into details, it must be emphasized that the proposed framework **does not replace other frameworks on human-AI teaming**. The idea was to provide a *light-weight* framework to *guide design thinking*, support *selection of additional frameworks* for human-AI teaming applicable to the specific case as well as supporting *cross-case comparisons*. See section 4.2.5 on situation awareness (Figure 26) for an example of including a more advanced models). Based on the analysis for each case, using the proposed reference framework, the core dimensions (autonomy, automation, teaming) can also be tailored further to each case, if needed. **Although it is an overarching framework, it does add one activity/method, the LACC-LOA analysis and matrix**, which is detailed below. The LACC-LOA analysis is part of a larger framework for human-machine collaboration - the *Joint Control Framework* (Lundberg & Johansson, 2021) - but LACC-LOA can be used independently (as it is here) as an integrative technique.

The framework uses *three* points of departure. First, the **Levels of automation (LOA)** framework (Bainbridge, 1983; EASA, 2023) that is widely used in industry. This approach grounds our framework in application domains and provides common ground with industry. *Second*, the framework uses a scheme of **Levels of Cognitive Autonomy (LACC)**, derived from decades of work in academia on human control of processes in high-stakes domains (Lundberg & Johansson, 2021). *Third*, at the **LACC-LOA intersections**, the framework identifies **areas of human-AI teaming**, to further assess and work with, with **more detailed approaches**, such as situation awareness assessment schemes for evaluation.

The *Levels-of-automation* (LOA) approach originated in remote underwater teleoperations (Bainbridge, 1983), but is now widely used in industry (e.g., EASA, 2023; SESAR 2019). There are various LOA schemes, but they all share the same core dimension. At one end, work is fully manual, at the other end, it is fully automated. In-between, the computer gradually takes over human work. It starts near fully manual work, with some information acquisition support and basic processing and visualization in situation displays. In the middle going toward full automation, the automation starts planning and proposing plans. At the end - near full automation - systems start recommending what plan to execute, and finally it executes those plans fully, gradually reducing the ability of the human to intervene. In early design work, HAIKU has used two LOA versions. First, a cross-case simplified LOA used in design work, consisting of the ability to analyse, manage and act, on-demand or proactively (see an example in Figure 25). Second, we considered a LOA proposed by (SESAR, 2019), used in one project workshop. However, for the main analyses in WP6, we will use the new industry standard LOA framework from EASA (2023) for the human-digital assistant role-dimension (LOA). See Figure 23 for a comparison between the EASA (2023) and SESAR (2019) LOA.

In HAIKU, to address autonomy, a *second dimension* was added to include **what kind of cognitive work the digital assistants can perform** for the operator; is the assistant working on plans or implementing those plans? Or helping the operator to execute actions? Or is it performing higher level work such as determining what the situation is about, setting or selecting goals, making trade-offs and calculating performance indicators (goal achievement)? For this, we can use the levels of autonomy in cognitive control (LACC) which is an overarching framework that ties many previously used schemes from academia together. This simple - but powerful approach - clarifies issues such as *human-in-the-loop*, *human-on-the loop* – by specifying *what* loop(s) the human is in or on (it is possible in the same system to be in one loop, and on another loop). For example, is it in the planning loop, or in the goal-setting loop?

Combining these two dimensions in a matrix, we can identify critical areas for human-AI teaming. In the LACC-LOA matrix, the aim is to find the areas where operators work independently and where the AI/Automation works independently, and areas in between where they work together (teaming). After an analysis with our framework, the knowledge obtained will direct design and be used for finding additional approaches to tailor the cognitive processes for specific cases, focusing on teaming.

This is done by assessing (in terms of the framework) the needs for (and providing a starting point for) describing task time criticality, cognitive state (SKR mode, Rasmussen et al, 1981), AI autonomy level, shared situation awareness requirements, bidirectional human-AI training mechanisms, and individual differences / AI personalization. Figure 21 shows the LACC\_LOA Matrix. We will now discuss the two dimensions in detail.

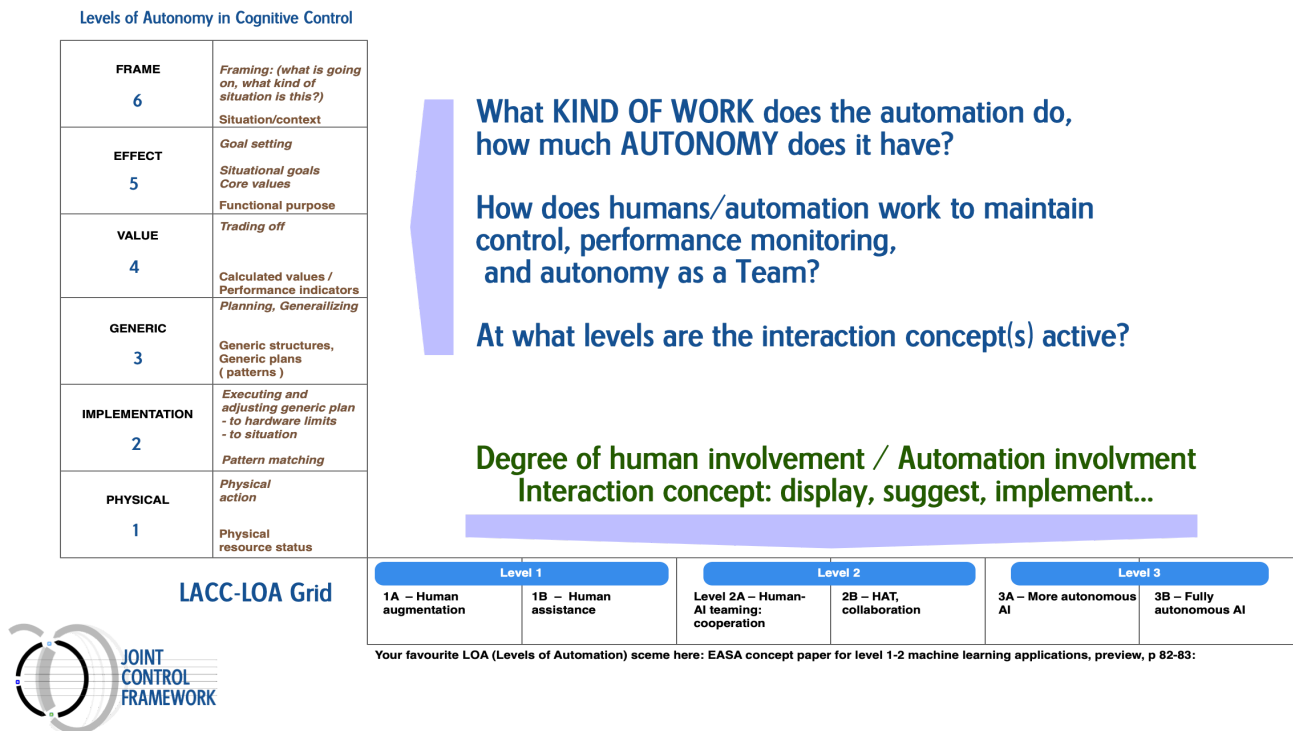


Figure 21: The LACC-LOA matrix; with the EASA (2023) LOA and the Lundberg & Johansson (2023) LACC.

### 4.1.1 Dimension 1: Levels of Automation (LOA)

There are various variants to the Levels-of-automation approach, but they all share the same foundation and scale; at one end of the singular dimension, work is fully manual, at the other end, it is fully automated. In-between, the system/computer is seen as gradually taking over different kinds of *cognitive work* from the human, first solely by analysing and presenting information, then by organizing (e.g. planning) and prioritizing, and finally by executing the cognitive tasks (with decreasing need/ability for humans to intervene). In all the intermediate steps, there are also tasks in which the human and automation/AI must work together. There can also be tasks with degraded automated/AI performance where the LOA levels shift, hence the LOA can also be seen as a dynamic property of a system. The support from the automation/AI is degraded at the intended level, and a different LOA level must be used, for a limited period of time. These situations are problematic - if intermittent - since specialized training must then be performed for the human to be able to work on a different LOA level.

LOA has also been used to describe critical scenarios down to single critical decisive steps with specific automation/AI components as well as characterizing whole systems. Both are needed – an overarching vision of the intended level of a system can be useful, but also to inspect more carefully that it holds in critical situations (decisive steps).

A cross-case LOA was used for concept design in HAIKU:

- 1a Observer: Analyze, on-demand
- 1b Informer: Analyze, proactively

*A digital assistant, providing information to the user, by capturing, processing and analyzing data)*

2a Secretary: Manage, on-demand

2b Coordinator: Manage, proactively

*A digital assistant supporting the user, in managing the workflow, organizing and prioritizing tasks*

3a Rescuer: Act, on-demand

3b Executor: Act, proactively

*A digital assistant capable of performing actions/tasks (to face a situation, or recover from errors)*

The project could use one common LOA scheme (adjusted to each case) or one cross-project LOA. We decided to use the most recent LOA scheme from EASA (2023) in our LACC-LOA.

The LOA schemes are limited in that they all have rather vague statements on exactly what it is, that the humans are to collaborate with the Automation/AI on. The statements are similar in that they speak of "most" tasks, or that the automation can "initiate" tasks. To gain a bit more descriptive power an additional scheme is described in the next section, that will be used together with LOA.

#### **4.1.2 Dimension 2: Levels of Autonomy in Cognitive Control (LACC)**

To describe the kind of work done by an autonomous agent (digital assistant), the work done by the human, and the work that they carry out as a team, we can add a second dimension - Levels of Autonomy in Cognitive Control (the LACC dimension). Its origin is in the Joint Control Framework (JCF), and was derived by comparing theoretical frameworks of human cognition in dynamic control contexts such as Cognitive (systems) engineering (Hollnagel & Woods, 2005), sensemaking (Klein et al., 2010) and situation awareness (Lundberg, 2015; Endsley, 1995; Endsley 2023), and naturalistic decision making (Klein & Calderwood, 1991). Interestingly, it is possible to unify these frameworks and their abstract cognitive control concepts can be stacked on six levels (Figure 22, see also below). For an example from Urban Air Mobility, see Figure 24 (for further information on that example, see Lundberg et al, 2021).

The six levels are defined as follows (see tables for in-depth examples)

**Level 1:** Object and Object status information, specific actions that are executed, actions to keep a steady state. The lowest cognitive control task level. For instance, the location and speed of a specific drone. Keeping the drone flying in a straight line at a specific altitude.

**Level 2:** Limitations in low-level implementation, e.g. dependencies on the local context, and on objects or subjects used in the implementation, such as the maximum rate-of-climb of a specific aircraft, the noise levels of a specific drone at a specific speed.

**Level 3:** Plans (potentially generic), blueprints. For instance, a reusable plan for daily deliveries of packages between two locations, including the path to use, the altitude to use, preferred drone speeds.

**Level 4:** Trade-offs calculated based on plans, performance indicators, compromises. For instance, priorities for different kinds of services – an urgent medical delivery could be given higher priority than a prioritised package from a regular delivery service.

**Level 5:** Goals (overarching goals, goal setting in unfamiliar situations/specific situations). For instance, overarching safety goals for the whole airspace, specific performance goals for a delivery service, goals associated with specific situations such as emergencies.

**Level 6:** Framing (what goes on?). The highest cognitive control task level. The overarching frame of the activity, for instance to have a global system to keep the airspace safe and expedite fair traffic allocations. Framings of specific situations, such as an emergency due to a low battery for a drone.

Levels of Autonomy in Cognitive Control		What KIND of cognitive work does it do?	
FRAME 6	Framing: (what is going on, what kind of situation is this?) Situation/context	Does it decide what KIND of PROBLEM/SITUATION it is?	WHY
		<b>WITHIN THE FRAME:</b> Does it set GOALS?	
EFFECT 5	Goal setting Situational goals Core values Functional purpose	<b>WITH THE GOALS:</b> Does it PRIORITIZE?	WHAT
		<b>WITH THE PRIORITIES:</b> Does it PLAN?	
VALUE 4	Trading off Calculated values / Performance indicators Planning, Generalizing	<b>WITHIN THE PLAN/EVENT/WITH THE FUNCTIONS:</b> Does it EXECUTE the plan?	HOW
		<b>WITH THE PHYSICAL / IMPLEMENTED SYSTEM AND PLAN</b> Does it keep track of RESOURCES?	
GENERIC 3	Generic structures, Generic plans ( patterns )		
IMPLEMENTATION 2	Executing and adjusting generic plan - to hardware limits - to situation Pattern matching		
PHYSICAL 1	Physical action Physical resource status		

Figure 22: The LACC dimension represents different levels of cognitive work related to control of an external process. The lowest level (physical) denotes low-level of work (i.e., manual work related to control). The highest level (Frame) represents the ability - with a full situational understanding of situations - to manage overarching control, and ability to reframe problems and goals.

In the next section, we discuss how the LACC-LOA approach can be used to identify teaming issues between man and machine.

#### 4.1.3 Identifying teaming issues with LACC-LOA

To identify areas where human-AI teaming issues might arise, a full LACC-LOA matrix can be constructed. This is done through constructing a matrix with the LACC in the vertical dimension, and the LOA on the horizontal dimension:

1. Create Dimension 1: What the **Level of Automation** is. What overarching role the automation has, i.e. how automated the task is from sensor input, to analysis, to implementation, and how interactive it is, i.e. how much it presents to the human operator, and how much decisive power the human versus the automation has.
2. Create Dimension 2: What the **Level of Cognitive Control** is (how autonomously it can perform its tasks), i.e. how much control it has over its own activities, from controlling object statuses and actions, to implementing plans and adjusting them to local circumstances, to planning and generalizing the specific to the generic, to calculating performance indicators and making trade-offs, to goal setting, to deciding what the problem or situation is that should be managed.
3. Identify critical **teaming** areas at the LACC-LOA **intersecting points** in the matrix. These are areas where it is important to further assess issues such as situation awareness, mutual learning, and so on.

Level 1		Level 2		Level 3	
<b>1A – Human augmentation</b>	<b>1B – Human assistance</b>	<b>Level 2A – Human-AI teaming: cooperation</b>	<b>2B – HAT, collaboration</b>	<b>3A – More autonomous AI</b>	<b>3B – Fully autonomous AI</b>

Your favourite LOA (Levels of Automation) scheme here: EASA concept paper for level 1-2 machine learning applications, preview, p 82-83:

"The implementation of an AI-based system is not expected to have an impact on the current operation of the end user." (p 82)

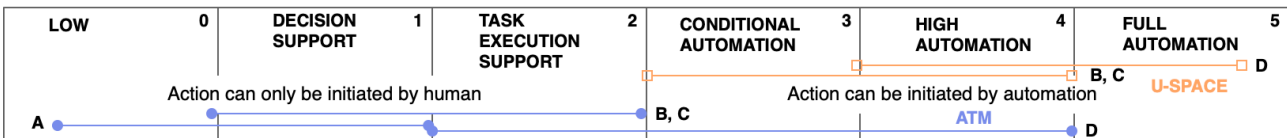
"The implementation of an AI-based system is expected to impact the current operation of the end user with the introduction of, for example, a cognitive assistant." p82

"Level 2A corresponds to the implementation of an AI-based system capable of teaming with an end user. The operation is expected to change by moving from human-human teams to human-AI-based system teams. More specifically, Level 2A is introducing the notion of cooperation as a process in which the AI-based system works to help the end user accomplish their own objective and goal. The operation evolves by taking into account the work from the AI-based system based on a predefined task allocation pattern." p82

"Level 2B corresponds to the implementation of an AI-based system capable of collaboration. On top of the evolution linked to the notion of HAT, the collaboration will make the operation evolve towards a more flexible approach where the human and the AI-based system will both communicate and share strategies/ideas to achieve a common goal." p83

"The AI-based system is operating independently with the possibility from the end user to override an action/decision only when needed. No permanent oversight from the end user. A significant modification in the current operation is expected." p83

"There is no more end user. The AI-based system is fully autonomous."



Your favourite LOA (Levels of Automation) scheme here

SESAR (2019) European ATM Master Plan. Digitalising Europe's Aviation Infrastructure. Executive View. 2020 Edition. SESAR Joint Undertaking, Luxembourg: Publications Office of the EU, Dec. 17, page 24

Automation supports the human operator in information acquisition and exchange and information analysis

Automation supports the human operator in information acquisition and exchange and information analysis and action selection for some tasks/functions

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for some tasks/functions.

Actions are always initiated by Human Operator.

Adaptable/adaptive automation concepts support optimal socio-technical system performance.

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for most tasks/functions.

Automation can initiate actions for some tasks.

Adaptable/adaptive automation concepts support optimal socio-technical system performance.

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for all tasks/functions.

Automation can initiate actions for most tasks.

Adaptable/adaptive automation concepts support optimal socio-technical system performance.

Automation performs all tasks/functions in all conditions.

There is no human operator.

Figure 23: The LOA dimension denotes the continuum from full human control of a process to fully autonomous machine control. Top, EASA (2023), used as the main LOA for HAIKU. Bottom, SESAR (2019), to highlight similarities between LOA schemes.

In the next section, examples of the approach are provided. 4.1.4 LACC-LOA Example - UAM case

In the following, an example is given of the LACC-LOA analysis method as a result of design activities in the UAM case in HAIKU (with two assistant types for each broader category of *present status of*, *plan/manage*, and *execute*). This grid has examples filled-in.

Levels of Autonomy in Cognitive Control

Level	Description	Present status of...	Plan/ manage.....	Execute....	Notes
6	FRAME Framing: (what is going on, what kind of situation is this?) Situation/context	Determining and presenting the overarching situations in the airspace (what is seen) (e.g. conflicts in the airspace, emergencies that occur)	Suggesting relevant ways of framing a situation, how it is seen (e.g. conflicts seen as occurring between multi-drone services, or between particular drones)	Selecting what situations to address	WHY something should be done
5	EFFECT Goal setting Situational goals Core values Functional purpose	Showing goal achievement	Suggesting relevant goals in a situation, (e.g. send an emergency response drone)	Selecting goals to pursue	
4	VALUE Trading off Calculated values / Performance indicators Planning, Generalizing	Calculating and presenting a performance indicator	Proposing a change (e.g. reduction of congestion in drone traffic)	Determining that a level has been exceeded, Prioritizing between goals	WHAT to do
3	GENERIC Generic structures, Generic plans (patterns)	(potentially reusable) plan	Suggesting a plan Monitoring a plan	Planning and selecting a plan	
2	IMPLEMENTATION Executing and adjusting generic plan - to hardware limits - to situation Pattern matching	Plan problem (e.g. conflict)	Showing the particular constraints in a particular situation, for plan implementation (e.g. for solving a particular conflict)	Implementing a plan (e.g. solving a particular conflict)	HOW to do it
1	PHYSICAL Physical action Physical resource status	Resource status (e.g. in conflict, battery low)	Resource suggestion	Resource selection/modification	

Figure 24: A LACC-LOA matrix for the UAM case, exemplifying possible cognitive tasks by the operator or by the digital assistant, using the simplified LOA from the early concept work in HAIKU.

#### 4.1.4 Analysing teaming issues with LACC-LOA

This section outlines a checklist approach to identify the main HAIT concerns for each use case, to guide the initial work (main design decisions) within each area of concern. This assessment uses the LACC-LOA assessment, and is the basis for the next step, to prioritize concerns and to identify connected concerns. See the section below on Situation Awareness for an example illustrating how the LACC-LOA analysis can be a starting point when including a more advanced analysis model, if needed, for a HAIKU case.

#### Time

The following questions can be used to guide the design and analysis of temporal considerations, based on the LACC-LOA analysis. They focus specifically on hand-overs between automations and humans (changes in system LACC-LOA performance), on preparations versus real-time work, and on the time available for operators and systems to act versus the speed of the process.



operator must build SA by observations at lower levels, from the system. For instance, plans (Level 3), predicted conflicts (Level 2), drone positions (Level 1).

Finally, more advanced models can be integrated into the LACC framework to analyse specific aspects. See for instance Lundberg, 2015 for an integration of Situational Awareness.

### *Individual differences / AI personalization*

The following questions can be used to guide the design and analysis of AI personalization and individual differences, based on the LACC-LOA analysis.

1. At what levels are individual differences for human operators to be expected? What kinds of differences/how much variation?
2. AI personalization can be considered a kind of learning, of a preferred choice. At what levels should such choices be afforded?
3. Requirement: Basic personalization setting When/how is the personalization to be performed?

### *Interface design, information contents and modalities*

The LACC-LOA framework helps focusing on what content to present in general (similar to the questions guiding SA), and in what modalities, through the following checklist questions.

1. At what levels do the automation work currently and in the envisioned IA setting (LACC-LOA)?
2. At what levels does it provide information about its work, and what are the operator needs (considering own/joint work)?
3. In what modalities are information currently presented?
4. Considering the operative context (including e.g. noise) and the current interface (how loaded is it currently, is there room for the IA to be integrated), what modalities would be the best starting points?
5. Considering technical limitations and opportunities (e.g. voice recognition technologies for specific application areas and its required operative performance (e.g. in safety-critical areas it can be close to 100%), computational limitations in e.g. wearable devices), are any modalities preferred?

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## Annex A: Glossary

Term	Definition [1]=AVSI, 2020; [2]=EC AI HLEG, 2020; [3]=NAS, 2021; [4]=EASA, 2020.
Accessibility	Extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use (which includes direct use or use supported by assistive technologies). [2]
Accountability	The idea that one is responsible for their action – and as a corollary their consequences – and must be able to explain their aims, motivations, and reasons. Accountability has several dimensions. Accountability is sometimes required by law. For example, the General Data Protection Regulation (GDPR) requires organisations that process personal data to ensure security measures are in place to prevent data breaches and report if these fail. But accountability might also express an ethical standard, and fall short of legal consequences. Some tech firms that do not invest in facial recognition technology in spite of the absence of a ban or technological moratorium might do so out of ethical accountability considerations. [2]
Accuracy	The goal of an AI model is to learn patterns that generalise well for unseen data. It is important to check if a trained AI model is performing well on unseen examples that have not been used for training the model. To do this, the model is used to predict the answer on the test dataset and then the predicted target is compared to the actual answer. The concept of accuracy is used to evaluate the predictive capability of the AI model. Informally, accuracy is the fraction of predictions the model got right. A number of metrics are used in machine learning (ML) to measure the predictive accuracy of a model. The choice of the accuracy metric to be used depends on the ML task. [2]
Ad hoc teams	Teams that form rapidly and uniquely for short-term tasks and missions. [3]
Adaptable automation	Automation that can be activated or have its level of automation modified by the human in real time during system operation. [3]
Adaptive automation	Automation that automatically changes its performance or level of automation based on time, human performance or state, or other predefined characteristics of team performance. [3]
Aggregation (see also <i>anonymisation, encryption, and pseudonymisation</i> )	A process whereby data is gathered and expressed in a summary form, especially for statistical analysis. [2]
AI	Technology that appears to emulate human performance typically by learning, coming to its own conclusions, appearing to understand complex content, engaging in natural dialogues with people, enhancing human cognitive performance (also known as cognitive computing) or replacing people on execution of non-routine tasks [4]. Systems that seek to provide the intellectual processes characteristic of people, such as the ability to reason, discover meaning, generalise, or learn from past experience. AI systems may be applied to parts of a task (e.g., perception and categorisation, natural language understanding, problem solving, reasoning, system control), or to a combination. AI software approaches may involve symbolic approaches (i.e., rule-based or case-based reasoning), often taking form as decision-support systems; may apply other advanced algorithms such as Bayesian belief-nets, fuzzy systems, and connectionist or machine learning-based approaches (e.g., logistic regression, decision trees, or neural networks); or may incorporate hybrid architectures that include more than one algorithmic approach. [3]
AI bias	AI (or algorithmic) bias describes systematic and repeatable errors in a computer system that create unfair outcomes, such as favouring one arbitrary group of users over others. Bias can emerge due to many factors, including but not limited to the design of the algorithm or the unintended or unanticipated use or decisions relating to the way data is coded, collected, selected or used to train the algorithm. Bias can enter into algorithmic systems as a result of pre-existing cultural, social, or institutional expectations; because of technical limitations of their design; or by being used in unanticipated contexts or by audiences who are not considered in the software's initial design. AI bias is found across platforms, including but not limited to search engine results and social media platforms, and can have impacts ranging from inadvertent privacy violations to reinforcing social biases of race, gender, sexuality, and ethnicity. [2]
AI reliability	An AI system is said to be reliable if it behaves as expected, even for novel inputs on which it has not been trained or tested earlier. [2]

AI system	Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimisation), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems). [2]
Anonymisation (see also <i>aggregation, encryption, and pseudonymisation</i> )	A procedure that prevents any identification of individuals from personal data. The link between an individual and personal data is definitively erased. [2]
Auditability	The ability of an AI system to undergo the assessment of the system's algorithms, data and design processes. This does not necessarily imply that information about business models and Intellectual Property related to the AI system must always be openly available. Ensuring traceability and logging mechanisms from the early design phase of the AI system can help enable the system's auditability. [2] The ability to document and assess the data and models used in developing an AI-embedded system. [3]
Automation	The use of control systems and information technologies reducing the need for human [input] typically for repetitive tasks. [4] A device that performs functions independently, without continuous input from an operator. Automation can be fixed (mechanical) or programmable (based on defined rules and feedback loops to ensure proper execution), either via a static set of software commands, or involving flexible, rapid customisation by a human operator. Tasks may be fully automated (i.e., autonomous) or semi-automated, requiring human over- sight and control for portions of the task. It is also often defined as "the execution by a machine agent (usually a computer) of a function that was previously carried out by a human. [3]
Autonomous AI system	An autonomous AI system is an AI system that performs behaviors or tasks with a high degree of autonomy, that is, without external influence. [2]
Autonomy	Systems that have a set of intelligence-based capabilities that can respond to situations that were not explicitly programmed or were not anticipated in the design (i.e., systems that can generate decision-based responses). Autonomous systems have a degree of self-government and self-directed behavior (serving as a human's proxy for decisions). Systems may be fully autonomous or partially autonomous (i.e., requiring human actions or inputs for portions of the task). [3]
Bias	An error from erroneous assumptions in the learning [process]. High bias can cause an algorithm to miss the relevant relations between attributes and target outputs (=underfitting).[4] A preference toward certain information or options. Bias is created through systematic error introduced by selecting or encouraging one outcome or answer over others. In the case of AI, bias may be introduced through a limited set of training data that fails to consider the wider range of circumstance where it may be employed, or by algorithms that focus on features in the datasets that may be incidental to performance. [3]
Black box AI	AI systems in which the reasoning and processes are not transparent or observable. [3]
Brittleness	The inability of automation to perform at the limits of its designed performance envelope, resulting in often unexpected system failures. Includes characteristics of the users, the activities they perform, how the work is distributed across people and machine agents, the range and complexity of situations that can arise, as well as the broader sociotechnical environment in which the system will be integrated. [3]
Confidence score	Much of AI involves estimating some quantity, such as the probability that the output is a correct answer to the given input. Confidence scores, or confidence intervals, are a way of quantifying the uncertainty of such an estimate. A low confidence score associated with the output of an AI system means that the system is not too sure that the specific output is correct. [2]
Context of use	Includes characteristics of the users, the activities they perform, how the work is distributed across people and machine agents, the range and complexity of situations that can arise, as well as the broader sociotechnical environment in which the system will be integrated. [3]
Cooperation	"Negotiating and aligning individual goals when they differ from a joint goal" (Chiou and Lee,2021, in [3])

Coordination	Managing dependencies between activities. This includes the timing or arrangement of joint decisions, or dependency management. [3]
Correctness	The implementation is correct with respect to its defined intended behaviour, under foreseeable operating conditions. [1]
Data governance	A term used on both a macro and a micro level. On the macro level, data governance refers to the governing of cross-border data flows by countries, and hence is more precisely called international data governance. On the micro level, data governance is a data management concept concerning the capability that enables an organisation to ensure that high data quality exists throughout the complete lifecycle of the data, and data controls are implemented that support business objectives. The key focus areas of data governance include data availability, usability, consistency, integrity, and sharing. It also regards establishing processes to ensure effective data management throughout the enterprise such as accountability for the adverse effects of poor data quality and ensuring that the data which an enterprise has can be used by the entire organisation. [2]
Data protection impact assessment (DPIA)	Evaluation of the effects that the processing of personal data might have on individuals to whom the data relates. A DPIA is necessary in all cases in which the technology creates a high risk of violation of the rights and freedoms of individuals. The law requires a DPIA in case of automated processing, including profiling (i), processing of personal data revealing sensitive information like racial or ethnic origin, political opinions, religious or philosophical beliefs (ii), processing of personal data relating to criminal convictions and offences (iii) and systematic monitoring of a publicly accessible area on a large scale (iv). [2]
Directability	One's ability to influence the behavior of others and complementarily be influenced by others [3].
Distributed teams	Teams that are distributed spatially (e.g., blocked from view by objects, in separate rooms, or separate geographical areas) or temporally. [3]
Encryption (see also <i>aggregation</i> , <i>anonymisation</i> , and <i>pseudonymisation</i> )	The procedure whereby clear text information is disguised by using especially a hash key. Encrypted results are unintelligible data for persons who do not have the encryption key. Contrast with <i>aggregation</i> , a process whereby data is gathered and expressed in a summary form, especially for statistical analysis. [2]
Explainability	The ability to provide satisfactory, accurate, and efficient explanations of the results (i.e., recommendations, decisions, and/or actions) of an AI system [3]. Feature of an AI system that is intelligible to non-experts. An AI system is intelligible if its functionality and operations can be explained non technically to a person not skilled in the art [2]. Support for understanding the logic, process, factors, or reasoning upon which a system's actions or recommendations are based [3].
Fairness	Refers to a variety of ideas known as equity, impartiality, egalitarianism, non-discrimination and justice. Fairness embodies an ideal of equal treatment between individuals or between groups of individuals. This is what is generally referred to as 'substantive' fairness. But fairness also encompasses a procedural perspective, that is the ability to seek and obtain relief when individual rights and freedoms are violated. [2]
Human oversight	Helps ensure that an AI system does not undermine human autonomy or causes other adverse effects. Oversight may be achieved through governance mechanisms such as a human-in-the-loop (HITL), human-on-the-loop (HOTL), or human-in-command (HIC) approach. [2]
Human-in-command	The capability to oversee the overall activity of the AI system (including its broader economic, societal, legal and ethical impact) and the ability to decide when and how to use the system in any particular situation. This can include the decision not to use an AI system in a particular situation, to establish levels of human discretion during the use of the system, or to ensure the ability to override a decision made by a system. Moreover, it must be ensured that public enforcers have the ability to exercise oversight in line with their mandate. Oversight mechanisms can be required in varying degrees to support other safety and control measures, depending on the AI system's application area and potential risk. All other things being equal, the less oversight a human can exercise over an AI system, the more extensive testing and stricter governance is required. [2]
Human-in-the-loop	The capability for human intervention in every decision cycle of the system, which in many cases is neither possible nor desirable. [2]
Human on-the-loop	The capability for human intervention during the design cycle of the system and monitoring the system's operation. [2]. Operations in which people <b>oversee</b> a system that is operating at a high level of automation at very fast timeframes and/or volumes exceeding human capacity. There is no expectation that people will be able to monitor or intervene in operations prior to automation errors occurring, however, it may be possible to take actions to turn off the automation or change automation behaviors in an outer control loop. [3]
Human AI team	A team consisting of "one or more people and one or more AI systems requiring collaboration and coordination to achieve successful task completion. [3]

Interpretability	Refers to the concept of comprehensibility, explainability, or understandability. When an element of an AI system is interpretable, this means that it is possible at least for an external observer to understand it and find its meaning. [2]
Labeling	A factor influencing data quality for ML solutions employing supervised learning. Algorithms learn from a dataset of examples labeled with an output variable representing the right answer.[1]
Level of automation	The amount of control or authority that is granted to the automation (or AI system) for a given task or function. [3]
Lifecycle	The lifecycle of an AI system includes several interdependent phases ranging from its design and development (including sub-phases such as requirement analysis, data collection, training, testing, integration), installation, deployment, operation, maintenance, and disposal. Given the complexity of AI (and in general information) systems, several models and methodologies have been defined to manage this complexity, especially during the design and development phases, such as waterfall, spiral, agile software development, rapid prototyping, and incremental. [2]
Machine Learning	Rooted in statistics and mathematical optimisation, <i>machine learning</i> is the ability of computer systems to improve their performance by exposure to data without the need to follow explicitly programmed instructions. <i>Machine learning</i> is a branch of artificial intelligence, and can follow three methods: <ul style="list-style-type: none"> <li>• Supervised learning - the process of learning a function that maps an input to an output based on example input-output training samples.</li> <li>• Unsupervised learning - this strategy is used in cases where there is no labelled data set available to learn from. The neural network analyses the data set, and then a cost function tells the neural network how far off target it was. The neural network then adjusts to increase accuracy of the algorithm.</li> <li>• Reinforcement learning - in this algorithm, the neural network is reinforced for positive results, and punished for a negative result, forcing the neural network to learn over time. [4]</li> </ul>
Mental model	Mechanisms whereby humans are able to generate descriptions of system purpose and form, explanation of system functioning and observed system states, and predictions of future states [3]
Model drift	Occurs when the relationship between input and output data changes over time, negatively affecting the accuracy of the model's predictions [3]
Model Evasion	One of the most common attacks on machine learning models (ML) performed during production. It refers to designing an input, which seems normal for a human but is wrongly classified by ML models. A typical example is to change some pixels in a picture before uploading, so that the image recognition system fails to classify the result. [2]
Observability	Ability of system state to be observed during execution.[1]
Out of the loop	The tendency for people working with automated systems to be slower to detect a problem with system performance and slower to understand the problem once detected. [3]
Pen test	Short for "Penetration Test." Also known as <i>ethical hacking</i> . An authorised simulated cyberattack on a computer system, performed to evaluate the security of the system. The test is performed to identify both weaknesses (also referred to as vulnerabilities), including the potential for unauthorised parties to gain access to the system's features and data, as well as strengths, enabling a full risk assessment to be completed. [2]
Predictability / determinism	A system is predictable/deterministic if when given identical inputs, produces identical outputs. [4]
Pseudonymisation (see also <i>anonymisation, aggregation, and encryption</i> )	Refers to the idea that it is not possible to attribute personal data to a specific data subject without additional information. Contrast with <i>anonymisation</i> which prevents any identification of individuals from personal data, as the link between an individual and personal data is definitively erased. [2]
Red team	The practice whereby a red team or independent group challenges an organisation to improve its effectiveness by assuming an adversarial role or point of view. It is often used to help identify and address potential security vulnerabilities. [2]
Redress by design	Relates to the idea of establishing, from the design phase, mechanisms to ensure redundancy, alternative systems, alternative procedures, etc. in order to be able to effectively detect, audit, rectify the wrong decisions taken by a perfectly functioning system and, if possible, improve the system. [2]
Reinforcement Learning	A machine learning paradigm in which the trained model's output (action) is iteratively optimised via a reward heuristic. Positive rewards encourage similar behaviors over time, while negative rewards discourage them.[1]

Representativeness	A factor influencing data quality for ML solutions concerning the level to which training data contains all foreseen scenarios in which the system will be used.[1]
Reproducibility	The closeness between the results of two actions, such as two scientific experiments, that are given the same input and use the methodology, as described in a corresponding scientific evidence (such as a scientific publication). A related concept is replication, which is the ability to independently achieve non-identical conclusions that are at least similar, when differences in sampling, research procedures and data analysis methods may exist. Reproducibility and replicability together are among the main tools of the scientific method. [2]
Resilient teams	Groups of people and/or automated agents that have the capacity to respond to change and disruption in a flexible and innovative manner to achieve successful outcomes. [3]
Responsivity	The input–output gain of a detector system, reflecting an ability to adjust to sudden, altered conditions in the environment and to resume stable operation. Automation or AI responsivity refers to the “degree to which the automation effectively adapts to the person and situation” (Chiou and Lee, 2021, in [3]).
Robustness	For an input varying in a region of the state space, the system is producing the same outputs. [4] Robustness of an AI system encompasses both its technical robustness (appropriate in a given context, such as the application domain or life cycle phase) and as well as its robustness from a social perspective (ensuring that the AI system duly takes into account the context and environment in which the system operates). This is crucial to ensure that, even with good intentions, no unintentional harm can occur. Robustness is the third of the three components necessary for achieving Trustworthy AI. [2]
Self-learning AI system	An AI system that can recognise patterns in the training data in an autonomous way, without the need for supervision. [2]
Shared mental model	A consistent understanding and representation of how systems work across teammates (i.e., the degree of agreement of one or more mental models). This includes models of the technology and equipment, models of taskwork, models of teamwork, and models of teammates (e.g., knowledge, skills, attitudes, preferences) [3]
Shared situation awareness	The degree to which team members possess the same SA on shared SA requirements [3]
Situation awareness	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) in [3]
Supervised Learning	A process by which computer algorithms are “trained” by a “training dataset” of inputs tagged with desired outputs. Supervised learning can be applied, for example, as uni- or multivariate regression, to find the best algorithmic fit to a given dataset, thereby enabling prediction of the output from a new data point. [1]
Supervisory control	Control by a human operator of automation, which, at a lower level, is controlling a dynamic system. The human operator handles higher-level tasks and determines the goals of the overall system, monitors the system to determine whether operations are normal and proceeding as desired, and diagnoses difficulties and intervenes in the case of abnormality or undesirable outcomes [3]
Team	A distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited lifespan of membership” (Salas et al., 1992, in [3]).
Team and situation awareness	The degree to which every team member has the SA required for his or her responsibilities [3]
Team mate	A fellow member of a team. Teammates may be human or non-human (e.g., an animal, bird, robot, or autonomous software agent). [3]
Team mental model	A mental model of one’s teammate(s) that provides an understanding of teammates’ capabilities, limitations, current goals and needs, and current and future performance [3]
Team work	An interrelated set of knowledge, skills, and attitudes that facilitate coordinated, adaptive performance in teams. This includes an understanding of roles, responsibilities, interdependencies and interaction patterns, communications, and information flow. Teamwork is often contrasted with taskwork.[3]
Traceability	Ability to track the journey of a data input through all stages of sampling, labelling, processing and decision making. [2]
Transparency	The understandability and predictability of the system, including its “abilities to afford an operator’s comprehension about an intelligent agent’s intent, performance, future plans, and reasoning process” (Chen et al., 2014, in [3]).

Trust	The attitude that an “agent will help achieve an individual’s goals in a situation characterised by uncertainty and vulnerability” (Lee and See, 2004). Trust can mediate the degree to which people rely on each other as well as on a technology, such as AI.
Trustworthy AI	Trustworthy AI has three components: (1) it should be lawful, ensuring compliance with all applicable laws and regulations (2) it should be ethical, demonstrating respect for, and ensure adherence to, ethical principles and values and (3) it should be robust, both from a technical and social perspective, since, even with good intentions, AI systems can cause unintentional harm. Trustworthy AI concerns not only the trustworthiness of the AI system itself but also comprises the trustworthiness of all processes and actors that are part of the AI system’s life cycle. [2]
Unsupervised Learning	The process whereby the input dataset is not a priori structured and the computer algorithm is used to find structure(s) in the data. Unsupervised learning can be applied, for example, as a form of data mining in unstructured datasets to reveal otherwise unknown structures and relationships in the dataset. [1]
Use case	A specific situation in which a product or service could potentially be used. For example, self-driving cars or care robots are use cases for AI. [2]
Validation	An engineering activity with the goal to assure that a product satisfies its intended customer use. In the context of datasets, a validation dataset is used to select the best subset of models before explicitly testing. [1]
Verification	An engineering activity with the goal to assure that an implementation satisfies all requirements or specifications. In the context of ML datasets, a verification dataset is used to verify the behavior of the executable code once it has been integrated into the target platform/system. [1]
White box AI	AI approaches that can explain how they behave, how they produce predictions, and what the influencing factors are (i.e., transparent approaches). [3]

## Annex B: Example Applications

This Annex presents details of various relevant example applications, across the following domains:

- Aviation flight deck (B1.1);
- Aviation ground, including airport and ATM (B1.2);
- Manufacturing (B2);
- Smart home technology (*Domotics*) (B3); and
- Automotive (B4).

Technologies were selected both for their innovativeness and robustness of their underlying human-AI teaming concepts, but also their potential relevance for the HAIKU use cases. Each application is summarized using the same ad hoc template. Reference links are provided for further information.

### B.1.1. Flightdeck domain

Technology: CAMA (Crew Assistant Military Aircraft)		
Designers: University of German Armed Forces Munich, DaimlerChrysler Aerospace, Elektronik System GmbH (ESG), Deutsches Zentrum für Luft- und Raumfahrt (DLM)		Year: 2001
Interface features		
Visual X	Haptic	Voice X
<b>Input:</b> <ul style="list-style-type: none"> <li>• Speech</li> <li>• Touch screens</li> <li>• Line select keys</li> <li>• Switches</li> </ul>		<b>Output:</b> <ul style="list-style-type: none"> <li>• Presentation of calculated flight plan proposals</li> <li>• Situation presentation</li> <li>• Warnings about detected conflicts</li> <li>• Recommendation about explicit actions</li> <li>• Messages in reply to requests</li> <li>• Acknowledgment of speech input</li> <li>• Presentation of complex actions</li> </ul>
Context of use		
Aviation / flightdeck		
Description		
CAMA is a prototype cognitive assistant for military transport aircraft cockpit that works under extended operational conditions including Instrument Flight Rules (IFR). Its architecture is based on Rasmussen's human cognitive process scheme in which each of the functional unit is modelled from each cognitive task of the Rasmussen's scheme.		
Generic Features	<ul style="list-style-type: none"> <li>• Weather, proximity to terrain and technical environment monitoring</li> <li>• Autonomous recognition of relevant objects such as landing strips and obstacles, aiding landing under low visibility conditions on unequipped airfields.</li> <li>• Pilot's behaviour monitoring</li> <li>• Diagnosis and detection of conflicts and opportunities</li> <li>• Traffic conflict issues visual and acoustic advice as part of the Traffic Alert and Collision Avoidance Systems (TCAS)</li> <li>• a warning, visual and by voice, is issued in case of violations of safety margins</li> <li>• Provides 'proposals' as part of the conflict resolution which involves planning and decision-making support</li> </ul>	
Expected benefits	<ul style="list-style-type: none"> <li>• Ensure the highest degree possible of situation awareness of the flight crew and a satisfactory workload level</li> <li>• Solution to counteract susceptibility to pilot errors typical of lack of attention or other cognitive limitations</li> </ul>	
Human-AI Teaming	<ul style="list-style-type: none"> <li>• Pilots interact with the system by speech, touch screens, line select keys or switches to request flight plan proposal, activate, modify, reject proposals, perform actions related to warnings, retrieve information, operate autopilot and configure the MMI.</li> <li>• CAMA presents calculated flight plan proposals and situations, warns about detected conflicts, recommends actions to perform, and presents of complex actions</li> </ul>	

**Image & References**

<https://linkinghub.elsevier.com/retrieve/pii/S1270963801011373>

**Technology: Tracing Pilots' Situation Assessment by Neuroadaptive Cognitive Modelling**

Designers: Airbus Central, Airbus Defence & Space, Zander Laboratories B. V. **Year:** 2020

**Interface features**

**Visual** **Haptic** **Voice**

**Input:** Electroencephalogram (EEG) **Output:** Event related potentials (ERP)

**Context of use**

Aviation / flightdeck

**Description**

The system analyses pilots' brain activity response to alerts in the cockpit to assess whether they have been perceived correctly. Using additional information such as historic pilot responses and operational parameters, the system can infer the cognitive state of the pilot and offer relevant support opportunities in single-pilot operations.

<b>Generic Features</b>	<ul style="list-style-type: none"> <li>Distinguishing between processed and missed alerts based on pilot's brain activity</li> <li>Anticipation of pilot behaviour based on cognitive model identification</li> </ul>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>Detect unprocessed alerts to offer cognitive assistance for the course of operation</li> </ul>
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>Pilots' brain activity is monitored during operations. If the assistant detects unprocessed alarms, it offers support to deal with the problem that triggered the alert</li> </ul>

**Image & References**

<https://www.frontiersin.org/article/10.3389/fnins.2020.00795/full>

**Technology: Adaptive visual information support system**

Designers: Northwestern Polytechnical University, Athabasca University **Year:** 2021

**Interface features**

**Visual** **Haptic** **Voice**

**Input:**

- Eye gaze (movements), AOI sequences
- Flight parameters
- Event data

**Output:**

- Display of information relationship representation

**Context of use**

Aviation / flightdeck

**Description**

This technology is a new adaptive system that detects the visual information that pilots did not acquire or missed, analyses the relationship between the pieces of information to generate a suitable presentation to the pilot displayed in a proper way and at the proper time.

<b>Generic Features</b>	<ul style="list-style-type: none"> <li>Visual cognitive graph (database of AOI sequences for each flight task)</li> <li>Missed information detection</li> <li>Relation between information extraction</li> <li>Adaptative information display</li> </ul>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>Present proper information adaptively to improve pilot' SA.</li> </ul>
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>The system tracks pilot's eye gaze, AOI sequences, flight parameters and event data to identify the flight task</li> <li>The system detects whether the pilot is performing the task correctly and support him by display the relevant information at the right time</li> </ul>

**Image & References**

<https://ieeexplore.ieee.org/document/9730326/>

**Technology: Pilot Assist System, a Holographic Checklist Assistant for the Single Pilot**

Designers: Technical University of Applied Sciences Wildau (THW), Germany / Technical University of Berlin, Germany		Year: 2019	
<b>Interface features</b>			
<b>Visual X</b>	<b>Haptic</b>	<b>Voice X</b>	
Input: <ul style="list-style-type: none"> <li>Voice command</li> </ul>		Output: <ul style="list-style-type: none"> <li>Augmented visual cues over the instruments and the commands in the cockpit</li> </ul>	
<b>Context of use</b>			
Aviation / flightdeck			
<b>Description</b>			
Pilot Assist System is a tool that provides visual and spatial cues about action to perform while completing operation checklists. The pilot loads a checklist through voice command and Pilot Assist System guides the pilot through each step of the checklist.			
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>Activates over voice commands</li> <li>Guides pilots with visual and spatial cues about the action to perform for each item of the checklists</li> </ul>		
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>Workload reduction for single pilot operations (PAS will replace the pilot monitoring as a checklist assistant)</li> </ul>		
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>The system tracks the pilot's voice for commands and actions</li> <li>The pilot uses cues given by the system to locate area of interests, perform relevant actions and check the procedure steps until completion</li> </ul>		
<b>Image &amp; References</b>			
<a href="https://ieeexplore.ieee.org/document/9730326/">https://ieeexplore.ieee.org/document/9730326/</a>			

<b>Technology: The Cognitive Adaptative Man Machine Interface (CAMMI), Crew Workload Manager</b>			
Designers: Honeywell, Delft University of Technology		Year: 2011	
<b>Interface features</b>			
<b>Visual X</b>	<b>Haptic</b>	<b>Voice</b>	
Input: <ul style="list-style-type: none"> <li>Electroencephalography</li> <li>Electrocardiography</li> </ul>		Output: <ul style="list-style-type: none"> <li>Visual instruments that display the workload states of both pilots using graphical and textual representations.</li> </ul>	
<b>Context of use</b>			
Aviation / flightdeck			
<b>Description</b>			
The Crew Workload Manager has been designed to make the workload of pilots visible to each other. The goal is to provide support for the crew to detect workload imbalances and address it as early as possible. The system measures, compares and displays the workload between pilots and can recommend task sharing. By acting as a third party, the state assessment may be better received by the pilots.			
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>Workload states detection for both pilots on the flight desk</li> <li>Visual output of both pilot's workload states that allows comparison</li> <li>Open-loop mitigation: pilots need to address the situation between them, the system will not initiate any change</li> </ul>		
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>Balancing workload and reducing the time spent in high workload should lead to improved performance, fewer errors and less fatigued pilots</li> </ul>		
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>The system tracks pilots' workload states and provides workload awareness to the pilots</li> <li>The pilots can initiate tasks reallocation between each other to balance the workload on the flight desk</li> </ul>		
<b>Image &amp; References</b>			
<a href="http://pro.sagepub.com/lookup/doi/10.1177/1071181311551004">http://pro.sagepub.com/lookup/doi/10.1177/1071181311551004</a>			

**Technology: Digital assistant for non-stabilized approaches in single pilot operations**

<b>Designers:</b> ENAC, Deep Blue, Computer Vision and Behaviour Analysis Lab		<b>Year:</b> 2022	
<b>Interface features</b>			
<b>Visual X</b>	<b>Haptic</b>	<b>Voice X</b>	
<b>Input:</b>		<b>Output:</b>	
<ul style="list-style-type: none"> <li>• Eye tracking</li> </ul>		<ul style="list-style-type: none"> <li>• Graphical, textual and audio alerts</li> </ul>	
<b>Context of use</b>			
Aviation / flightdeck			
<b>Description</b>			
HARVIS is an assistant that provides decisional support to the flying pilot, replacing the monitoring pilot. It can support single pilot operators for non-stabilised approaches in the final approach phase. It analyses flight parameters and alerts the pilot if a deviation is detected. It also estimates if a go-around is necessary and warns the pilot if so.			
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• Pilot's behaviour identification</li> <li>• Approach deviation detection</li> <li>• Approach deviation alert</li> <li>• Go-Around recommendation</li> </ul>		
<b>Expected benefits</b>	To help single pilot operators to make informed decisions during final approaches where the workload is very high and where issues are usually discussed between both pilots		
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>• The system monitors pilot's eye gaze to detect if the pilot is looking at deviating parameters during the final approach</li> <li>• The system provides deviation alerts to the pilot before the go-around is necessary</li> <li>• The system recommends go-around when necessary</li> </ul> <p>The pilot makes the decision to perform the go-around or not</p>		
<b>Image &amp; References</b>			
<a href="https://doi.org/10.1016/j.trpro.2022.12.025">https://doi.org/10.1016/j.trpro.2022.12.025</a>			

<b>Technology: Dynamic rerouting assistant for Single Pilot Operations (SPO)</b>			
<b>Designers:</b> Skylife Engineering, ENAC, Deep Blue, Computer Vision and Behaviour Analysis Lab		<b>Year:</b> 2022	
<b>Interface features</b>			
<b>Visual X</b>	<b>Haptic</b>	<b>Voice X</b>	
<b>Input:</b>		<b>Output:</b>	
<ul style="list-style-type: none"> <li>• Verbal and tactile input to ask details about rerouting landing options.</li> </ul>		<ul style="list-style-type: none"> <li>• Graphical and textual information</li> </ul>	
<b>Context of use</b>			
Aviation / flightdeck			
<b>Description</b>			
HARVIS is an assistant that provides decisional support to the flying pilot, replacing the monitoring pilot. One feature of HARVIS is to support the flying pilot for rerouting operations. It calculates the trajectories to the surrounding airports and proposes a ranking of possible landing options to the pilot. The benefits and drawbacks for each option is presented to the pilot who can make an inform decision about where to land. The system provides two types of recommendation which are displayed as a list on the HMI depending on the time available to deal with the emergency by rerouting the flight: <ul style="list-style-type: none"> <li>• During light emergency, the system provides information based on trajectory, fuel, infrastructure, weather, etc. and a recommendation of the most likely runaway, approaching and landing route</li> <li>• During severe emergency, the system provides all the possible and feasible trajectories calculated</li> </ul>			
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• Compute trajectories to surround airports</li> <li>• Rankings of possible landing options</li> <li>• Display information to pilots through EFB</li> <li>• Adapt computation, trajectories, and information display according to emergency severity</li> </ul>		
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>• To help single pilot operators to make informed decisions in case of flight rerouting</li> </ul>		
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>• The assistant monitors the aircraft status and flight conditions to detect and notify emergency to the flying pilot</li> <li>• Depending on the emergency, the assistant computes alternative trajectories</li> </ul>		

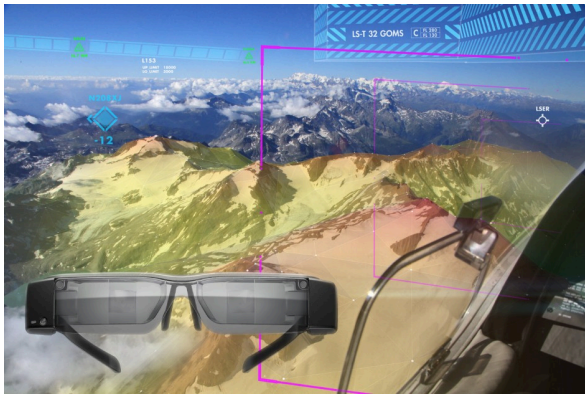
	<ul style="list-style-type: none"> <li>• The assistant displays a list of potential rerouting trajectories ordered by priority</li> <li>• The pilot interacts with the assistant to request more information about the rerouting recommendations</li> <li>• The pilot interacts with the assistant to amend the optimisation parameters</li> <li>• The assistant can update the list of rerouting options according to new optimisation parameters</li> </ul>
<b>Image &amp; References</b>	
<a href="https://linkinghub.elsevier.com/retrieve/pii/S2352146522007463">https://linkinghub.elsevier.com/retrieve/pii/S2352146522007463</a>	

<b>Technology: Aero Glass</b>		
<b>Designer:</b> Aero Glass		<b>Year:</b> 2014
<b>Interface features</b>		
Visual <b>X</b>	Haptic	Voice
Input: Visual		Output: Visual
<b>Context of use</b>		
Aviation / flightdeck		
<b>Description</b>		
<p>Aero Glass is a mixed reality navigation technology for pilots, using smart glasses. The company’s mission is to “make the sky safer and to create a breath-taking navigation experience”. The technology is inspired from head up displays, improving situational awareness and saving the pilot valuable time. Aero Glass provides a unique turnkey solution addressing pilots' need to properly visualise terrain, navigation, traffic (ADS-B), instruments, weather conditions, and airspace information with access to vital safety procedures and protocols, without the requirement of inspecting instruments, phone, or iPad. Aero Glass claims to be the first to bring Augmented Reality (AR) to pilots, providing an unparalleled 3D, 360° experience in the cockpit, regardless of the visibility. With this technology, pilots can see reality unobstructed, with key flight information projected onto the see-through smart glasses just in front of their line of sight.</p> <p>The working principle is relatively simple. The movement of the pilot’s head is monitored using a custom head tracking system, in which a small infrared camera is looking at markers on a marker board overhead. This information, combined with the aircraft attitude and position (*), allows Aero Glass to know where the pilot is looking from and what he/she is looking at. In this way, the smart glasses know where to precisely display all information required.</p> <p>(*) Navigation data comes from the FAA and other sources, which are turned into a 3D database and loaded into the smart glasses. Live traffic data comes from ADS-B receivers.</p>		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• Smart glasses: introduces AR in the cockpit</li> <li>• Custom head tracking system: monitors the pilot’s head movements. Combined with the aircraft attitude and position, it allows to display the flight information accurately and accordingly through the smart glasses.</li> <li>• Navigation features displayed during VFR flights: airports, flight plan, navigation points, terrain, airspaces, ADS-B traffic.</li> <li>• Navigation features displayed during IFR flights: airways, SIDs and STARs, approaches.</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>• Self-contained smart glasses: no more need for head up displays or to constantly inspect instruments.</li> <li>• Stereoscopic view: displays move and rotate around with the pilot’s head, thanks to the head tracking system. This enables: <ul style="list-style-type: none"> <li>○ All-around 360° display capability</li> <li>○ 3D Augmented Reality (AR)</li> <li>○ Artificial horizon: especially useful for parabolic flights or aerobatics.</li> </ul> </li> <li>• Anywhere the pilot looks, they will have the graphic overlay of information on the terrain and the sky, instead of having to mentally combine information from navigation charts, the instruments, and the scenery around them.</li> <li>• Fully portable and easy to install in any type of aircraft</li> <li>• No certification required</li> </ul>	
<b>Human-AI Teaming</b>	The system assists the user in performing monitoring tasks i.e., constantly scanning the instruments and navigation charts. Aero Glass enhances the pilots’ experience	

during the flight, while also improving their situational awareness. Finally, the system contributes to the overall safety of the flight by providing the user with an enhanced view of key flight information, saving the pilot valuable time.

**Image & References**

<https://glass.aero/>  
<https://vimeo.com/210800728>  
<https://www.skybrary.aero/articles/head-display>



**Technology: Mission+ (Electronic Flight Assistant)**

Designer: NavBlue | Year: 2021

**Interface features**

Visual **X** | Haptic | Voice

Input: Touchscreen | Output: Visual

**Context of use**

Aviation / Flightdeck

**Description**

Mission+ is an interface that pilots and crew can use to check and gather any relevant information related to the flight schedule and performance. This interface is embedded with a digital assistant that gathers information pilots need in one single application on a globe-centric display. It includes electronic navigation charts, mission management and weather depiction on the globe. It integrates flight management data and documentation, cockpit check-list, navigation charts and airport maps, real time weather conditions, aircraft performance data.

**Generic Features**

Mission+ is an interface that contains several modules:

- Mission+ FLIGHT. The module provides briefing packages, flight follow-up, and reporting capabilities to pilots, such as Operational Flight Plan (OFP), filtered NOTAMs and weather information, last-minute change handling functionalities, flight follow-up (fuel and weight), en-route alternate management and secondary flight plans e-reporting (OOOI, air safety report...). A ground tool that manages the workflow between OCC systems and the application in the flight deck covering all mission data required for a flight is also provided.
- Mission+ MAPS. It includes aeronautical data for Enroute, Terminal charts, and Supplement information. It includes terrain display and an Airport Moving Map (AMM) which is seamlessly integrated into the Enroute map enhancing situational awareness. The FOMAX connection can be activated to retrieve the aircraft's own-ship position using the Aircraft Interface Device (AID).
- Weather Options. Graphical weather data can be displayed on the Enroute Map with different layers that can be activated and deactivated by the pilot. The available weather data is composed of the following items: TAF/METAR, wind, SIGMET, turbulence, icing, thunderstorms.

**Expected benefits**

- Optimises the pilot's journey from preparation to closure of a flight, thus consistently reducing their workload and making the whole process more efficient.
- The use of the digital assistant also enhances situational awareness, by highlighting the important information in each situation when required, the pilots can focus on the most relevant tasks.

	<ul style="list-style-type: none"> <li>It increases efficiency, by reducing manual entries and the risk of errors. Finally, it allows a high level of customization to fit the individual needs of each airline.</li> </ul>
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>Flight crew can consult the Flight Plan information prepared by the dispatcher for analysis and coordination of tasks, through the interface. The digital assistant automatically generates the briefing package from the Ops Control Centre. The interface reports the flight parameters, such as crew list, fuel, and load, and generates the flight acceptance, which is then sent to the dispatcher.</li> <li>The user can consult the state and performance of the flight directly from the touchscreen interface. Evaluation and analyses of critical information are displayed through the interface.</li> <li>The interface allows pilots to select different layers of flight information using the globe display.</li> <li>Fuel and time follow up on the NAVLOG can be done manually or automatically through an AID. Users can consult the Airport moving map, which helps them see the relevant information about the airport infrastructure. It enables contextual functions, like the Auto-switch from the approach chart to the AMM during the landing phase.</li> <li>Once at the gate, all the information and parameters for the flights are consolidated so that the pilot can see it and send it to the dispatcher.</li> </ul>

**Image & References**

<https://www.navblue.aero/product/mission/>

<https://www.mrobusinesstoday.com/innovation-of-the-week-navblues-mission-rousing-success-eight-airlines-under-its-fold-in-a-year/>



**B1.2 Ground / ATM / Airport domain**

<b>Technology: AIMEE</b>		
Designer: Searidge Technologies	Year: 2017	
<b>Interface features</b>		
Visual <b>X</b>	Haptic	Voice <b>X</b>
Input: Visual - Vocal		Output: Visual - Vocal
<b>Context of use</b>		
Aviation / ATM		
<b>Description</b>		
<p>AIMEE is an advanced neural network framework for the development of AI-based solutions for ATC and airport efficiency. The technology has been developed to simplify the configuration and training of neural networks with large and complex data sets, to allow the continuous evaluation and testing of output, and most importantly, to predict and certify performance within a safety critical context.</p> <p>AIMEE has three key functional areas:</p> <ol style="list-style-type: none"> <li><b>1. Flight data surveillance</b></li> </ol> <p>Aircraft and ground vehicles equipped with transponders are tracked by Airport Surveillance Radar (ASR) and GPS location data. Radar data is received from different radar heads, to give a maximum coverage of the airfield, while further tracking</p>		

data is available from multilateration position identification. This provides ATCOs with an overview of aircraft movements on the airport surface area.

### 2. Computer vision: detection, tracking, and classification

AIMEE is trained to understand the visual characteristics of objects of interest (e.g., aircraft, vehicles, humans, etc.) using a set of archived video footage. In this way, it can detect any objects of interest within the coverage area of the cameras, without any other external data or sensors. The system has the capability of tracking vehicles around the gate and in the field of view to provide a complete picture of all activity on the non-movement area. Furthermore, remotely controlled cameras can be automated to follow objects of interest without operator control. In this way, ATCOs can select an aircraft on their display and follow it via the remotely controlled cameras, thus enhancing their situational awareness by constantly having the aircraft in their line-of-sight.

### 3. Natural language processing: controller-pilot communication

AIMEE is trained to enable AI voice technology. In the future, this feature could potentially automate the delivery of departure clearances at smaller airfields. However, the technology is yet too primitive to be extended to other clearances, such as the permission to start engines, leave stand, or manoeuvring of the aircraft.

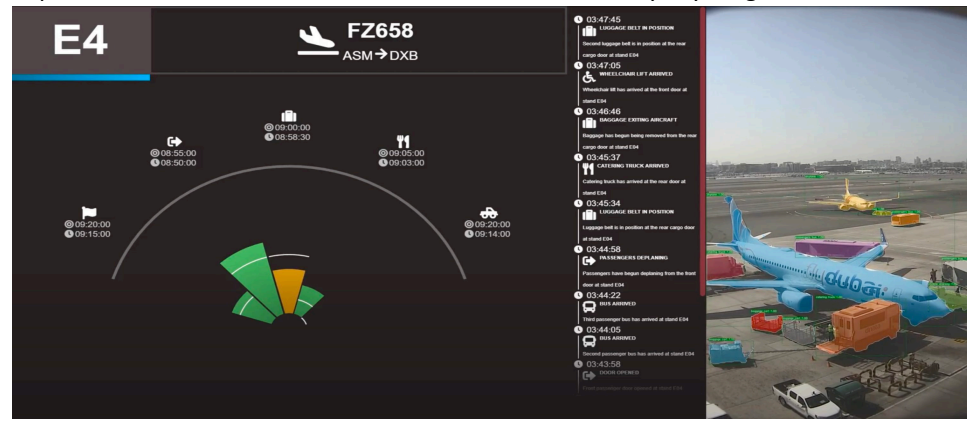
There is also the AIMEE Voice Services (AVS) solution, which uses radiotelephony (R/T) transmissions from the pilot to initiate operation. The pilot request is interpreted and checked against the existing ATC flight strip, after which the system responds to the pilot with the appropriate clearance or request for clarification. The goal is to remove this interaction with the pilot to reduce ATCO workload.

<p><b>Generic Features</b></p>	<ul style="list-style-type: none"> <li>Rich visualisation layer: enables intuitive display of data and an user-friendly HMI for configuration.</li> <li>Algorithm is learned using AI, instead of being designed for one sole purpose</li> <li>AIMEE has the potential to speed up system development. The system enables the implementation of new operational solutions that enhance ATC and airside safety, while improving efficiency.</li> <li>The system can predict potential incidents by comparing data. In this way, ATC stakeholders can be informed in advance.</li> <li>Simultaneous data processing from different sources: video sensors, ATC radio, ADS-B, and airport operations systems. By analysing this data, AIMEE aims to identify useful patterns for system behaviour prediction.</li> </ul>
<p><b>Expected benefits</b></p>	<ul style="list-style-type: none"> <li>Non-technical users are able to develop AI solutions</li> <li>AIMEE recognises patterns in very large datasets at speeds that surpass human capabilities. Therefore, efficiency is guaranteed to be improved.</li> <li>In the future, AIMEE could greatly reduce ATC and airport operators' workload by taking over part of their tasks.</li> <li>Increased airport throughput capacity and optimised</li> <li>Prediction capabilities: allows controllers and operators to make more informed decisions.</li> </ul>
<p><b>Human-AI Teaming</b></p>	<p>The system assists the user in performing monitoring and repetitive tasks e.g., controller-pilot communication and aircraft surveillance. AIMEE enhances the airport operators' view and provides them with key information and predictions. The latter help them make more informed decisions that will positively impact the overall efficiency of the airport and its operations. Finally, the AI integrated in this tool, together with ATC and airport operators, improves safety, situational awareness, and reduces workload for the users.</p>

### Image & References

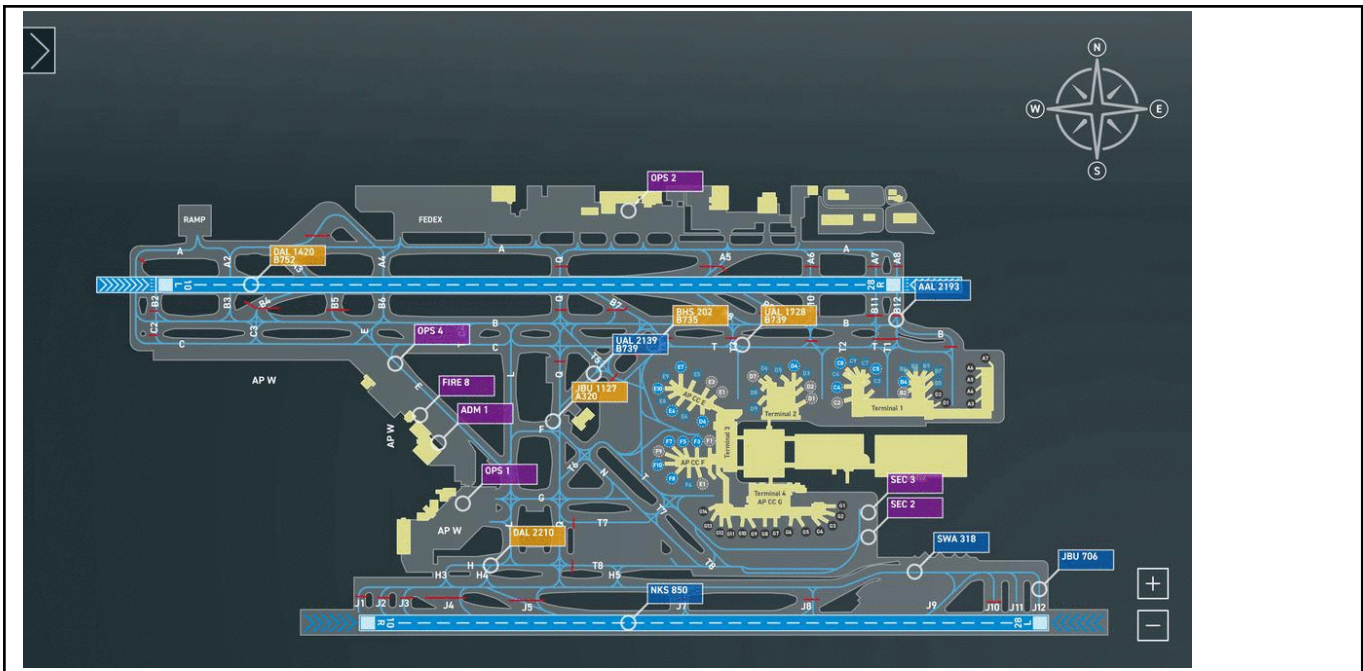
<https://searidgetech.com/aimee/>

<https://www.eurocontrol.int/sites/default/files/2019-11/skyway-magazine-autumn-winter-2019.pdf>





Technology: Airport Surface Display	
Designer: Searidge Technologies	Year: 2014
Interface features	
Visual <b>X</b>	Haptic
Input: Data from instruments and ATM systems	Output: Visual
Context of use	
Aviation / Airport	
Description	
<p>The Airport Surface Display (ASD) aims to help airport operators by creating a comprehensive surveillance means. The tool presents real-time aircraft and vehicle positions and movements in an intuitive map display, real-time weather information, NOTAMs, and user-configurable alerts. To display all this information, ASD incorporates multiple data sources, including SWIM, ADS-B, and vehicle transponders.</p>	
Generic Features	<ul style="list-style-type: none"> <li>• Multiple data sources are added together to create one single overview of the entire airport system</li> <li>• Displays real-time information: weather, NOTAM updates, aircraft and vehicle movements.</li> <li>• Provides precise aircraft and vehicle positions in the air and on the ground - this is very useful for ATC, allowing operators to make informed decisions.</li> <li>• ATC and airport operators can customise ASD. There are multiple display filters and alerts can be configured by the user.</li> </ul>
Expected benefits	<ul style="list-style-type: none"> <li>• Cost-effectiveness: ASD provides the airports and airlines with an affordable surface management system.</li> <li>• Enhanced situational awareness: using the system's complete surveillance picture, airport operators gain a better understanding of real-time operations.</li> <li>• Increased operational performance and safety.</li> <li>• ASD proactively manages surface traffic and allows users to configure their preferred alerts.</li> </ul>
Human-AI Teaming	<p>The system assists the user in performing monitoring tasks i.e., airport surface surveillance. ASD enhances the airport operators' view and provides them with key real-time information. The latter helps them make more informed decisions that will positively impact the overall efficiency of the airport and its operations. Finally, the surface management system improves safety, situational awareness, and reduces workload for the users.</p>
Image & References	
<a href="https://searidgetech.com/airport-surface-display/">https://searidgetech.com/airport-surface-display/</a>	



Technology: Fly to Gate	
Designer: Thales	Year: 2022
<b>Interface features</b>	
Visual <b>X</b>	Haptic
Input: Visual	Output: Operational data
<b>Context of use</b>	
Aviation / Airport	
<b>Description</b>	
<p>Fly to Gate offers a touchless, quick, and easy biometric passenger experience. This new self-service solution aims to transform the airport experience for air travel stakeholders (terminal staff, airport operators, immigration control, and passengers). Using automated biometrics, identity management, border security, and systems integration technologies, Fly to Gate will accelerate the flow of travellers from check-in to boarding. It is an end-to-end solution that will improve passenger satisfaction and airport efficiency while complying with IATA's 'one ID' concept - streamlining passenger journey with advance sharing of information and contactless processes at the airport based on biometric recognition.</p> <p>Passengers first create a Digital Travel Credential (DTC), either via an app on their smartphone or at a kiosk in the airport terminal. The DTC is created by scanning the boarding pass, passport, and faces of the passengers. Next, the DTC, combined with the passenger's check-in information, is shared with the airline so they can be identified at all touchless self-service steps in the terminal. Fly to Gate pods are distributed at all mandatory checkpoints of the airport journey, from check-in to boarding baggage drop, security screening, and immigration control. With their DTC in place, passengers can simply approach these pods for face recognition, with no need to present their passport or boarding pass. The Fly to Gate face pods quickly process live images, verifying them against the database of enrolled passengers, in only a few seconds. Finally, passengers do not have to worry about data privacy. Their DTCs are deleted after boarding but remain safely in their possession in their digital wallet, ready to be reused for the next trip.</p> <p>Fly to Gate also provides support in managing operations, helping airline operators to optimise airport security and overall passenger traffic in real time. It analyses large volumes of operational data to provide an accurate view of airport operations. Operators can then visualise these insights on a user-friendly map, allowing them to make quick interventions and master the impact of unplanned events and incidents. Finally, the customisable dashboard facilitates the monitoring of Key Performance Indicators (KPIs) and the improvement of operational efficiency and passenger flows.</p>	
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● Digital Travel Credential (DTC): a digital representation of the traveller's identity which temporarily substitutes their conventional passport. DTC is created from: <ul style="list-style-type: none"> <li>○ ID verification (face scan) - either via the app or the self-service kiosks at the airport.</li> <li>○ Document reader - for ID or passport and boarding pass scan.</li> </ul> </li> </ul>

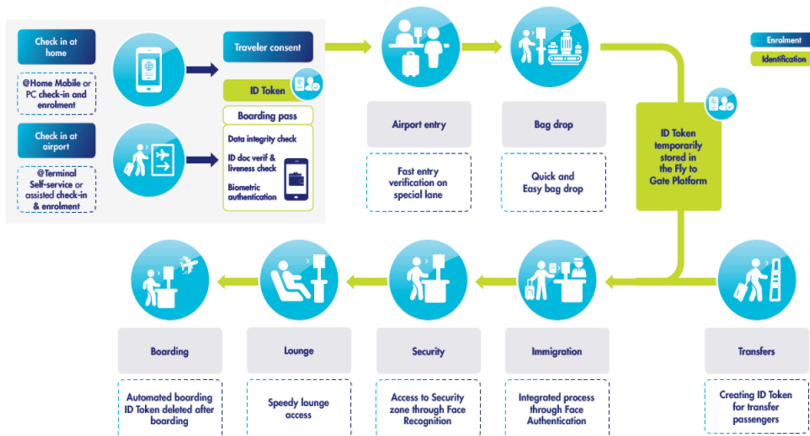
	<ul style="list-style-type: none"> <li>● Multimodal biometric pod: an innovative pod integrating iris and face recognition. It allows multimodal biometric capture to both enrol and verify passenger identity.</li> <li>● Monitoring of airport operational data: generates passenger analytics and passenger handling capabilities.</li> </ul>
<p><b>Expected benefits</b></p>	<ul style="list-style-type: none"> <li>● Greater flexibility: passengers can enrol anywhere using their smartphone or a self-service kiosk at the airport.</li> <li>● Efficient airport operations and enhanced passenger experience: time required for airport passenger processing can be decreased by up to 30%. This means: <ul style="list-style-type: none"> <li>○ Increased airport throughput capacity</li> <li>○ Less time spent in queues, so potentially, reduced duration of the 'airport journey' (check-in to boarding).</li> </ul> </li> <li>● Improved predictability of passenger flows</li> </ul>
<p><b>Human-AI Teaming</b></p>	<p>The system assists the user in performing repetitive tasks. Not only it enhances passenger experience, it also facilitates the work of airport operators in executing verification tasks, monitoring, and predicting passenger flows. Thanks to the face pods, passengers do not have to present their passport or boarding pass, while airport operators gather significant operational data.</p>

**Image & References**

<https://www.thalesgroup.com/en/markets/digital-identity-and-security/government/eborder/airport-self-service-solutions>

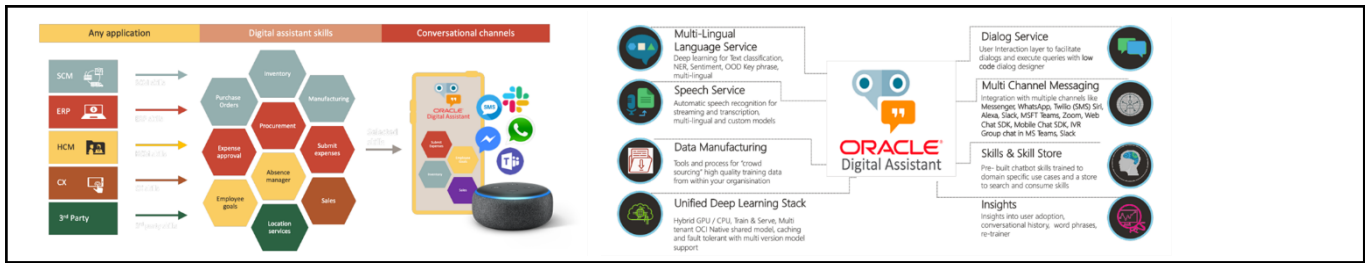
<https://youtu.be/s2jmqzv6lFA>

<https://www.iata.org/en/programs/passenger/one-id/#:~:text=One%20ID%20aims%20to%20offer,airlines%2C%20airports%2C%20and%20governments.&text=One%20ID%20will%20bring%20multiple,end%20to%20end%20passenger%20journey.>



## B2. Manufacturing domain

Technology: Oracle Digital Assistant		
Designer: Oracle Corporation		Year: 2021
Interface features		
Visual <b>X</b>	Haptic	Voice
Input: Vocal - Textual		Output: Auditory - Visual (text-based)
Context of use		
Manufacturing		
Description		
<p>Oracle Digital Assistant is an AI platform that creates conversational experiences for business applications through text, chat, and voice interfaces in the form of intelligent composite chatbots. The Digital Assistant can be trained to support multiple-application domain skills from HR, ERP, CRM, and CX. The assistant proactively recognizes context, derives intent, and identifies and learns user patterns and behaviour to automate routine tasks such as expense approvals and meeting rescheduled. Designed and built on the Oracle Cloud Infrastructure, Oracle Digital Assistant provides simple, single skilled, linear responses such that businesses can harness their automation and intelligent bot development. This allows the business to map how to increase engagement, drive efficiency, and lower costs.</p>		
Generic Features	<ul style="list-style-type: none"> <li>• Natural language processing to support multi-language text and voice interactions</li> <li>• Integration with a variety of popular channels and devices, (e.g., Microsoft Teams, Facebook Messenger, Amazon Echo or Google Home)</li> <li>• A list of prebuilt, AI-trained digital assistant “skills” for Oracle business applications (including ERP, HCM, CX and others) and a low code development platform</li> <li>• Built-in analytics that identify conversational bottlenecks and usage patterns and make data-driven decisions</li> <li>• Delivers various output including images, signatures, lists, barcodes, and charts.</li> <li>• Provides bot-initiated action and alerts on top of tasks and a domain-specific vocabulary and deep semantic parsing to allow for complex industry conversations.</li> <li>• Provides knowledge base search and answer, live agent handoff, complex policy automation and process execution such as transactions and scheduling.</li> </ul>	
Expected benefits	<ul style="list-style-type: none"> <li>• Employees can easily work in a cross-functional way, accessing different backend systems within the same conversational interface. They can also strengthen their proficiency during changing business conditions and improve work safety.</li> <li>• Through self-service and automation capabilities, manufacturers can lower their operational costs as digital assistants address tasks without requiring human assistance.</li> </ul>	
Human-AI Teaming	<ul style="list-style-type: none"> <li>• Users are engaged in conversation with the bot via several channels, such as the web, mobile, SMS texting, smart speakers, Slack, Microsoft Teams. The user can simply ask the bot for recommendations, service, or guidance.</li> <li>• Users are allowed to design, build and customise their own conversational experiences with a point-and-click, no-code dialogue flows interface. The bot can be trained on custom domain vocabulary.</li> <li>• The users are allowed to determine and teach the assistant the vocabulary and task it should focus on.</li> </ul>	
Image & References		
<p><a href="https://www.oracle.com/chatbots/">https://www.oracle.com/chatbots/</a></p> <p><a href="https://www.oracle.com/a/ocom/docs/industries/industrial-manufacturing/fast-evolving-digital-assistants.pdf">https://www.oracle.com/a/ocom/docs/industries/industrial-manufacturing/fast-evolving-digital-assistants.pdf</a></p>		

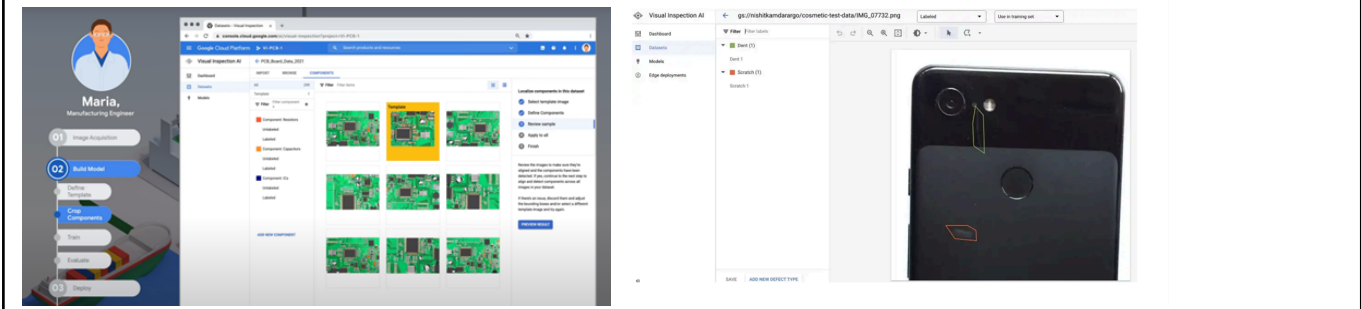


Technology: Visual Inspection AI		
Designer: Google		Year: 2021
Interface features		
Visual X	Haptic	Voice
Input: Touchscreen - Textual		Output: Visual
Context of use		
Manufacturing		
Description		
Using Google Cloud's leading computer vision technology, Visual Inspection AI automates the quality control process, enabling manufacturers to detect defects before products are shipped. Visual Inspection AI's deep learning allows customers to train models that detect, classify, and precisely locate multiple defect types in a single image. It provides a purpose-built AI based quality inspection platform specifically designed to solve manufacturing problems.		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• No special expertise is required. Quality, test, and manufacturing engineers can use the solution without any computer vision or AI subject-matter expertise. An intuitive user interface guides employees through all of the necessary steps.</li> <li>• Machine learning models can be trained using 10 labelled images (vs. thousands) and will automatically increase in accuracy over time as they are exposed to more products.</li> <li>• Full edge-to-cloud capability: Inspection models can be downloaded to machines on the factory floor and run autonomously at the edge, whether it be for data governance reasons or to improve latency. Visual Inspection AI is fully integrated in Google Cloud's portfolio of analytics and ML/AI solutions, enabling manufacturers to combine insights from Visual Inspection AI with other data sources, for instance to identify root causes of quality problems or to cross-reference with supplier and customer data.</li> <li>• Run autonomously on-premises: Manufacturers can run inspection models at the network edge or on-premises. The inspection can run either in Google Cloud or fully autonomous on your factory shop floor.</li> <li>• Can locate and identify the specific defect within each part of the component.</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>• By identifying defects early in the process, customers can improve production throughput, increase yields, reduce rework, and reduce return and repair costs. Visual Inspection AI operates across a wide range of industries and use cases, potentially saving manufacturers millions of dollars at each facility.</li> <li>• Google Cloud's Visual Inspection AI platform solves for 3 distinct Manufacturing use cases, namely image anomaly detection (defective parts identification, parts wear and tear detection, deformation, packaging and labelling anomalies etc), cosmetic inspection (dents, scratches, cracks, deformations, etc. on any kind of surface), and assembly inspection (defects at various stages of the assembly process - wrong, misplaced, missing, rotated, or deformed components).</li> </ul>	
<b>Human-AI Teaming</b>	<p>The platform provides 4 steps in building an Visual Inspection AI (VIAI) service through an intuitive UI and does not require any code:</p> <ul style="list-style-type: none"> <li>• Image collection for both defective and non-defective items to be saved on the cloud. The user can create datasets of images and upload them.</li> <li>• Image labelling, for which each image has to be annotated to identify and label the items as defective or correct. The user can draw a shape (eg. a polygon) around the defected area) and that will be categorised and recognised by the system as a defect in the training phase.</li> <li>• Model training. The training is broken down into several steps. The initial training uses an aspect of AI called active learning which helps suggest items to be labelled. The second step uses these newly labelled items to improve the accuracy. The user can access the evaluation page which contains details of the model evaluation metrics like Precision, Recall, Confusion matrix etc thereby providing a view of accuracy of the model.</li> <li>• Model deployment. The user can preliminarily test their model online. On completion of the training (and online testing), a new VIAI model is created and stored in the registry. The model is ready to be exported for deployment and live predictions.</li> </ul>	
Image & References		

<https://cloud.google.com/solutions/visual-inspection-ai>

<https://metrology.news/google-clouds-visual-inspection-ai-reinvents-manufacturing-quality-control/>

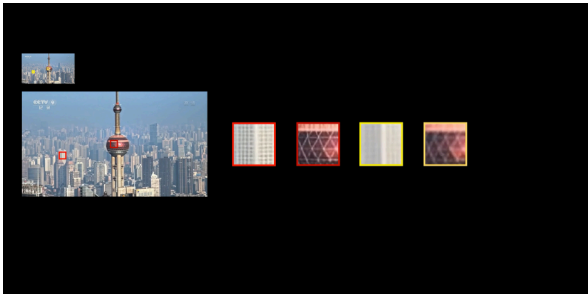
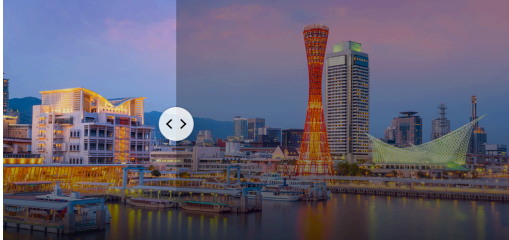
<https://medium.com/@nishitkamdar/visual-inspection-ai-a-differentiated-service-for-manufacturing-industry-google-cloud-d2ac14ff600d>


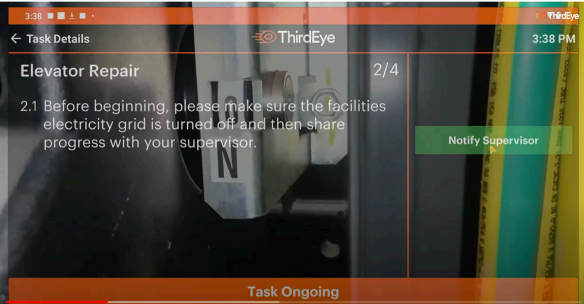


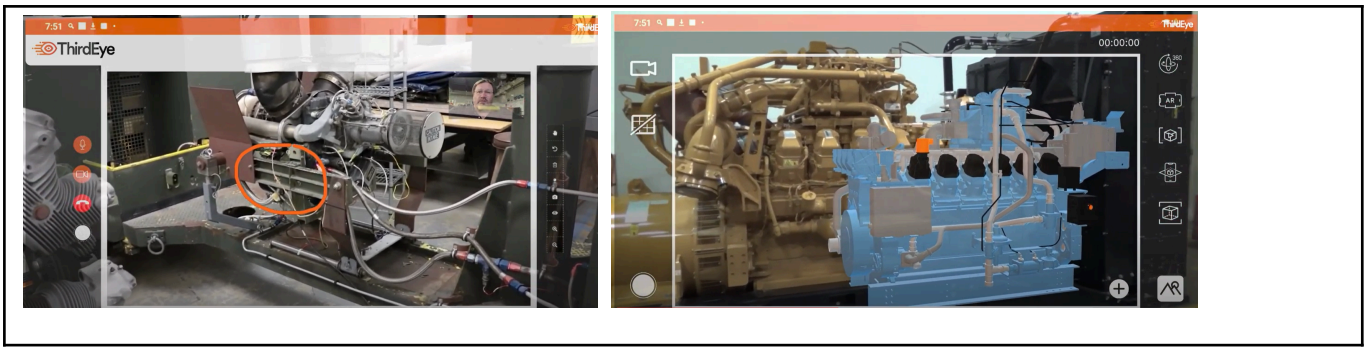
Technology: MindSphere (Smart Machine Assistant)	
Designer: Siemens	Year: 2018
Interface features	
Visual <input checked="" type="checkbox"/>	Haptic <input type="checkbox"/> Voice <input type="checkbox"/>
Input: Touchscreen	Output: Visual
Context of use	
Manufacturing	
Description	
<p>Smart Machine Assistant is a self-learning application for determining the optimal settings of an industrial machine in a complex environment. The application uses machine-learning capabilities to identify unknown relationships of machine parameters and KPIs. It gives machine operators concrete recommendations for adjustment of production parameters during operation to increase overall product quality and machine efficiency. With Smart Machine Assistant you can optimise your production by having the right parameterization at hand. Intuitive visualisations help you to timely identify misconfigurations of the machine parameters. The provided recommendations and available data in MindSphere support you in identifying the root causes of production drops.</p>	
Generic Features	<ul style="list-style-type: none"> <li>• Data normalisation to create meaningful data sets of machine configuration, production information and IoT time series data</li> <li>• Neural network-based module that periodically creates proposal data sets and stores them in the IoT Value Plan</li> <li>• Intuitive visualisation of proposal data sets in a standard application</li> </ul>
Expected benefits	<ul style="list-style-type: none"> <li>• Improve machine and process productivity by enhancing the quality loop of production processes leading to reduction in scrap and increase in first yield pass.</li> <li>• By accelerating experiential learning processes for operators, productivity and confidence in machine operations improves as a consequence, enabling the fast and easy scaling to multiple machine types across multiple, global production networks.</li> </ul>
Human-AI Teaming	<ul style="list-style-type: none"> <li>• Operators can consult the Smart Machine Assistant calculations to adjust production parameters avoiding productions drops and/or allowing for production optimisation</li> <li>• Manufacturing Settings can study data sets recorded by the AI system to foresee trends and take strategic decisions for future production</li> </ul>
Image & References	
<a href="https://siemens.mindsphere.io/en">https://siemens.mindsphere.io/en</a>	

Technology: SenseCore	
Designer: SenseTime	Year:
Interface features	
Visual <input checked="" type="checkbox"/>	Haptic <input type="checkbox"/> Voice <input type="checkbox"/>
Input: Visual	Output: Visual
Context of use	

Manufacturing	
<b>Description</b>	
<p>SenseCore is the universal AI infrastructure created by SenseTime. Through integrating strong computing power and leading algorithm capabilities, it can re-discover the potential values of information, breaking the boundaries of AI knowledge and applications and reducing the production costs of AI applications, thereby achieving efficient, low-cost and scalable AI innovation and empowerment. SenseCore technology is applied and tailored to different domains (e.g., Smart Industries/ Smart Business/ Smart City/ Smart Life/ Smart Auto) so as to deliver different applications and softwares. Hereby we will concentrate on the domains “Smart City” and “Smart Life” as in these domains SenseCore’s applications are particularly relevant to our desk research review.</p>	
<b>Generic Features</b>	<p><b>SenseCore for Industrial Quality Control: SenseSpring</b></p> <p>The SenseSpring platform uses characteristics of SenseMe and SenseFoundry to launch an AI-enabled automatic engine defect detection solution with its industrial quality inspection training platform. The SenseSpring platform addresses this industry problem by delivering solutions that cover three perspectives: multi-optical solution, multi-component support and multi-quality inspection.</p> <p>The SenseSpring platform supports over ten different image processing solutions under different lighting conditions, ensuring high-quality image quality inspection, data pre-processing and data enhancement. The platform is able to provide high-precision image segmentation for tiny defects with just 3-5 pixels, and even in extreme scenes where the image resolution reaches hundreds of millions of pixels, through the following techniques:</p> <ul style="list-style-type: none"> <li>● <b>Dehazing:</b> Based on industry-leading image processing technology, the technology removes heavy fog and haze from images.</li> <li>● <b>Dark Light Enhancement:</b> The industry-leading image processing technology improves the overall brightness and definition of images and videos shot under a dark light environment.</li> <li>● <b>Ultra HD video super-resolution:</b> Ultra HD video super-resolution converts videos to any resolution and size. Using a deep learning algorithm, the technology converts transmitted low-resolution videos to high-definition videos to improve image quality for a better viewing experience.</li> </ul> <p>Moreover, the platform provides unsupervised, semi-supervised and fully supervised model training for assembly defects and production process defects in industrial production to improve the accuracy of quality inspections.</p>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● <b>Creating new business models:</b> Digitizing and analysing the physical world to facilitate intelligent decision-making, forming new business models</li> <li>● <b>Accurate Quality Inspection:</b> Leveraging on the AutoML technology specially designed for small industrial datasets, the SenseSpring platform can achieve the best balance between computing power and accuracy in industrial quality inspection.</li> <li>● <b>Efficiency Improvement:</b> Through accurate quality inspection and summary analysis of defects, factories can quickly distinguish the key defects from the general defects, speeding up the iteration of the process from "month" to "week". The platform can also detect the defects in multi-component parts, such as the concave, arch and multi-dimensional parts.</li> <li>● <b>Accelerating large scale AI applications:</b> SenseCore enables efficient and scalable AI applications, reducing the production cost of scenario-specific models</li> <li>● <b>Addressing long-tail scenarios:</b> SenseCore provides the capability of addressing long-tail scenarios in city management, enterprise services, people’s life, integrating AI into more value chains</li> </ul>
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>● Users are better equipped to do maintenance jobs and assess quality of production</li> <li>● Users can decide whether they want to be unsupervised, semi-supervised and/or fully supervised during quality checks in order to identify assembly defects.</li> </ul>
<b>Image &amp; References</b>	
<a href="https://www.sensetime.com/en">https://www.sensetime.com/en</a>	



Technology: Remote Eye	
Designer: Third Eye	Year: N/A
Interface features	
Visual X	Haptic X      Voice X
Input: Visual	Output: Visual - Auditory
Context of use	
Manufacturing	
Description	
RemoteEye are smart glasses that bring about a new era of hands-free wearable computing and human interaction, by placing digital information directly into the user's field of view. Equipped with RemoteEye, frontline workforces can communicate remotely with supervisors, receive instructions in real time, diagnose equipment problems, and provide better support during every project more efficiently. Expert guidance, workflow instruction, and augmented reality collaborations are provided to the users through Live AR Communication in their visual and peripheral view area, significantly helping in the successful completion of mission-critical tasks.	
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● <b>Hands-Free Technology:</b> Remote expert assistance is transforming the way workforces are able to get tasks done more efficiently and effectively. With the ability to communicate with remote supervisors and/or experts in real-time, frontline workers can receive live assistance and instructions to streamline operations</li> <li>● <b>Live AR Communication:</b> Through a heads-up display enabled by live audio + video communication, provide your employees in the field with adequate instructions and feedback as if you were there in person.</li> <li>● <b>Screenshot &amp; Annotate:</b> ThirdEye has taken AR-enabled remote teleconferencing to the next level with live annotations. Remote experts/supervisors can improve communication with workers in the field by drawing on-screen annotations in the user's field of view. This functionality allows field workers to obtain more accurate instructions and feedback while continuing to complete tasks, resulting in improved operational efficiency</li> </ul>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● Reduce Travel and Production Costs</li> <li>● Empower workforce to make informed decisions, avoiding delays in their everyday challenges</li> <li>● Increasing success rates in the completion of mission-critical tasks</li> <li>● Increase training efficiency</li> </ul>
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>● Providing Task Flow in the vision field or 3D models through the glasses can help operators in the execution of the right sequence of tasks and manufacturing processes</li> <li>● Requiring assistance from experts through the vision field of the glasses is possible, which can increase productivity and ensure safety during risky operations</li> </ul>
Image & References	
<a href="https://remoteeye.live/">https://remoteeye.live/</a> <a href="https://www.youtube.com/watch?v=F9l2yuLROF4">https://www.youtube.com/watch?v=F9l2yuLROF4;</a> <a href="https://www.youtube.com/watch?v=YR9u7TjmUPM">https://www.youtube.com/watch?v=YR9u7TjmUPM</a>	
	

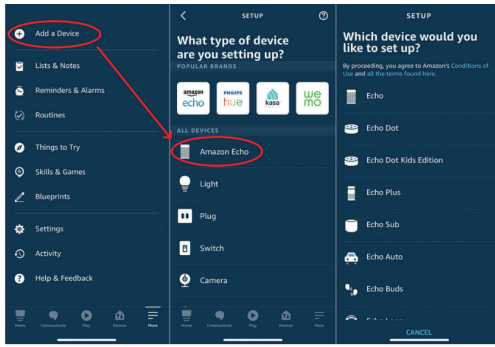






Technology: Amazon Alexa		
Designer: Amazon	Year: 2014	
Interface features		
Visual <b>X</b>	Haptic	Voice <b>X</b>
Input: Vocal - Touchscreen		Output: Auditory - Visual
Context of use		
Domotic		
Description		
<p>Amazon Alexa is a voice-controlled virtual assistant technology developed by Amazon and available on millions of devices (e.g., Smart speakers or smart display) from Amazon and any third-party device manufacturers. Alexa offers services to the user through a vocal interaction. Users can ask questions or input direct commands to the virtual assistant to get an answer to their need or to make an event happen. Alexa is capable of voice interaction, music playback, making to-do lists, setting alarms, streaming podcasts, playing audiobooks, and providing weather, traffic, sports, and other real-time information, such as news. Moreover, through common protocols like Wi-Fi and Bluetooth, it can act as a home automation system, thus multiplying its possible applications and uses (e.g., controls many smart devices). Initial configuration is done through the Alexa application, which is also used to manage preferences commands and devices manually.</p>		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● Smart speaker: VUI (Voice User Interface) and visual interface (via LED strips that change colour).</li> <li>● Smart display: VUI and visual interface (via a display).</li> <li>● Alexa App: VUI and visual interface (via smartphone display).</li> <li>● Users can ask a question to the device. This audio is then converted into text and into a machine-understandable meaning processed on the cloud. After having analysed the input from the user, an appropriate output is generated that could either be converted into text to be “read” by the device or it could be data needed for a specific action like playing a song with a specific app.</li> <li>● The application allows the user to execute the same commands or questions manually (set an alarm, create a reminder, start a timer...).</li> <li>● The application also gives the possibility to connect other devices (e.g., cameras, lamps, etc.) so that Alexa can act as a home automation system, create routines (series of actions performed in a single command) and launch new skills.</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● Facilitate use and interaction through voice commands.</li> <li>● Increase speed and improve convenience in issuing commands and receiving a response vocally rather than manually.</li> <li>● Greater accessibility for some categories of people (e.g., people with disabilities).</li> <li>● Set reminder events, calendars, timers, and to-do-lists, reducing workload.</li> <li>● Customise voice commands according to the user’s routine</li> <li>● Facilitate the control of compatible devices (e.g., lights, switches, thermostats...).</li> <li>● Integrate data from different data sources (weather, news...) in real-time to inform the user.</li> </ul>	
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>● The digital assistant acts as a supportive partner that will only help the user when the virtual assistant is called vocally. The assistant also acts as a consultant, in remembering appointments, events, reminders, etc. and informing the user by integrating data from different sources according to the downloaded skills.</li> <li>● The cooperation reduces the mental workload and improves information acquisition, thus enhancing decision-making.</li> <li>● Set-up phase: The user connects the device to the power supply.</li> <li>● Execution of a generic command: The user activates the device using a wake word such as “Alexa” followed by a question or a command (e.g., “Alexa, add milk to the shopping list”). Alexa executes the command and replies (e.g., ‘milk added to shopping list’).</li> <li>● Create a custom routine: The user chooses the name, the voice command, and a series of actions (e.g., Weather and news of the day) that Alexa will execute with that single voice command.</li> </ul>	
Image & References		

<https://www.amazon.co.uk/b?ie=UTF8&node=12728352031>  
<https://www.flentas.com/alexa-overview-sample-use-case>  
<https://digiaide.com/swot-analysis-of-alexa/>  
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**Technology: Nest Learning Thermostat**

**Designer: Google Nest** **Year: 2020**

**Interface features**

**Visual X** **Haptic** **Voice X(\*)**

**Input: Physical - Vocal** **Output: Auditory - Visual**

**Context of use**

**Domotic**

**Description**

The Nest Learning Thermostat is a smart thermostat, electronic, programmable, and self-learning Wi-Fi-enabled thermostat able to optimise the heating and cooling of homes and businesses to conserve energy. Google's Nest Learning Thermostat is based on a machine learning algorithm: for the first few weeks, users have to adjust the thermostat to provide a set of reference data. In this way, the thermostat can then learn people's schedules, what temperatures they are used to set, and when, building a schedule by learning each time the user walks in front of the thermostat or adjusting the temperature. This is possible thanks to an occupancy sensor that detects if someone is in the room and thanks to the thermostat's ability notes if the user manually adjusts the temperature on the device. The Nest Learning Thermostat will remember these changes and consequently adjust the schedule. Furthermore, by using the built-in sensors and phones' locations, it can switch to energy-saving mode when it realises that no one is at home.

(\*)The Nest Learning Thermostat can also connect to a digital assistant (such as Alexa or Google Assistant) via a specific app: in this way, the user can use voice commands to raise or lower the temperature, set it, or choose the operating mode (e.g. heating mode).

<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• The Nest Thermostat is built around an operating system that allows interaction with it via a ring around the body of the thermostat to adjust temperatures, access device settings, energy history, and scheduling.</li> <li>• The user has to just turn the ring up or down to adjust temperature to their needs. The user can see on the screen the current ambient temperature, the temperature settings, and icons like the Nest Leaf. Moreover, the colour will change between orange (heating) blue (cooling) and black (off or ECO) depending on the system's current state.</li> <li>• To access device settings and other options, instead, the user must press the thermostat ring to see more options, turn the ring to select an option, and press the ring again to confirm the selection.</li> <li>• The thermostat screen will turn off when it notices that there hasn't been any recent activity nearby.</li> </ul>
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<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>• Learn user preferences.</li> <li>• Automatically adjust home settings according to the patterns of use.</li> <li>• Facilitate use through voice commands.</li> <li>• Remote access to the thermostat via the app when the user is away.</li> <li>• Help the user to save energy by learning from the user's habits or when no one is at home.</li> <li>• Suggestions to adjust temperatures and temperature schedules for the thermostat.</li> </ul>
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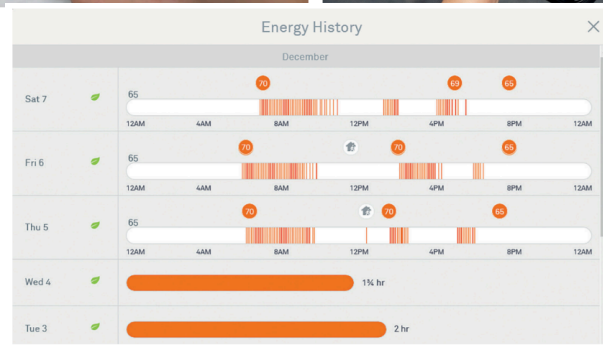
## Human-AI Teaming

- The digital assistant acts as a supportive partner as it learns people's schedules, adapting the temperature within the home according to the patterns of use, creating an auto-schedule.
- In fact, the digital assistant does more routine, repetitive tasks, considering different types of data (e.g., how big, and draughty the house is, what kind of heating and cooling system it has, and what the user schedule is...). On the other hand, if the user doesn't like the temperature that the thermostat is set to, they can either teach the thermostat a new schedule by turning the ring a few times until it learns, or they can make manual adjustments to the schedule. Auto-schedule continues learning but it will also respect target temperatures the user has manually created or adjusted.
- Such cooperation reduces the mental workload (e.g., remembering to turn on or turn off the system) and improves information acquisition (e.g., energy usage) and energy savings, enhancing the life of the user and the planet and to make smart choices about the schedule and temperature preferences.
- Set-up phase: After installation, the user answers a few questions about the house (e.g. the language, the position, what temperatures s/he like, the heating and cooling system).
- Connect thermostat to app: The thermostat must be connected to the Wi-Fi network. The user downloads the Nest app, signs up, and adds the new device. The thermostat can be connected to the app by scanning a QR code or through manual setting.
- Change the target temperature: The user can change the target temperature in different ways: 1) by turning the thermostat's ring clockwise or counter clockwise, 2) by dragging the larger and longer line around the ring on the app, 3) by tapping the plus or minus buttons at the bottom of the ring on the app, 4) by saying vocally the command (e.g. "make it warmer (or cooler)" or "set the temperature to [#] degrees") after downloading the virtual assistant app and associating it with the thermostat.
- Home and away function: in cases in which no recent manual changes to the temperature have been detected, or the occupancy sensor of the thermostat doesn't detect anybody in the room, or in the case the Home/Away Assist detects that the user is not at home, the thermostat automatically switches to an Eco Temperature (if it's activated), helping the user save energy.
- Manual change to the schedule: For the thermostat, the schedule can be changed through its display or through the app
- Review energy history: From both the thermostat display and the app, users can access a graphic showing the energy history. Graphs show the total time the user system was on during the day, the days when the user saved energy and earned a Nest Leaf (e.g., when Eco Temperature is activated), and the main reasons why the energy usage went up or down and temperature values (compared to the previous days).

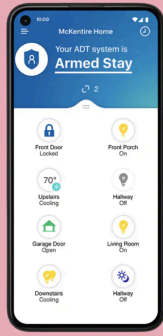
**Image & References**

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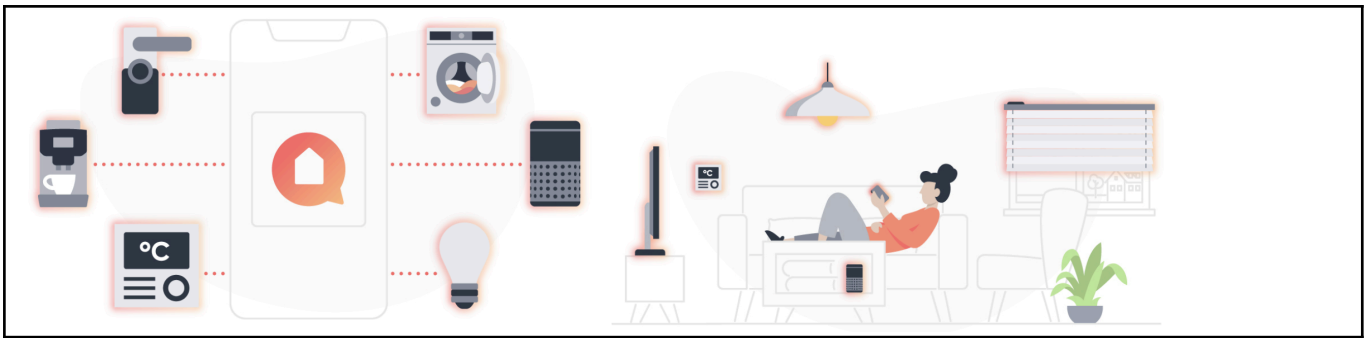
[https://support.google.com/googlenest/topic/9361772?hl=en&ref\\_topic=9361189,9371069,7029808](https://support.google.com/googlenest/topic/9361772?hl=en&ref_topic=9361189,9371069,7029808)



<b>Technology: ADT Command</b>		
Designer: ADT Corporation	Year: 2022	
<b>Interface features</b>		
Visual <b>X</b>	Haptic <b>X</b>	Voice <b>X (*)</b>
Input: Vocal - Touchscreen		Output: Auditory - Visual
<b>Context of use</b>		
Domotic		
<b>Description</b>		
<p>ADT Command is a new smart home security system that allows users to control all their home equipment from just one panel (touchscreen). Users can control their indoor, outdoor, and doorbell cameras, smart lights, locks, thermostats, and garage door controller through one touchscreen or the ADT mobile app. The ADT Command smart home security touchpad not only provides real protection for the things you value most, but also really smart, really simple integration and control of your smart security and home automation devices.</p> <p>(*) When paired with a smart speaker - such as 'Amazon Alexa' or 'Hey Google' - it is possible to give commands to the ADT Command system by a vocal input i.e., talking out loud.</p>		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● HD video security allows users to look in on their home and to see who is at their front door from anywhere with a clear HD video.</li> <li>● Smart home automation: the technology enables to create automations for different times of the day and situations. Geo-fencing can also be used to trigger smart devices like lights and thermostats.</li> <li>● Remote control: in addition to the touch screen panel, users can also control their smart devices (lights, thermostats, locks, etc.) remotely using smartphones and the ADT app.</li> <li>● Touchscreen keypad: main control centre, consisting of an intuitive, wireless touchscreen keypad from where one can automise and control their smart home.</li> <li>● Voice control integration (*): By integrating the ADT Command system with a smart home platform like 'Hey Google' or 'Amazon Alexa', it is possible to use voice control.</li> <li>● Advanced encryption technology: ADT Command uses the latest two-way encryption technology for a more secure connection with all paired devices.</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● Control your smart home equipment remotely</li> <li>● Automate your smart home equipment i.e., in store schedules for lights, thermostat, washing machine, etc.</li> </ul>	
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>● The digital assistant acts as a supportive partner that will only help the user when it is activated manually (via the touchscreen panel) or vocally (when paired with a smart speaker).</li> <li>● The role of the digital assistant is that of a consultant, in remembering set schedules for all paired devices and adapting different parameters (temperature, lightning, etc.) according to the patterns of use, thus creating an auto-schedule. Furthermore, by introducing constant monitoring of the house via cameras and other sensors incorporated in the smart devices, the assistant enables improved home security.</li> <li>● The human-machine cooperation reduces the mental workload (e.g., remembering to turn on or turn off the system) of users and improves information acquisition (e.g. energy usage), thus enhancing the life of users and the planet. Decision-making is also improved as it enables users to make smart choices in regard to their smart home devices' schedules and parameter preferences (temperature, duration, start/end time, light intensity, etc.).</li> </ul>	
<b>Image &amp; References</b>		
<a href="https://www.adt.com/command">https://www.adt.com/command</a> <a href="https://www.pcmag.com/reviews/adt-command">https://www.pcmag.com/reviews/adt-command</a>		

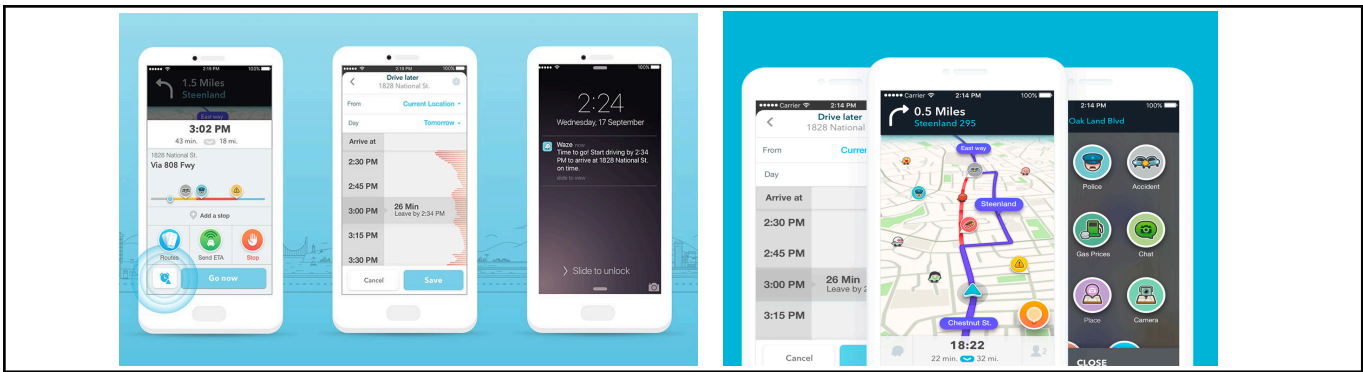


Technology: Home Connect Plus		
Designer: HomeConnect	Year: 2021	
Interface features		
Visual X	Haptic X	Voice X (*)
Input: Vocal - Touchscreen		Output: Auditory - Visual
Context of use		
Domotic		
Description		
<p>With the new Home Connect Plus app, users can connect, automate, and centrally control various smart home devices and entire systems from a large range of brands. This intends to make their smart life easier and to gain time for the things that are really important to them.</p> <p>(*) When paired with a smart speaker - such as 'Amazon Alexa' or 'Hey Google' - it is possible to control the Home Connect appliances through voice commands.</p>		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● Smart interaction: the technology enables to set up home automations using an "if-then" principle. These can be generated for different times of the day, situations, and devices e.g., lights, thermostat, speakers.</li> <li>● Remote control: users can control their smart devices (lights, thermostats, locks, etc.) remotely using their smartphones and the Home Connect Plus app.</li> <li>● One app for all devices: Multiple brands and applications are brought together into one single platform, facilitating the life of the users by allowing them to control all these devices from one single app.</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● The biggest advantage is being able to control all your smart home devices centrally, from one single app. Many brands offer apps for their smart devices, but it is very cumbersome to use, time consuming (switching back and forth between apps) and occupies storage on users' smartphones. Instead, the Home Connect Plus app combines all these apps and their functionalities into one.</li> <li>● Automate the user's smart home equipment: adjust schedules, temperature, etc.</li> <li>● Convenience: the app is free of charge</li> <li>● Personalisation: the app can be customised according to the users' preferences, needs, and everyday situations. It is possible to create different panels, linked to a set number of devices e.g., housecleaning, home office, gardening, etc.</li> </ul>	
<b>Human-AI Teaming</b>	<ul style="list-style-type: none"> <li>● The digital assistant acts as a supportive partner that will only help the user when it is activated manually (via the app) or vocally (when paired with a smart speaker).</li> <li>● The role of the digital assistant is that of a consultant, in remembering set schedules for all paired devices and adapting different parameters (temperature, lightning, etc.) according to the patterns of use, thus creating an auto-schedule.</li> <li>● The human-machine cooperation reduces the mental workload (e.g., remembering to turn on or turn off the system) of users and improves information acquisition (e.g., energy usage), thus enhancing the life of users and the planet. Decision-making is also improved as it enables users to make smart choices in regard to their smart home devices' schedules and parameter preferences (temperature, duration, start/end time, light intensity, etc.).</li> </ul>	
Image & References		
<a href="https://www.home-connect-plus.com/de/en/app/">https://www.home-connect-plus.com/de/en/app/</a> <a href="https://www.home-connect-plus.com/de/en/works-with/">https://www.home-connect-plus.com/de/en/works-with/</a>		



## B4. Automotive

Technology: Waze	
Designer: Waze Mobile	Year: 2010
Interface features	
Visual <b>X</b>	Haptic
Input: Touchscreen - Vocal - Tracking	Voice <b>X</b>
Output: Auditory - Visual	
Context of use	
Automotive	
Description	
<p>Waze is a free road navigation application that provides real-time traffic updates and more. Users can be informed about roadblocks, roadworks, and speed cameras and be advised on the best route to take as well as arrival time with the help of AI.</p> <p>Waze is also user-generated: the more people who use it, the better it gets.</p> <p>After typing in the destination address, users can in fact contribute either passively, by simply driving with the app open on their phone, or actively, by sharing reports of accidents or other hazards along the route.</p>	
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>• The interface provides both visually and acoustically the necessary information for taking the recommended route.</li> <li>• It is possible to focus attention on the road, avoiding possible accidents and facilitating driving, while at the same time visually consulting the route in case of doubts or misunderstandings.</li> <li>• Graphically, some icons highlight points of interest such as petrol stations or warnings (checkpoints, traffic jams, speed cameras) reported by other users belonging to the Waze Community.</li> </ul>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>• Reaching one's destination easily and in the shortest possible time.</li> <li>• Determining the best route.</li> <li>• Reduction of user workload.</li> <li>• Increased efficiency and safety on the road.</li> <li>• Movement monitoring with route recalculation in the event of user error.</li> </ul>
<b>Human-AI Teaming</b>	<p>The user will only be partially involved, the interaction will be more of an advisor type: the driver follows the directions provided by the artificial intelligence.</p> <ul style="list-style-type: none"> <li>• Planning: the driver sets the arrival destination in the search bar. The AI processes data from the network infrastructure and other Waze users to propose the best route.</li> <li>• Driving: the driver starts driving. The system indicates, step by step, the manoeuvres and route to be followed.</li> <li>• Recalculation: In case of driver error or changed conditions, the AI recalculates the route autonomously, without user intervention.</li> </ul>
Image & References	
<p><a href="https://support.google.com/waze/answer/6071177?hl=en&amp;ref_topic=9022747">https://support.google.com/waze/answer/6071177?hl=en&amp;ref_topic=9022747</a></p> <p><a href="https://medium.com/marketing-right-now/how-waze-uses-ai-to-navigate-and-dominate-the-game-729e075a09b2">https://medium.com/marketing-right-now/how-waze-uses-ai-to-navigate-and-dominate-the-game-729e075a09b2</a></p>	



Technology: AR Head-up Display 2.0 with Eye-Tracking	
Designer: Panasonic + Phiar	Year: 2021 - in progress
Interface features	
Visual <b>X</b>	Haptic
Input: Touchscreen - Tracking	Output: Auditory - Visual
Context of use	
Automotive	
Description	
<p>The head-up display (HUD) 2.0 with eye-tracking and augmented reality (AR) is the second HUD system developed by Panasonic in collaboration with Phiar Technologies. The HUD 2.0 is capable of projecting useful driving information within the field of view of the vehicle driver. The aim is to reduce the enormous cognitive load that drivers are subjected to, making it more natural to understand possible dangers (pedestrians, cyclists, various obstacles) and warnings from the car (warning lights, alarms) to increase road safety, facilitate driving and better understand the surroundings. The product differs in that it features an eye-tracking system (ETS) that uses an infrared camera integrated into the AR HUD projector, eliminating the need for an additional external camera. The ETS technology identifies the height and movement of the driver's head, dynamically adjusting and compensating for images within the field of view, as well as detecting drowsiness and distraction.</p>	
Generic Features	<ul style="list-style-type: none"> <li>• The main feature of the interface is that it is projected onto the windscreen of the vehicle (HUD) and merges with the observed reality (AR).</li> <li>• The system visually provides information on speed limits in the lower right-hand corner, while the lower left-hand corner presents information on upcoming manoeuvres and street names.</li> <li>• The central part of the interface is intended for various warnings such as hazard detection (pedestrians or cyclists), crossing zones, front-end collision risk, lane monitoring, lane departure, right or left turns, subway height, etc.</li> </ul>
Expected benefits	<ul style="list-style-type: none"> <li>• Cognitive load reduction.</li> <li>• Improved understanding of possible dangers.</li> <li>• Increased road safety.</li> <li>• Improved and safer driving experience.</li> <li>• Improved knowledge of the surroundings.</li> </ul>
Human-AI Teaming	<p>The human-AI relationship is advisor-like: the digital assistant supports and warns the driver, without ever taking control of the vehicle.</p> <ul style="list-style-type: none"> <li>• Danger detection (cyclists, pedestrians, objects): the driver encounters a sudden obstacle. The digital assistant detects the obstacle and alerts the driver, both visually and acoustically.</li> <li>• Driving: the driver has to move from point A to point B. The AI visually provides information to the driver while driving the vehicle (direction, speed, lane of travel).</li> <li>• Crossing zones: the driver encounters several zebra crossings along the route. The digital assistant signals their presence both visually and acoustically.</li> <li>• Front-end collision warning: the car in front of the driver brakes abruptly. The system immediately detects and warns the driver of possible danger to avoid rear-end collisions both visually and acoustically.</li> </ul>

- Approaching a lane: the driver approaches the adjacent lane out of drowsiness or distraction. The digital assistant signals this possible approach both visually and acoustically.
- Subway height detection: the digital assistant signals the height of subways along the route.

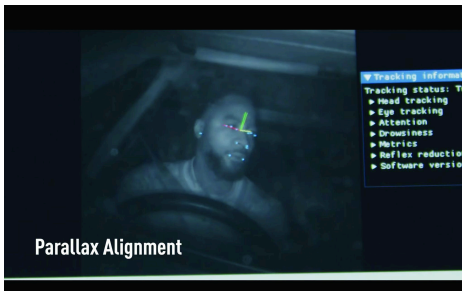
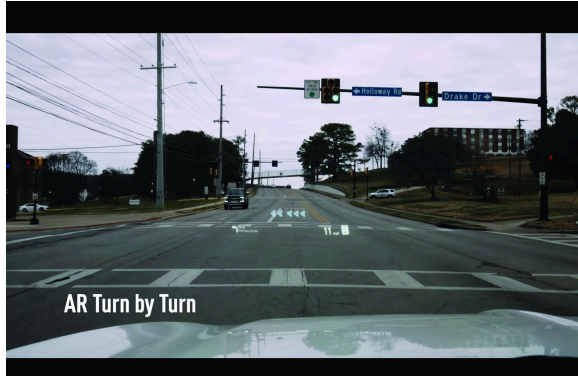
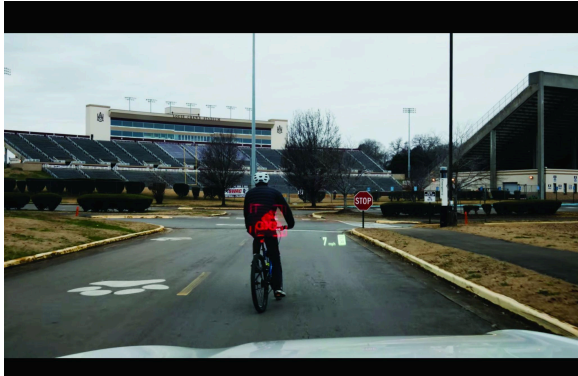
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<https://www.phiar.net/about>

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<https://na.panasonic.com/us/news/panasonic-automotive-unveils-driveable-ar-hud-20-patented-eye-tracking-system-ce-s-2022>



Technology: Qualcomm C-V2X (Cellular Vehicle-To-Everything)		
Designer: Qualcomm Technologies	Year: 2016 - in progress	
Interface features		
Visual <b>X</b>	Haptic	Voice
Input: Touchscreen - Physical - Tracking		Output: Auditory - Visual
Context of use		
Automotive		
Description		
<p>Qualcomm, a US-based R&amp;D company in the field of wireless networks, claims that the future of the car will be driven by a technology called C-V2X (cellular vehicle-to-everything), which defines the passage of information from the vehicle to any element that affects its behaviour.</p> <p>There are four types of C-V2X depending on the type of entity connected to the vehicle:</p> <ul style="list-style-type: none"> <li>● V2I - Vehicle to Infrastructure: connection between the vehicle and an element belonging to the road infrastructure.</li> <li>● V2V - Vehicle to Vehicle: transmission of information between vehicles in order to avoid potential dangers due to close collisions or rear-end collisions.</li> <li>● V2N - Vehicle to Network: communication between the vehicle and a network infrastructure, used to transmit information about traffic, accidents, closed sections with detours...</li> <li>● V2P - Vehicle to Pedestrian: communication between a vehicle and a pedestrian to inform of the approach of a dangerous vehicle.</li> </ul>		
Generic Features	<ul style="list-style-type: none"> <li>● The aim is to use the ubiquitous connectivity of C-V2X technology to provide warnings to drivers or pedestrians, to reduce the risk of road accidents of various kinds (distraction, unfavourable road conditions, excessive speed, road works...).</li> <li>● Since it is still under development and has several automotive and non-automotive partners (Audi, Ford, BMW, Ducati...), a communal and official interface has not yet been defined.</li> <li>● Warnings are conveyed to the driver, both visually, with situation-specific icons (stop signs, warning triangles), and acoustically, with audible alarms.</li> <li>● The positioning of the display, the vehicle of information, is still uncertain: some models incorporate the interface within the digital cockpit, while others have a side screen, positioned to the right of the steering wheel, between the driver and passenger.</li> </ul>	
Expected benefits	<ul style="list-style-type: none"> <li>● Reduction of road accidents.</li> <li>● Safer and more intelligent transport system (cooperation between vehicles).</li> <li>● Reduction of road traffic.</li> <li>● Reduction of air pollution and emissions.</li> <li>● Improved and safer driving experience.</li> </ul>	
Human-AI Teaming	<p>The human-AI relationship is advisor-like: the digital assistant advises the driver without ever taking control.</p> <ul style="list-style-type: none"> <li>● Crossroads movement assistance: the driver arrives at an intersection. The digital assistant signals the arrival or presence of a vehicle by advising on manoeuvres or priorities, both visually and acoustically. (Communication V2V).</li> <li>● Warning of the presence of roadworks: the driver is about to cross a stretch of road where there is roadworks. The C-V2X technology warns of roadworks, lane restrictions and the recommended speed for the driver, both visually and acoustically. (Communication V2N, V2V, V2P).</li> <li>● Speed limit: the driver has entered a stretch of road where the maximum speed limit has changed. The digital assistant alerts the driver of this change, both visually and acoustically. (Communication V2I).</li> <li>● Recommended speed: The digital assistant advises the driver of the ideal speed according to traffic and road conditions, both visually and acoustically. (Communication V2I).</li> <li>● Warning of the presence of a stationary vehicle on the road: along the stretch of road the driver encounters a stationary car. The digital assistant warns the driver of that vehicle, both visually and acoustically. (Communication V2V).</li> <li>● Road condition warning: C-V2X technology warns the driver of road conditions based on the weather. (Communication V2N).</li> </ul>	

- Traffic light status: the driver is about to cross an intersection regulated by traffic lights. The AI communicates traffic light status information to the driver, both visually and acoustically. (Communication V2I).
- Pedestrian presence warning: the digital assistant notifies the vehicle of the presence of a pedestrian in the vicinity, and the pedestrian of an approaching car directly on the smartphone, both visually and acoustically. (Communication V2P).

**Image & References**

<https://www.qualcomm.com/products/application/automotive/c-v2x>

<https://www.qualcomm.com/research/5g/cellular-v2x#:~:text=Cellular%20vehicle%2Dto%2DDeverything%20>

<https://www.cta.tech/Resources/i3-Magazine/i3-Issues/2021/March-April/Mobility-at-CES-2021>



**Technology: PRYSTINE**

Designer: European research project

Year: 2018 - 2021

**Interface features**

Visual **X**

Haptic **X**

Voice

Input: Tracking

Output: Auditory - Visual - Haptic

**Context of use**

Automotive

**Description**

The European ECSEL research project PRYSTINE concerns vehicle automation, identified as one of the main tools to overcome societal challenges such as individual mobility and energy efficiency.

One of the main challenges in achieving highly automated driving is the transition from SAE level 2 (partial driving automation) to SAE level 3 (conditional driving automation). In this case the driver remains available to intervene and manually perform all driving functions (DDT fallback) in the event of a fault or if the operating conditions under which the automation system operates are limited.

In fact, PRYSTINE's main goal is to realise the Fail-operational Urban Surround perceptiON (FUSION), which is based on a robust sensor fusion (radar, LiDAR, hand and head tracking, drowsiness detection) and shared control and arbitration functions between the automation system and the driver (intelligent co-driver) to enable safe automated driving in urban and rural environments.

**Generic Features**

The interfaces created for PRISTINE are demos of two different types and have two objectives:

- Study of driver-automation interaction and methods for the transition of vehicle decision-making authority.
- Study of the driver's role in supervising or controlling the vehicle when required.

In the first case, there are two interfaces. The first is vertical (Head Unit Version) and consists of two halves: the upper half presents information on automation status, speed information, and the 'Virtual Traffic Light' function. The lower half shows the route map.

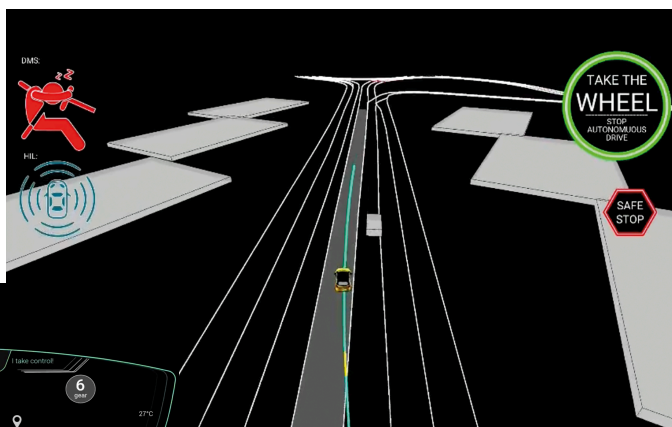
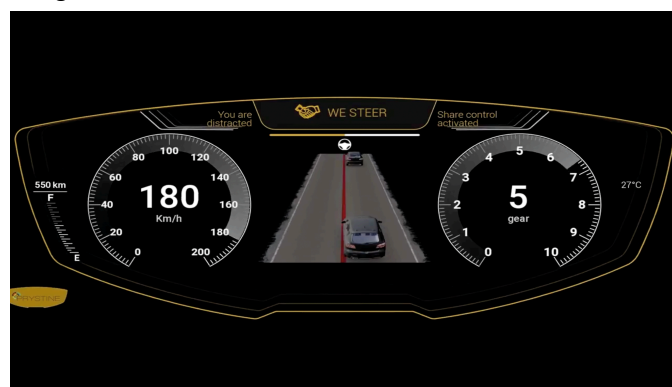
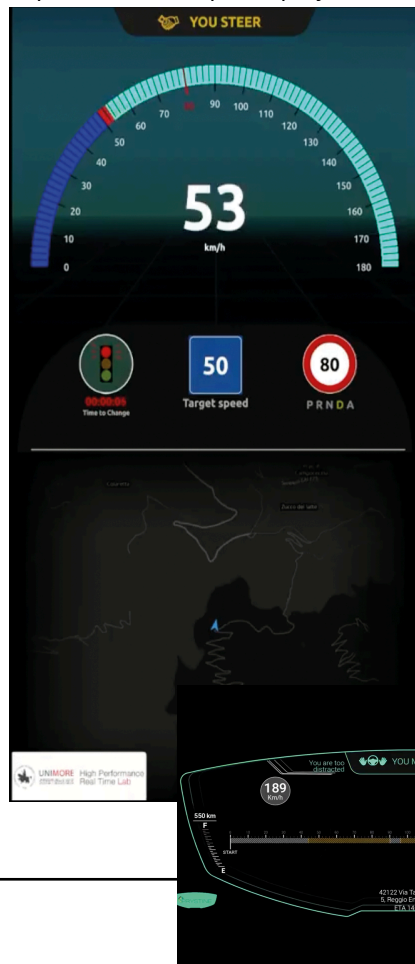
The second interface (Instrument Cluster Version) is horizontal and displayed on the instrument panel. The top half of the interface presents information on the automation status with explanations of the status change, and a dynamic progress bar showing the level of authority over vehicle control shared between the user and the automation system. The central part changes according to the automation status and shows general information about the vehicle (speed) and the route (via the map, 3D view, or timeline).

	<p>In the second case, the interface shows in the centre a 3D visualisation of the route to be taken. In the top left, there's an icon relating to driver drowsiness and an icon relating to the level of involvement required while driving. In the top centre, it shows warning signals like the presence of a pedestrian crossing. In the top right, a green icon indicates the activation of automated driving or manual driving, while an icon related to the 'Safe Stop' turns on in the event of the driver's failure to intervene in critical situations.</p>
<p><b>Expected benefits</b></p>	<p>Demo 1:</p> <ul style="list-style-type: none"> <li>● Activation and deactivation of the automation system without pressing any buttons.</li> <li>● Smooth and safe transitions from automated to manual and vice versa.</li> <li>● Reduction of mental workload when performing tasks.</li> <li>● Increased safety: protects the driver from dangerous actions while driving.</li> <li>● Automation intervention according to the driver's need for assistance.</li> <li>● The amount of information displayed is adapted according to the level of automation.</li> <li>● Provides explanations to improve driver awareness.</li> </ul> <p>Demo 2:</p> <ul style="list-style-type: none"> <li>● Generation of different possible driving routes based on comfort, safety and advantage.</li> <li>● Selection of the best driving route.</li> <li>● Suggesting the appropriate level of involvement for the driver.</li> <li>● Adequate and mutual understanding between driver and automation system</li> </ul>
<p><b>Human-AI Teaming</b></p>	<p>The teaming between the driver and the automation system is cooperative: the intelligent, adaptive co-pilot can decide, while driving, the level of authority and thus how the driving task can be shared, depending on external conditions, available system resources and the driver's cognitive state. This mode of shared control improves interaction by keeping the driver in the control loop, being constantly informed of the reasons for changes made by the automated driving system, and thus making clear the need for his or her participation in controlling the vehicle. This allows the user to enjoy greater safety and confidence and improved performance.</p>

**Image & References**

<https://prystine.eu/>

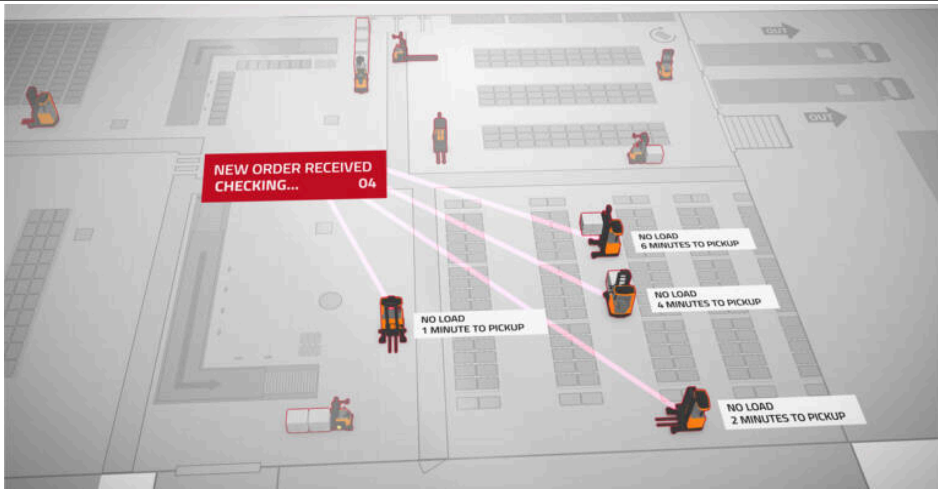
<https://cordis.europa.eu/project/id/783190/eng>





<b>Technology: SenseAuto</b>	
Designer: SenseTime	Year:
<b>Interface features</b>	
Visual <b>X</b>	Haptic
Input: Visual - Tracking	Output: Visual - Auditory
<b>Context of use</b>	
Automotive	
<b>Description</b>	
<p>The SenseAuto intelligent automotive application platform enables users to adopt cutting-edge AI technologies. It comprises five parts - SenseAuto Cabin, SenseAuto Pilot, SenseAuto RoboX, SenseAuto Connect and SenseAuto Empower.</p> <p>The SenseAuto Cabin Smart System comprises driver monitoring system (DMS), occupant monitoring system (OMS) and in-vehicle infotainment (IVI) system, bringing smarter, safer and more comfortable in-vehicle experience for both drivers and passengers.</p> <p>The SenseAuto Pilot Smart Driving System includes SenseAuto Pilot-V, a high-precision, low-cost mass-produced driving assistance system based on computer vision, SenseAuto Pilot-P, a multi-sensor fusion mass-produced smart driving product, and SenseAuto Pilot-L, a LiDAR sensing product.</p> <p>The SenseAuto Robobus is equipped with an all-rounded autopilot function and AR navigation function highly adaptable to complex environments such as rainy and foggy weathers. It is based on multi-sensor fusion, high-precision positioning, highly reliable decision-making and control, in-vehicle interaction, vehicle-road synergy and augmented reality (AR). The SenseAuto Connect Platform for Intelligent Sensing streamlines the connection between "car-road-cloud" as an organic whole. The cloud platform can also function as a hub for Vehicle to Everything (V2X) communications. The SenseAuto Empower is a customised in-vehicle version of SenseTime AI Infrastructure.</p>	
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● Driver Monitoring System (DMS): driver identity verification, drowsiness detection, distraction detection, absence detection and anomaly detection to enhance overall driving safety.</li> <li>● Occupant Monitoring System (OMS): detects unauthorised passengers and unattended objects in the cabin, and offers detection of infants/children, pets, lost items and safety seats.</li> <li>● In-Vehicle Infotainment (IVI): in-cabin augmented image quality, AR high-precision navigation and special effects for beauty cameras, smart albums and software agents' assistance functions.</li> <li>● SenseAuto Pilot-V: is able to identify a wide range of traffic signs and road features, detect vehicles up within 600 metres and pedestrians within 300 metres with stable performance.</li> <li>● SenseAuto Pilot-P: offers intelligent driving capabilities, including lane centering, traffic congestion assistance, driver-directed lane changes, and high-speed pilot smart driving.</li> </ul>
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● Reduction of road accidents.</li> <li>● Safer and more intelligent transport system (cooperation between vehicles).</li> <li>● Improved and safer driving experience.</li> <li>● Increased road safety.</li> <li>● Improved knowledge of the surroundings.</li> </ul>
<b>Human-AI Teaming</b>	<p>The teaming between the user and the digital assistant is collaborative in that, depending on the circumstances, the AI helps the driver while driving (lane centering, traffic congestion assistance...), and advisory in that the digital assistant warns the driver of any possible dangerous situations.</p> <p>It is also a monitoring partner since it monitors and detects drowsiness and distraction of the user.</p>
<b>Image &amp; References</b>	
<a href="https://www.sensetime.com/en/product-business?categoryId=1095&amp;gioIndex=1">https://www.sensetime.com/en/product-business?categoryId=1095&amp;gioIndex=1</a>	

Technology: T-ONE		
Designer: Toyota	Year: 2018	
Interface features		
Visual <b>X</b>	Haptic	Voice
Input: Touchscreen - Physical - Visual		Output: Visual - Auditory
Context of use		
Automotive		
Description		
<p>T-ONE, Toyota's in-house developed automation software, is installed as an integration layer communicating with the Toyota Autopilot automated guided vehicles (AGVs) and existing infrastructure such as warehouse management systems, goods identification and other material handling equipment.</p> <p>T-ONE can start orders in several ways, for example via buttons pushed by operators at workstations or scanners (often a barcode scanner mounted on a conveyor). The destination of an order can be determined when initiating the order or dynamically after ID scanning at pick-up. Moreover T-ONE manages the sequence in which the orders are carried out. The system provides a set of performance metrics, with graphs presented in the user interface to visualise the performance of the system.</p>		
<b>Generic Features</b>	<ul style="list-style-type: none"> <li>● Optimises how transport orders are executed and reduces order processing time thanks to the intelligent dynamic order allocation function</li> <li>● Keeps a steady and continuous material flow thanks to the advanced fleet control</li> <li>● Always chooses the most ideal path for the Autopilots by scanning the system and adapting to changes of the planned travel path</li> <li>● Makes sure the AGVs have less waiting time and fewer travels without a load</li> <li>● Allocates orders to the best-suited Autopilots, taking the entire operations flow into account.</li> <li>● Ensures that all loads are delivered when and where you need them, thanks to intelligent order allocation</li> <li>● Vehicle overview: list of all AGVs in real time with current status including vehicle ID, vehicle status and load status</li> <li>● Order overview: showing order execution time, queue time, completed order per vehicle</li> </ul>	
<b>Expected benefits</b>	<ul style="list-style-type: none"> <li>● Optimised order execution</li> <li>● Increased efficiency</li> <li>● Reduced order processing times</li> <li>● Optimising travel path</li> <li>● Monitoring of vehicles and orders enhancing situational awareness</li> </ul>	
<b>Human-AI Teaming</b>	<p>The system assists the user in performing mechanical and repetitive tasks. In this way, the user can take care of other tasks such as supervision and movement control. Thanks to the touchscreen interface the user can consult the state and performance of the travel path.</p>	
Image & References		
<p><a href="https://toyota-forklifts.eu/automated-solutions/software-t-one/">https://toyota-forklifts.eu/automated-solutions/software-t-one/</a>  <a href="https://www.youtube.com/watch?v=S1sJ3v-kGTo&amp;ab_channel=ToyotaMHEurope">https://www.youtube.com/watch?v=S1sJ3v-kGTo&amp;ab_channel=ToyotaMHEurope</a>  <a href="https://www.youtube.com/watch?v=zaP01-K2Kn0&amp;ab_channel=ToyotaMHEurope">https://www.youtube.com/watch?v=zaP01-K2Kn0&amp;ab_channel=ToyotaMHEurope</a></p>		




ONE [ORDERS](#) [VEHICLES](#) [METRICS](#) [CONFIGURATION](#) [SETTINGS](#) Toyota Local Development

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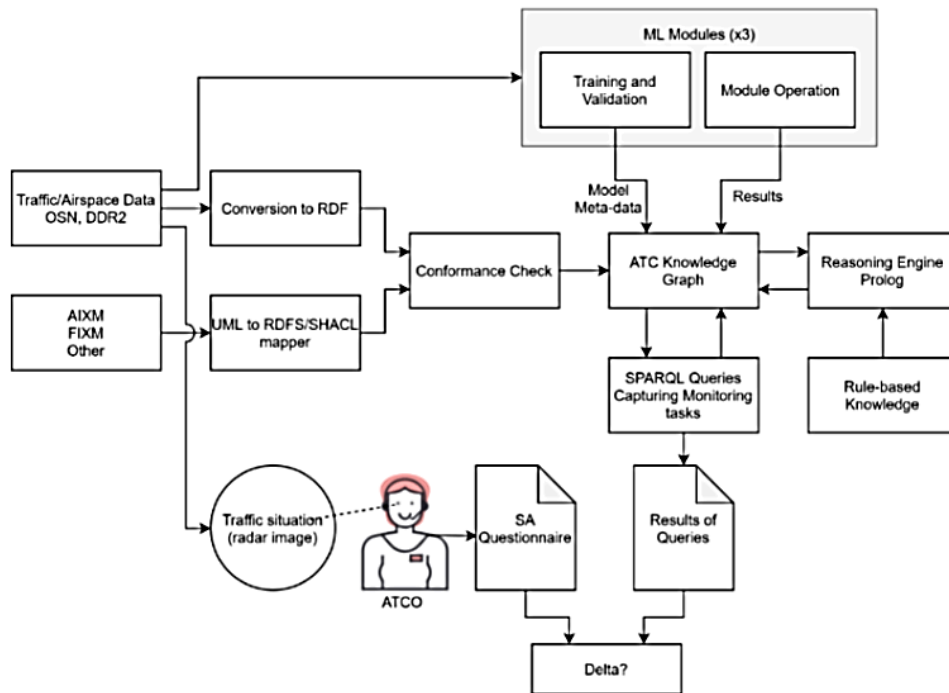
ID	VEHICLE	STATUS	PRIORITY	START TIME	DESCRIPTION	GOODS	ACTION
0f0697-7040-405e-415e-1e011058821b	1	Delivering	0	Oct 28, 2020, 11:35:53 AM	Drop-off at Station 37		<a href="#">ABORT</a>
0064e0-f044-4d7c-a183-ad892145ba	0	Fetching	0	Oct 28, 2020, 11:35:58 AM	Pick-up at Station 45		<a href="#">ABORT</a>
ec59e1-6362-4150-879c-01e70f435419	0	Pending	0		Pick-up at Station 14 Drop-off at Station 32		<a href="#">ABORT</a>
38620-18c7-4378-9043-532e55ba7c78	0	Pending	0		Pick-up at Station 15 Drop-off at Station 30		<a href="#">ABORT</a>
07582-8a63-4b73-afcd-384ae2549772	0	Pending	0		Pick-up at Station 10 Drop-off at Checkpoint 1_Check		<a href="#">ABORT</a>
3d10fb-5df5-472b-a2f0-1086da7a31f1	0	Pending	0		Pick-up at Station 34 Drop-off at Station 23		<a href="#">ABORT</a>
190004-21ba-4ee6-91f8-aa4337927705	0	Pending	0		Pick-up at Station 7		<a href="#">ABORT</a>
414656-aa13-4c10-a082-2fba09489681	0	Pending	0		Pick-up at Station 14 Drop-off at Station 32		<a href="#">ABORT</a>

Annex C: RELATED EU RESEARCH PROJECTS

<b>Title</b>	<b>AICHAIN</b> A platform for privacy-preserving Federated Machine Learning using Blockchain to enable Operational Improvements in ATM
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://www.aichain-h2020.eu/">https://www.aichain-h2020.eu/</a>
<b>Description</b>	<p>The goal of AICHAIN is to enhance air traffic management (ATM) system by articulating an <b>advanced privacy-preserving federated learning architecture</b> in which neither the training data nor the training model need to be exposed. This will be possible thanks to the innovative combination of two emerging technologies: <b>Federated Machine Learning (FedML)</b> and <b>Blockchain technologies</b>.</p>  <p>The project sought to improve flight allocations by applying machine learning to sensitive (and non-sensitive) data in a decentralised, protected way. The idea was that this would provide airlines with the security and confidence needed to share their data. Finishes on 31/12/2022</p>
<b>Achievements</b>	<p>Federated machine learning has been used to demonstrate that it could be used for <b>ATM (take-off time prediction and flight route prediction)</b>.</p> <p>AICHAIN also worked closely with relevant authorities to ensure that the machine learning tools could be certified for use in ATM.</p> <p>The project has been able to exert a positive influence on the certification process, in particular when data privacy and process transparency are both required.</p> <p>The project also demonstrated the power of <b>blockchain technology</b> in terms of traceability and generating <b>trust</b>.</p>
<b>References</b>	
<b>Additional Material</b>	<a href="https://www.aichain-h2020.eu/deliverables">https://www.aichain-h2020.eu/deliverables</a>

<b>Title</b>	<b>AISA</b> AI Situational Awareness Foundation for Advancing Automation
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://aisa-project.eu/">https://aisa-project.eu/</a>
<b>Description</b>	<p>Adoption of higher levels of automation is slow because of the fears of the <b>out-of-the-loop effects</b> where <b>air traffic controllers lose situational awareness</b> due to complacency caused by automation. In the worst-case scenario neither the human is completely aware of the traffic situation nor the machine is able to guarantee that the situation is being handled appropriately. Our approach to this problem aims to solve the problems by introducing <b>artificial situational awareness</b> into the, usually only human, team situational awareness.</p> <p>AISA will present a vision of automation in a specific ATM operational environment (en-route ATC) and address the challenges of <b>transparency</b> and <b>generalization</b>. During the project, a strategy for providing the necessary information to air traffic controllers in order to make them <b>trust</b> the automated system will be devised. Methods to increase the ability of an automated system to adapt to novel circumstances will be explored.</p>

- Explore the effects of human-machine **distributed situational awareness** and opportunities for **automation of monitoring tasks** in en-route operations.
- Identify the data needed by air traffic controller (ATCO) to ensure that the proposed solution is correct and develop the method to provide that data.
- Investigate methods for adaptation of the automated system to changes of the environment ensuring business continuity and safety.



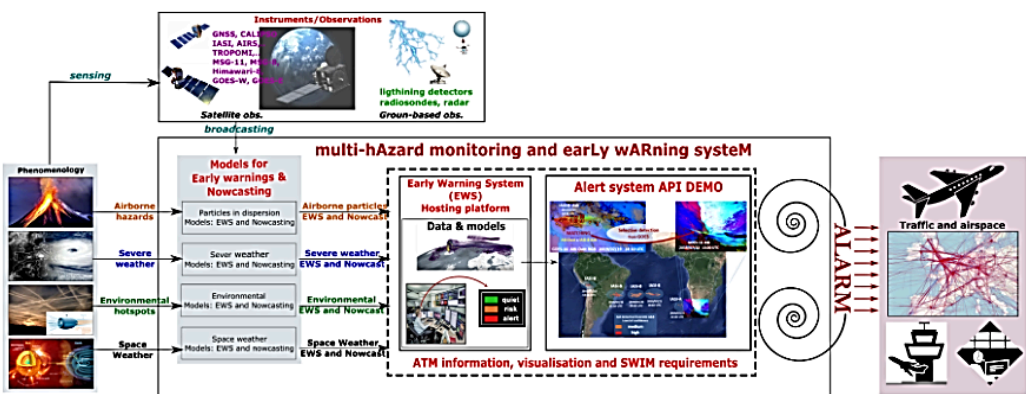
Instead of automating isolated individual tasks, such as conflict detection or coordination, we propose building a foundation for automation by developing an intelligent situation-aware system. **Sharing the same team situational awareness among air traffic controller members and AI** will enable the automated system to reach the same conclusions as ATCOs when confronted with the same problem and to **be able to explain the reasoning** behind those conclusions. This system will at first be able to automate some of the monitoring tasks, because machines cannot currently reach the same level of awareness as humans, but as the development progresses it will be able to take over more complex tasks.

**Achievements** This project developed an ATC tool based on **ML techniques for conflict detection**. The methodology develops a data-driven approach that predicts separation infringements between aircraft within airspace. The methodology exploits two different ML algorithms: classification and regression. The methodology was applied to Switzerland’s airspace. The results show that the ML algorithms could perform conflict prediction with high accuracy.

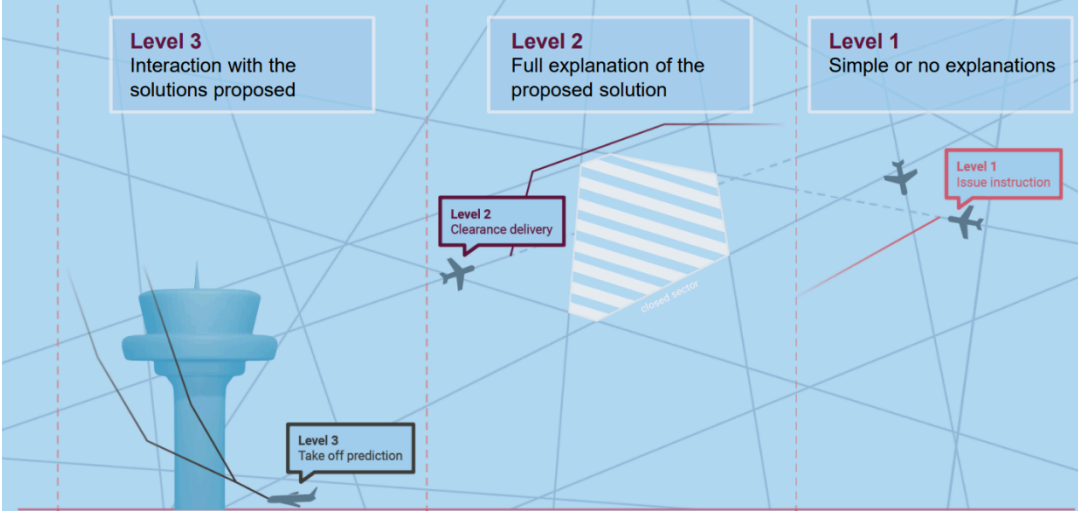
**References** Javier A. Pérez-Castán et al 2022 Design of an ATC Tool for Conflict Detection Based on Machine Learning Techniques. Aerospace 2022, 9(2), 67. <https://www.mdpi.com/2226-4310/9/2/67>  
 Javier A. Pérez-Castán et al, 2022 IOP Conference Series: Materials Science Engineering 1226 012019 Machine Learning classification techniques applied to static air traffic conflict detection. <https://iopscience.iop.org/article/10.1088/1757-899X/1226/1/012019/pdf>

**Additional Material** <https://youtu.be/mc5Cw0cAR4A> (Video)

**Title** **ALARM** multi-hazard monitoring and early warning system

<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://alarm-project.eu/">https://alarm-project.eu/</a>
<b>Description</b>	<p>The overall objective of ALARM project is to <b>develop a prototype global multi-hazard monitoring and Early Warning System</b> for all hazards arising from natural phenomena. ALARM ambitions to develop a prototype multi-hazard alert system capable of <b>integrating different data sources</b> (satellites and ground-based instrumentation) and models (e.g., available weather forecasts), to develop early warning &amp; nowcasting/forecasting solutions of the following phenomena: 1) aerosol particle and gas dispersion resulting from natural hazards (e.g. volcanic ash and SO<sub>2</sub>, dust from sandstorms); 2) <b>severe weather hazards</b> (deep convection and extreme weather); 3) space weather (situational risk and alert); and 4) environmental hotspots (via climate change functions). Finishes on 31/12/2022</p>
<b>Achievements</b>	<p>Delivering a <b>prototype real-time monitoring service</b>, as well as <b>forecasting tools</b> for thunderstorms, volcanic eruptions, dust clouds and space weather. Illustrative examples have been carried out at airports such as <b>Brussels and Milan Malpensa</b>, and the <a href="#">alert system platform</a> is freely available to access.</p>  <p>The first step was to provide a kind of snapshot of what is happening by combining data from low Earth orbit and geostationary satellites, to be able to monitor and differentiate particles in the atmosphere, improving the quality of information on volcanic eruptions, sandstorms and forest fires. The second step was to develop predictive models to provide the aviation sector with forecasts of between one hour ahead and one day ahead, so that ATM could use these predictive models to make in-flight deviations, or reschedule flights altogether. To achieve this, artificial intelligence (AI) was applied to observational data and historical observations. <b>The project's prototype AI system 'learned' from past localised forecasts and weather observations, in order to be able to better predict the likely evolution of any given natural event.</b> This could be used, for example, to accurately predict the behaviour of a severe thunderstorm over an airport. The project also broke new ground by focusing <b>on aviation-induced climate change.</b></p>
<b>References</b>	
<b>Additional Material</b>	<p>Alert System platform live: <a href="https://alarm-project.eu/alert-system-plaform-live/">https://alarm-project.eu/alert-system-plaform-live/</a>  Integrated platform for the Nowcasting and Forecasting of Multiple Meteorological hazards, including climatic impact:  <a href="https://alarm-project.eu/integrated-platform-for-the-nowcasting-and-forecasting-of-multipl-e-meteorological-hazards-including-climatic-impact/">https://alarm-project.eu/integrated-platform-for-the-nowcasting-and-forecasting-of-multipl-e-meteorological-hazards-including-climatic-impact/</a></p>

<b>Title</b>	<b>ARTIMATION</b> Transparent Artificial Intelligence and Automation to ATM Systems
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://www.artimation.eu/">https://www.artimation.eu/</a>

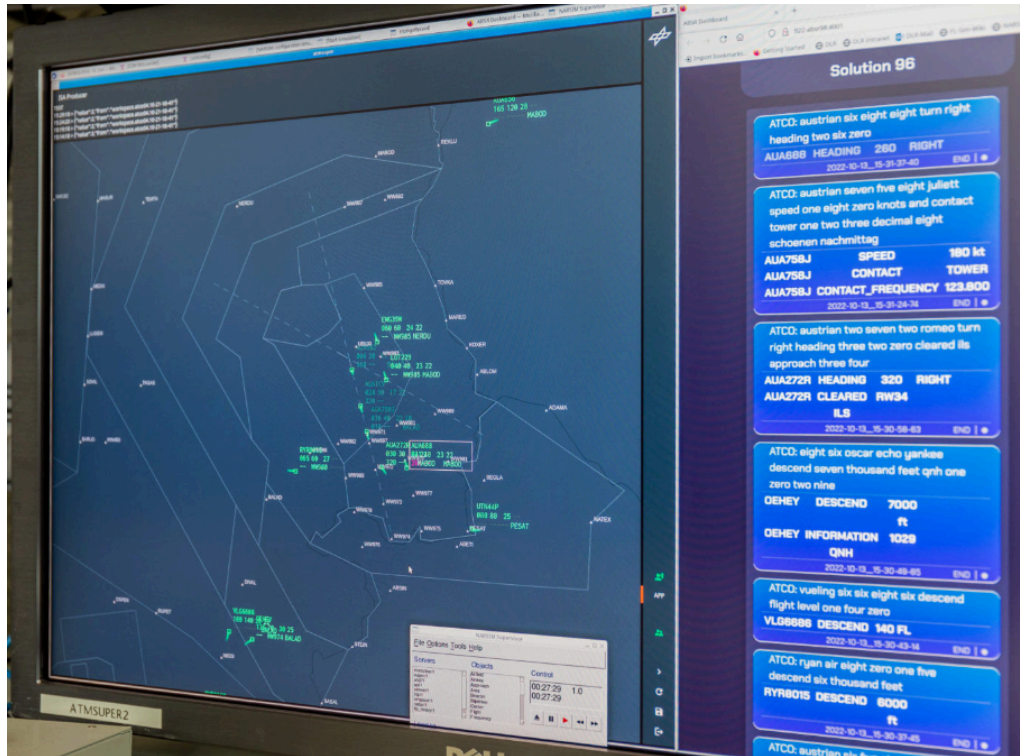
<b>Description</b>	<p>The project assessed the impact of both different <b>visualisation techniques</b> for AI algorithms to provide <b>explainability</b> to the <b>ATC</b> task of Conflict Detection and Resolution, and the impact of an Explainable AI (XAI) tool on Air Traffic <b>Controllers' trust</b> to optimise the use of runways, supporting the task of Delay Prediction.</p> <p>ARTIMATION gathered information about three different kind of visualisation techniques to represent an AI outcome for the task of Conflict Detection and Resolution. It then tested them with two different experimental groups, i.e., ATC experts and ATC students. Differences in <b>human factors indexes (e.g., stress, workload, approach, withdrawal, acceptance, trust)</b> were assessed both with <b>neurophysiological measures</b>, and traditional self-report questionnaires and semi-structured debriefing interviews. Moreover, 3 different algorithms have been trained to support the task of Delay Prediction to optimise the runway use. The 3 algorithms select different parameters to show to Tower Air Traffic Controllers to understand what selection provides the higher trust level and the higher agency towards the delay.</p>
<b>Achievements</b>	<p>As far as the Conflict Detection and Resolution visualisation use case, ARTIMATION assessed the <b>human performance differences between ATC experts and students</b>. The project explored the feasibility of introducing Explainable AI tools in training sessions for ATC students, to always provide a different point of view and a tool to compare the students' own decision-making process with an optimal solution designed considering several parameters. The Delay Prediction use case aims at optimising the runway use introducing explainability through the visualisation of parameters influencing an aircraft delay.</p>  <p>Aviation will benefit from ARTIMATION from both use cases. The Conflict Detection and Resolution use case will introduce the concept of <b>Explainable AI in training</b>, assessing the feasibility of <b>different kinds of visualisations to have a better mental picture</b> of a possible optimal resolution. The Delay Prediction use case will realise a proof-of-concept of the introduction of Explainable AI in <b>Control Towers</b> to optimise the use of runways.</p>
<b>References</b>	<p>Degas, A.; Islam, M.R.; Hurter, C.; Barua, S.; Rahman, H.; Poudel, M.; Ruscio, D.; Ahmed, M.U.; Begum, S.; Rahman, M.A.; Bonelli, S.; Cartocci, G.; Di Flumeri, G.; Borghini, G.; Babiloni, F.; Aricó, P. A Survey on Artificial Intelligence (AI) and eXplainable AI in Air Traffic Management: Current Trends and Development with Future Research Trajectory. Appl. Sci. 2022, 12, 1295.  <a href="https://doi.org/10.3390/app12031295">https://doi.org/10.3390/app12031295</a></p>
<b>Additional Material</b>	<p><a href="https://www.invircat.eu/files/ugd/7cab8a_6be54c98813741c7b1f67916031ceec0.pdf">https://www.invircat.eu/files/ugd/7cab8a_6be54c98813741c7b1f67916031ceec0.pdf</a> [Final Presentation, November 3-4, Rome]</p>

<b>Title</b>	<b>FARO saFety And Resilience guidelines for aviatiOn</b>
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<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://faro-h2020.eu/">https://faro-h2020.eu/</a>
<b>Description</b>	<p>This project addresses the evaluation of the impact of new automation solutions on resilient performance and safety. The main objective of this project is to contribute to the extant knowledge of safety and resilience of the ATM system by providing design guidelines to apply FARO's approach and identifying areas of improvement and future research needs as well. The FARO methodology mixes <b>knowledge-based and data-driven approaches</b>, aiming at <b>facilitating a predictive perspective</b> on safety by generating safety performance functions and defining the <b>impact on resilient performance of automation solutions</b>.</p> <p style="text-align: center;"><b>BAYESIAN NETWORK IMPLEMENTATION</b></p> <p>Finished on 31/10/2022</p>
<b>Achievements</b>	<p>FARO project has developed a <b>set of methodologies and techniques to assess ATM safety and resilience</b>. The project is also developing <b>safety and resilience guidelines</b>.</p> <p>The project's key innovation is a computer model, based on <b>Bayesian Belief Networks</b>, which can graphically represent the probable relationship between different variables in a system and its impact on safety.</p>
<b>References</b>	
<b>Additional Material</b>	<p><a href="https://faro-h2020.eu/downloads/">https://faro-h2020.eu/downloads/</a></p> <p><a href="https://faro-h2020.eu/wp-content/uploads/2022/08/FARO_D_6_3_Safety_And_Resilience_Guidelines_Ed_00_02.pdf">https://faro-h2020.eu/wp-content/uploads/2022/08/FARO_D_6_3_Safety_And_Resilience_Guidelines_Ed_00_02.pdf</a></p>

<b>Title</b>	<b>HAAWAII</b> Highly Automated Air Traffic Controller Workstations with Artificial Intelligence Integration
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://www.haawaii.de/wp/">https://www.haawaii.de/wp/</a>
<b>Description</b>	<p>HAAWAII develops a reliable, error resilient and adaptable solution to <b>automatically transcribe voice commands</b> from air traffic controllers (ATCO) and pilots. Using <b>machine learning</b>, the project builds on <b>very large collections of speech data</b>, organized with a minimum expert effort, to develop a <b>new set of speech recognition models</b> for the complex ATM environments of the London terminal area (TMA) and Icelandic enroute airspace. Speech and surveillance data recordings from real-life pilot-controller communications, i.e., directly from the operations rooms, are used.</p>

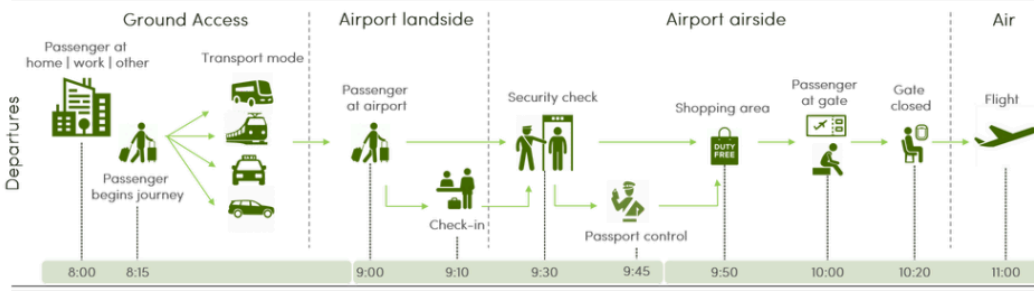
HAAWAII aims to significantly enhance ATM safety and reduce ATCOs workload. The digitization of controller-pilot-communication can be used for a wide variety of safety and performance related ATM improvements. Proof-of-concept applications are readback-error-detection, callsign-highlighting and ATCO-workload-estimation.



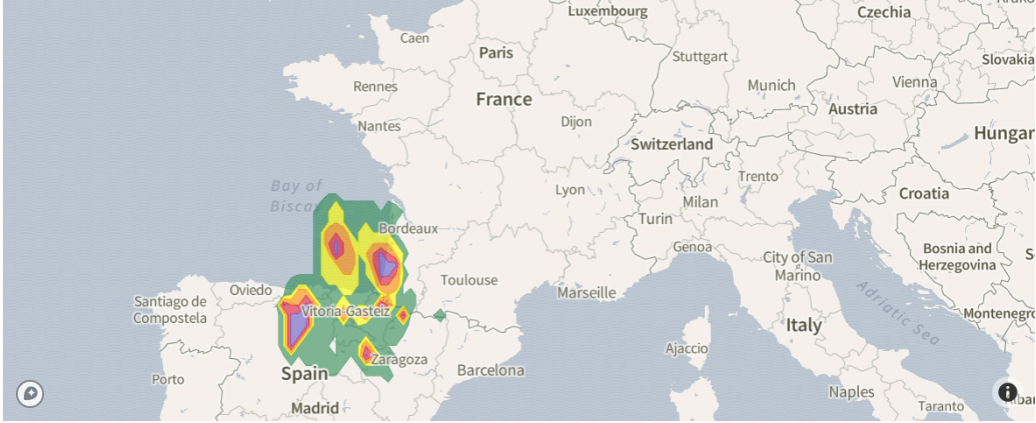
Finished on 30/11/22

<b>Achievements</b>	HAAWAII has developed a new speech recognition software based on <b>deep neural networks</b> . <b>Machine learning</b> was also used to create a <b>Readback Error Detection Assistant (REDA)</b> .
<b>References</b>	See <a href="https://www.haawaii.de/wp/dissemination/references/">https://www.haawaii.de/wp/dissemination/references/</a>
<b>Additional Material</b>	Video HAAWAII prototype: <a href="https://www.haawaii.de/wp/wp-content/uploads/2022/10/REDA-Demo3-WrongLevelReadback-1.mp4">https://www.haawaii.de/wp/wp-content/uploads/2022/10/REDA-Demo3-WrongLevelReadback-1.mp4</a>

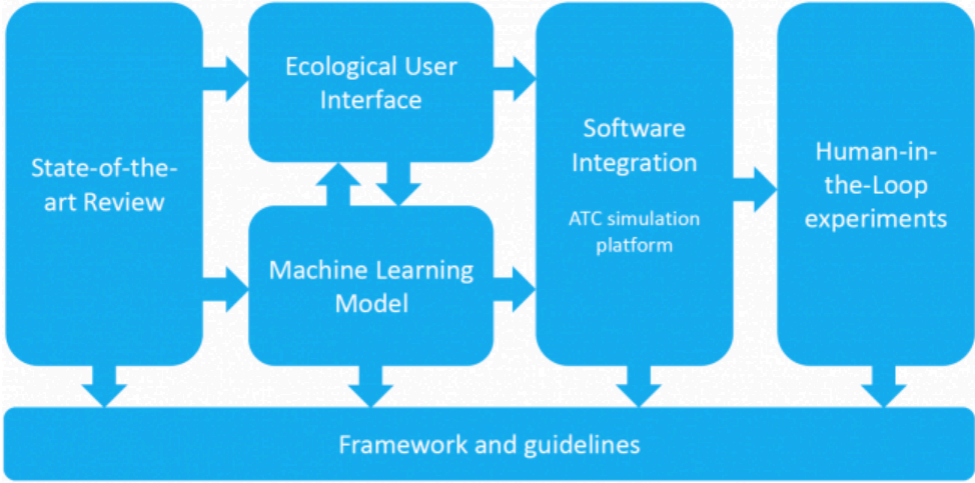
<b>Title</b>	<b>IMHOTEP</b> Integrated Multimodal Airport Operations for Efficient Passenger Flow Management
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://www.imhotep-h2020.eu/">https://www.imhotep-h2020.eu/</a>
<b>Description</b>	The goal of IMHOTEP was to develop a concept of operations and a set of <b>data analysis methods, predictive models and decision support tools</b> that allow information sharing, common situational awareness and real-time collaborative decision-making between airports and ground transport stakeholders. IMHOTEP developed the interconnected platforms and services that will enable <b>real-time collaboration between airports and ground transportation</b> . Project ended on 30/11/2022.
<b>Achievements</b>	The Project used <b>data collected from personal mobile devices and digital sensors</b> . This data was then fed into a set of algorithms capable of reconstructing <b>passenger flows in real time</b> and for different stages of the passenger journey. This led to the development of an <b>integrated prediction model of passenger behaviour</b> , both inside and outside the airport through <b>2 case studies</b> at <b>London City</b> and <b>Palma de Mallorca</b> airports. A key outcome of the

	<p>project is a <b>concept of operations</b> for making the most of these tools by including ground transport stakeholders in airport collaborative decision-making.</p>  <p>The outcomes of this process are delivered in the form of so-called <b>Activity-Travel-Diaries</b>. These diaries can be used for calibrating predictive models for forecasting the short-term evolution of airport and ground transport performance, via a <b>set of predictive models</b> and what-if decision support tools that can forecast passenger flow evolution within a typical day of operation. These models enable <b>common situation awareness across transport modes</b>, coordinated decision-making, and enhanced passenger information services.</p>
<p><b>References</b></p>	<p>Mota, M. M., Scala, P., Herranz, R., Schultz, M., &amp; Jimenez, E. (2020). Creating the future airport passenger experience: IMHOTEP. In European Modelling Simulation Symposium, Athens, Greece.  <a href="#">Download</a></p> <p>Schultz, M., Luo, M., Lubig, D., Mota, M. M., &amp; Scala, P. COVID-19 related challenges for new normality in airport terminal operations. In Winter Simulation Conference 2021.  <a href="#">Download</a></p> <p>Patrón, R. S. F., Scala, P., Mota, M. M., &amp; Murrieta, A. (2021). Airport passenger flow prediction using simulation data farming and machine learning. In 33rd European Modeling &amp; Simulation Symposium.  <a href="#">Download</a></p> <p>Mota, M. M., Scala, P., Schultz, M., Lubig, D., Luo, M., &amp; Perez, E. J. The Rise of the Smart Passenger I: Analysis of impact on Departing Passenger Flow in Airports. In 11th SESAR Innovation Days.</p>
<p><b>Additional Material</b></p>	<p><a href="https://cordis.europa.eu/project/id/891287">https://cordis.europa.eu/project/id/891287</a></p>

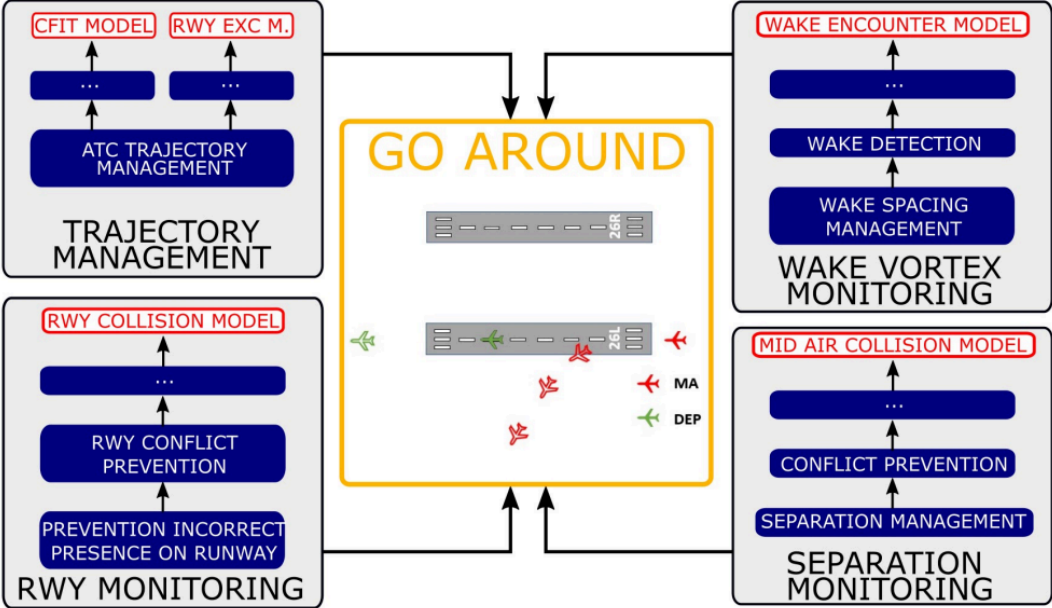
<p><b>Title</b></p>	<p><b>ISOBAR</b> Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning</p>
<p><b>Parent Programme</b></p>	<p>SESAR</p>
<p><b>Website</b></p>	<p><a href="https://isobar-project.eu/">https://isobar-project.eu/</a></p>
<p><b>Description</b></p>	<p>ISOBAR aims at the provision of a <b>service- and AI-based Network Operations Plan</b>, by integrating enhanced convective weather forecasts for predicting imbalances between capacity and demand and exploiting AI to select mitigation measures at local and network level in a collaborative ATFCM operations paradigm (use of <b>Machine Learning algorithms</b> to predict airspace capacity reductions caused by weather).  The ISOBAR project is using <b>AI, Earth Observation satellite data and advanced weather forecasting to better predict thunderstorm</b> activity, altitude, severity and probability.</p>

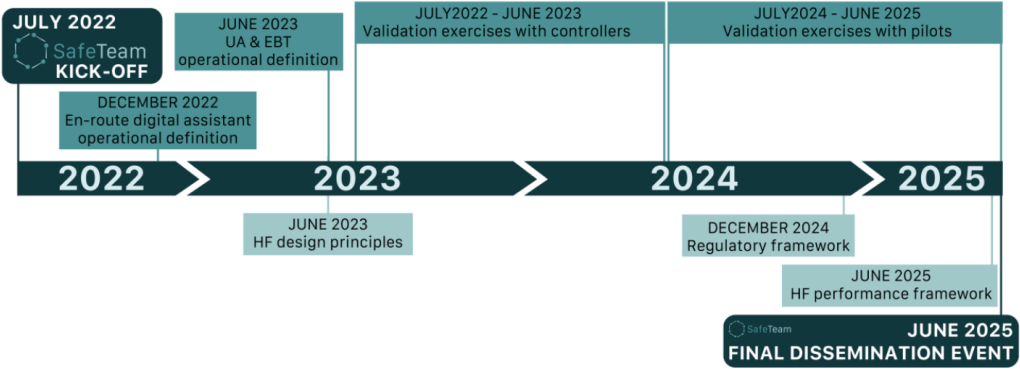
	 <p>With the <b>'hotspot' model</b>, used in conjunction with the weather forecasting model, ATM can predict where they can expect to see an imbalance in demand and capacity. A third <b>model provides alternative flight plans</b> for avoiding so-called hotspots. Finished on 30/11/22</p>
<b>Achievements</b>	<p>The ISOBAR Meteo Engine (MetEngine) provides weather forecasts at network and local level. The use of MetEngine improves the accuracy of storm forecasts based on convective indicators, by using and post-processing NWP. NWP use mathematical models of the atmosphere and oceans to predict weather based on current conditions. <b>Ensemble Prediction Systems (EPS) will be used to obtain probabilistic forecasts of convective weather.</b> These models are the most innovative available for the geographical areas of interest selected by the ISOBAR consortium, ensuring that model results can be transformed into convective indicators (France Iberic peninsula &amp; Western Europe)</p>
<b>References</b>	<ul style="list-style-type: none"> <li>• Dalmau, R., Gawinowski, G., and Anoraud, C., Comparison of various temporal air traffic flow management models in critical scenarios, Journal of Air Transport Management, 105: 102284. 2022. (<a href="https://doi.org/10.1016/j.jairtraman.2022.102284">https://doi.org/10.1016/j.jairtraman.2022.102284</a>)</li> <li>• Jardines, A., Soler, M., Cervantes, A. García-Heras, J. and Simarro, J. (2021): Convection indicator for pre-tactical air traffic flow management using neural networks. In: Machine Learning with Applications,100053 (<a href="https://doi.org/10.1016/j.mlwa.2021.100053">https://doi.org/10.1016/j.mlwa.2021.100053</a>)</li> <li>• Chen, Y., Hu, M., Xu, Y. and Yang, L., Locally Generalized Multi-agent Reinforcement Learning for Demand and Capacity Balancing with Customized Neural Networks. Chinese Journal of Aeronautics. 2022. (Accepted).</li> </ul>
<b>Additional Material</b>	<p>ISOBAR Meteo Engine: <a href="https://isobar-project.eu/dashboard/">https://isobar-project.eu/dashboard/</a> ISOBAR prototype: <a href="https://xd.adobe.com/view/99943f94-e3ed-49ea-82b5-2c7cd16949ab-ccc7/?fullscreen">https://xd.adobe.com/view/99943f94-e3ed-49ea-82b5-2c7cd16949ab-ccc7/?fullscreen</a></p>

<b>Title</b>	<b>MAHALO</b> Modern ATM via Human/Automation Learning optimisation
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="http://mahaloproject.eu/">http://mahaloproject.eu/</a>
<b>Description</b>	<p>Artificial Intelligence (AI) provides both opportunities and considerable challenges to the continued growth of Air Traffic Control (ATC) services. The MAHALO project focused on two constructs thought to underlie <b>human-AI interaction</b>. The first is <b>conformance</b>, which the project has defined as the apparent strategy match between human and AI systems. The second construct, <b>transparency</b>, refers to the degree to which the system makes its internal processes apparent to the operator. MAHALO set out to experimentally manipulate these two constructs, and to explore their main and interactive effects on a broad number of human performance measurements, including conflict detection performance, automation acceptance, and rated workload.</p>

	 <p>MAHALO conducted two field simulations at two sites, with 34 participants, to evaluate the impact of conformance and transparency manipulations on <b>controller acceptance, agreement, workload</b>, and general subjective feedback, among other measures. Each simulation consisted of two phases. First was a training pre-test in which <b>controllers</b> interacted with scripted traffic scenarios that presented two-aircraft closing conflicts, and which recorded controllers' resolution strategies. Second was a main experiment phase, in which the same <b>controllers interacted with Machine Learning (ML)</b> solved analogues of the pre-test scenarios.</p>
<b>Achievements</b>	<p>Over the project runtime the MAHALO project has achieved several results:</p> <ul style="list-style-type: none"> <li>• Conducted a state-of-the-art review of Machine Learning (ML) advances. <ul style="list-style-type: none"> <li>• Developed and demonstrated a ML capability.</li> </ul> </li> <li>• Designed an experimental user interface and simulation capability.</li> <li>• Conducted human-in-the-loop validation trials of the user interface.</li> <li>• Integrated ML capabilities with the simulator and experimental interface.</li> <li>• Conducted a first full simulation to demonstrate the entire test platform.</li> <li>• Specified experimental design for the final simulation sessions.</li> <li>• Defined some guidelines on how to incorporate conformance and transparent mechanisms of AI solutions to conflict detection and resolution.</li> </ul>
<b>References</b>	<p>Westin, C., Hilburn, B., Borst, C., Kampen, E. Van, Bang, M., (2020), Building Transparent and Personalized AI Support in Air Traffic Control, Digital Avionics Systems Conference, 2020.</p> <p>Westin, C., Nunes Monteiro, T., Borst, C., Bonelli, S., (2020), Balancing transparency and conformance of an AI conflict detection and resolution support system, Proceedings of the Tenth SESAR Innovation Days, 2020.</p> <p>Nunes Monteiro, T., Borst, C., Kampen, E. Van, Hilburn, B., &amp; Westin, C. (2021), Human-interpretable Input for Machine Learning in Tactical Air Traffic Control. Proceedings of the Eleventh SESAR Innovation Days, 92, 1--6. + presentation (WP3 &amp; WP4).</p> <p>Bonelli, S., Borst, C., Brambati, F., Cocchioni, M., Hilburn, B. &amp; Monteiro-Nunes, T., (2022), Transparent and Personalised AI Support in Air Traffic Control: First Empirical Results, The International Conference on Cognitive Aircraft Systems, 2022.</p>
<b>Additional Material</b>	<p><a href="https://www.invircat.eu/files/ugd/7cab8a_97fbd4ae4dda4dd5b5370ba0b0515726.pdf">https://www.invircat.eu/files/ugd/7cab8a_97fbd4ae4dda4dd5b5370ba0b0515726.pdf</a> [Final Presentation, November 3-4, Rome]</p>

<b>Title</b>	<b>SafeOPS</b> Strengthening Safe and Scalable ATM Services through Automated Risk Analytics based on Operational Data from Aviation Stakeholders
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Parent Programme	SESAR
Website	<a href="https://safeops.eu/">https://safeops.eu/</a>
Description	<p>SafeOPS investigates how predictive AI tools can be used in ATM as decision support technologies, to facilitate controllers making complex decisions. The project aims to pave the way towards the implementation of AI-based solutions by assessing their contribution to the security and resilience of the ATM system. The work performed in SafeOPS is split into three pillars which we call the Operational Layer, Predictive Layer and the Risk Framework.</p> <p>The project employs a three-layered approach that includes an <b>operational layer</b>, a <b>predictive layer</b>, and a <b>risk framework</b>. In workshops with Air Traffic Controllers, the operational layer developed scenarios in which a <b>go-around prediction</b> could provide benefits for <b>Air Traffic Management</b>. This led to an initial concept of operations and the definition of use cases and requirements in the initial phase of SafeOPS. Based on this, the predictive layer developed an initial machine learning model for go-around predictions, yielding insights in achievable accuracies and the transparency of the predictions. In parallel, the risk framework assessed the risks and benefits of the foreseen decision support concept in terms of operational safety, including also human factors considerations.</p>  <p>In the final phase of the project, the operational layer designed a simulation exercise based on the risk framework's and the predictive layer's findings, to investigate the impact of the SafeOPS concept on safety and resilience. Thus, SafeOPS focused on separation challenges, <b>workload</b>, and capacity of the Tower operations in the initially defined scenarios.</p>
Achievements	<p>SafeOPS developed an AI-model that can predict go-arounds, based on publicly available data sources. Based on this, it investigated risks and benefits of a decision support concept for Air Traffic Management in a complementary evaluation, consisting of a risk framework and simulation exercises. With this impact evaluation, SafeOPS could demonstrate that the envisioned concept can provide benefits in terms of <b>safety and resilience</b>. Even false predictions do not have negative effects on safety, which is an important finding; however, <b>false predictions</b> can negatively affect the capacity of airports. Air traffic controllers find it acceptable if AI fails to predict every single go-around event, as long as predicted events carry 90 % <b>confidence</b>. This makes sense from an operational perspective.</p>
References	
Additional Material	<p><a href="https://vimeo.com/649566354?embedded=true&amp;source=video_title&amp;owner=39555379">https://vimeo.com/649566354?embedded=true&amp;source=video_title&amp;owner=39555379</a> (Video)</p> <p><a href="https://innaxis-comm.s3.eu-central-1.amazonaws.com/SafeOPS/D3.3.pdf">https://innaxis-comm.s3.eu-central-1.amazonaws.com/SafeOPS/D3.3.pdf</a> (Deliverable concerning Human Factors Guidance on the interface for the SafOPS AI tool)</p>

<b>Title</b>	<b>SAFETEAM</b> Safe Human-Digital Assistant teaming for higher levels of automation in aviation
<b>Parent Programme</b>	Horizon Europe (same call as HAIKU)
<b>Website</b>	<a href="https://safeteamproject.eu/">https://safeteamproject.eu/</a>
<b>Description</b>	<p>SAFETEAM, which arises from the same call as HAIKU and can therefore be considered a ‘sister’ project, focuses on the <b>human factors aspects on the use of digital assistants to aviation</b>, including a deeper understanding on the technology and processes that will facilitate the adoption of AI tools and integration into operations, <b>enhancing human cognitive abilities</b> and potentially automation. The project will also look into <b>approval and certification issues</b>, concretely on aspects related to the human ability to operate sophisticated AI tools and <b>explainability</b> of AI operations.</p> <p>SAFETEAM’s objectives are as follows:</p> <ul style="list-style-type: none"> <li>• Facilitate a human-centric approach to automation and its integration into a wide spectrum of air traffic operations.</li> <li>• Propose methodologies for the assessment and monitoring of the system performance, with special focus on safety and resilience, to enable seamless Human-Machine cooperation.</li> <li>• Progress in the development of Digital Assistants for aviation operations in support of human performance for all development, testing, validation and verification phases.</li> <li>• Support the definition of regulatory and certification requirements for automation tools to address market needs and societal acceptance.</li> </ul> <p>3 case studies are proposed in SAFETEAM:</p> <ul style="list-style-type: none"> <li>• Digital assistance for area ATC (enroute)</li> <li>• Unstable Approaches prediction for aircraft cockpit (UA)</li> <li>• Digital Assistance for evidence-based training (EBT)</li> </ul> <p style="text-align: center;"><b>Project timeline</b></p>  <p>The project timeline is as follows:</p> <ul style="list-style-type: none"> <li><b>JULY 2022</b>: SafeTeam KICK-OFF</li> <li><b>DECEMBER 2022</b>: En-route digital assistant operational definition</li> <li><b>JUNE 2023</b>: UA &amp; EBT operational definition; HF design principles</li> <li><b>JULY 2022 - JUNE 2023</b>: Validation exercises with controllers</li> <li><b>JULY 2024 - JUNE 2025</b>: Validation exercises with pilots</li> <li><b>DECEMBER 2024</b>: Regulatory framework</li> <li><b>JUNE 2025</b>: HF performance framework</li> <li><b>JUNE 2025</b>: FINAL DISSEMINATION EVENT</li> </ul>
<b>Achievements</b>	The project has just begun, a few months ahead of HAIKU.
<b>References</b>	
<b>Additional Material</b>	

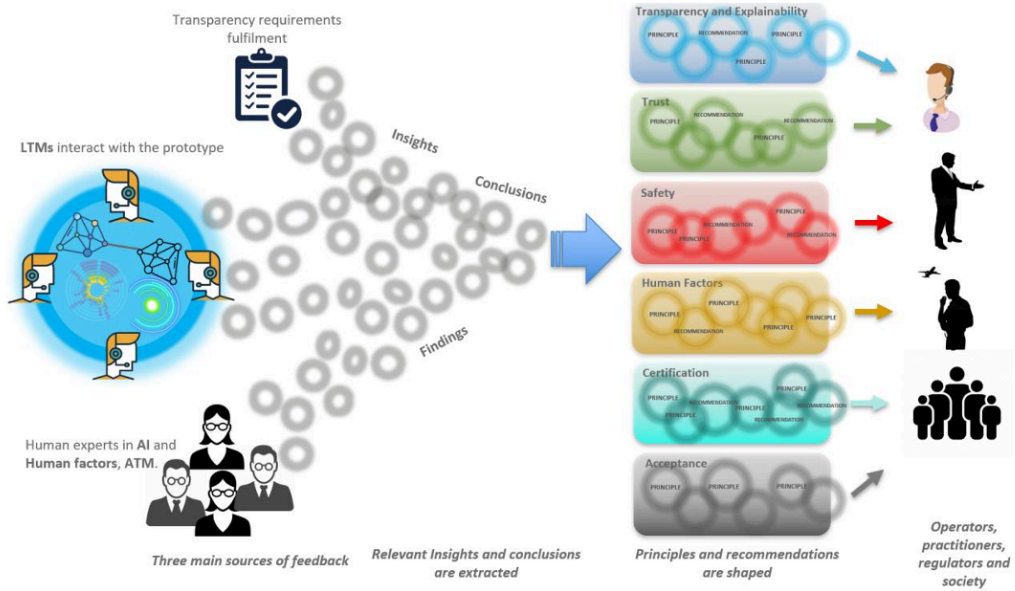
<b>Title</b>	<b>SIMBAD</b> Combining Simulation Models and Big Data Analytics for ATM Performance Analysis
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://www.simbad-h2020.eu/">https://www.simbad-h2020.eu/</a>

<p><b>Description</b></p>	<p>The goal of SIMBAD is to develop and evaluate a set of <b>machine learning approaches</b> aimed at providing state-of-the-art ATM microsimulation models with the level of reliability, tractability and interpretability required to effectively support performance evaluation at ECAC level.</p> <p>Objectives:</p> <ol style="list-style-type: none"> <li>1. Explore the <b>use of machine learning techniques</b> for the estimation of hidden variables from historical air traffic data, with particular focus on airspace users' preferences and behaviour</li> <li>2. <b>Develop new machine learning algorithms</b> for the classification of traffic patterns</li> <li>3. <b>Investigate the use of active learning meta-modelling</b> to facilitate a more efficient exploration of the input output space of complex simulation models through the development of more parsimonious performance metamodels</li> <li>4. Demonstrate and evaluate the newly developed methods and tools through a set of <b>case studies</b></li> </ol> <p>Finishes on 31/12/22</p> <div> <p style="text-align: center;"><b>SIMBAD APPROACH</b></p> <p>Representative traffic scenarios based on classification and pattern recognition algorithms</p> <p>Selection of the most informative input points through active learning</p> <p>Traffic demand</p> <p>New ATM concepts/solutions</p> <p>Microsimulation Model Hidden variables/parameters estimated through machine learning techniques</p> <p>Metamodel Parsimonious approximation of the microsimulation model</p> <p>KPIs</p> <p style="text-align: center;">Comprehensive and efficient exploration of input-output space Identification of optimal strategies</p> </div>
<p><b>Achievements</b></p>	<p>The new algorithms for traffic pattern characterisation have shown their ability to <b>identify representative traffic scenarios</b> at different spatial and temporal scales, which will result in more comprehensive simulation experiments. Additionally, <b>SIMBAD's metamodels have proven to be more efficient and faster than existing simulations when modelling new ATM technologies.</b></p> <p>The team were also able to <b>find hidden variables</b> through the analysis of historical air traffic data.</p>

<b>References</b>	Andrienko, N., Andrienko, G., Adilova, L., and Wrobel, S. (2022). Visual Analytics for human-centered Machine Learning. IEEE Computer Graphics & Applications, 42(1)
<b>Additional Material</b>	SIMBAD metamodels are being developed in collaboration with the EU-funded <a href="#">NOSTROMO</a> project, which has developed an API that facilitates the process of building these metamodels.

<b>Title</b>	<b>SINAPSE</b> Software defined networking architecture augmented with Artificial Intelligence to improve aeronautical communications performance, security and efficiency
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://sinapse-s2020.eu/">https://sinapse-s2020.eu/</a>
<b>Description</b>	<p>SINAPSE aims at proposing an intelligent and secured aeronautical datalink communications network architecture design based on the <b>Software Defined Networking (SDN) architecture model</b> augmented with <b>Artificial Intelligence (AI)</b> to <b>predict and prevent safety services outages</b>, to optimize available network resources and to implement <b>cybersecurity</b> functions protecting the network against digital attacks. It identifies cyber-vulnerability points in the system architecture that can be aided by AI.</p> <p>Finished on 31/10/22</p>
<b>Achievements</b>	SINAPSE uses an <b>algorithm based on machine learning</b> to analyse the network traffic for signatures known to match <b>cyberattacks</b> . The network's architecture means that only the AI's models are shared among users, without the need for underlying data to be shared, further enhancing security. The SINAPSE team assessed the technology with Controller Pilot Data Link Communications (CPDLC) data, captured in real time from the operational Aeronautical Telecommunication Network (ATN), a global exchange for air communications. A targeted use case demonstrated that <b>SINAPSE could continuously predict and forecast disruption events 10 minutes before they happened.</b>
<b>References</b>	
<b>Additional Material</b>	Technical deliverables: <a href="https://sinapse-s2020.eu/deliverables.php">https://sinapse-s2020.eu/deliverables.php</a>

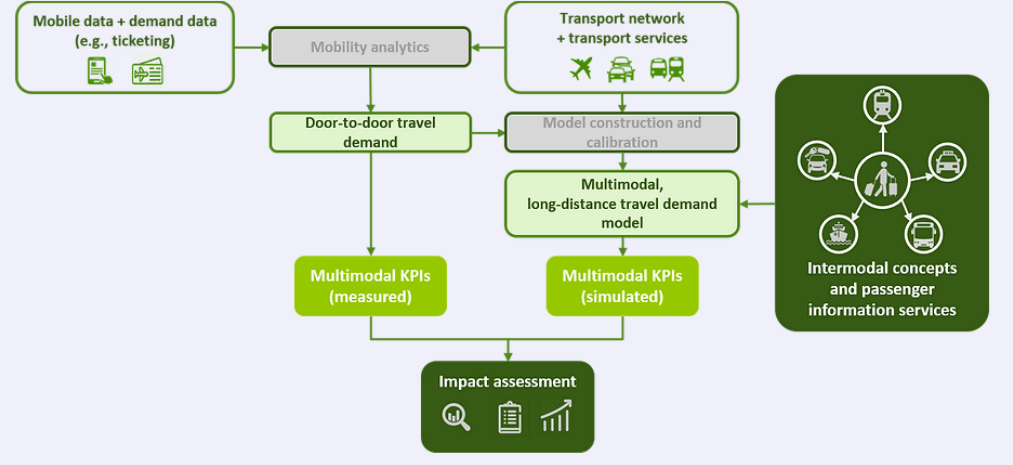
<b>Title of Project</b>	<b>TAPAS</b> Towards an Automated and exPlainable ATM System
<b>Parent Programme</b>	SESAR
<b>Website</b>	<a href="https://tapas-atm.eu/">https://tapas-atm.eu/</a>
<b>Description</b>	<p>The scope of this research is the systematic exploration of AI/ML solutions towards <b>increasing levels of automation</b> in specific <b>ATM</b> scenarios, through analysis and experimental activities, with the objective to deliver <b>principles of transparency</b>, enabling the application of AI/ML supported automation in ATM. Specifically, TAPAS will:</p> <ul style="list-style-type: none"> <li>Describe and analyse in detail two operational cases: Conflict Detection &amp; Resolution applied to Air Traffic Control (ATC, tactical), and Air Traffic Flow Management (ATFM, pre-tactical).</li> </ul>

	<ul style="list-style-type: none"> <li>• Develop <b>eXplainable</b> Artificial Intelligence (XAI) methods, addressing the requirements of both operational cases, which focus on the needs of operators (and potential other actors) concerning the quality and transparency of solutions generated by XAI methods.</li> <li>• Apply <b>Visual Analytics techniques</b> to assess and <b>enhance explainability</b> of AI/ML systems in ATM.</li> <li>• Run experiments that assess the applicability of XAI methods in the various levels of automation considered, exploring <b>different ways of interaction and information exchange</b>. The objective is to understand how operators (and potential other actors) increase their <b>trust</b> to XAI methods.</li> </ul>  <p>The diagram illustrates a feedback loop for XAI development. It starts with 'LTM interact with the prototype' and 'Human experts in AI and Human factors, ATM.' providing 'Three main sources of feedback'. This leads to 'Relevant Insights and conclusions are extracted', which are then processed into 'Insights', 'Conclusions', and 'Findings'. These findings are used to 'Shape Principles and recommendations' across six domains: Transparency and Explainability, Trust, Safety, Human Factors, Certification, and Acceptance. Each domain is represented by a set of interconnected circles labeled 'PRINCIPLE' and 'RECOMMENDATION'. The final output is for 'Operators, practitioners, regulators and society'.</p>
<b>Achievements</b>	Ongoing
<b>References</b>	
<b>Additional Material</b>	<a href="https://www.sesarju.eu/index.php/news/explainable-ai-key-unlocking-potential-automation-air-traffic-management">https://www.sesarju.eu/index.php/news/explainable-ai-key-unlocking-potential-automation-air-traffic-management</a> (Press Release)

<b>Title</b>	<b>TEAMING.AI</b>
<b>Parent Programme</b>	Horizon 2020
<b>Website</b>	<a href="https://www.teamingai-project.eu/">https://www.teamingai-project.eu/</a>
<b>Description</b>	TEAMING.AI concerns the manufacturing sector, and aims to overcome the lack of flexibility as a limiting factor of current Industry 4.0 while ensuring the role of the human being in the future industrial scenario by means of a human-centred AI collaboration. It has a significant focus on ethical and legal aspects (including GDPR), and engendering trust in a distributed multi-agent HAT. It also has a strong Human Factors focus (see deliverable referenced below).

	<p style="text-align: center;"><b>Vision with Teaming.AI</b></p>
<p><b>Achievements</b></p>	<p>The TEAMING.AI approach has been applied to three manufacturing use cases. The operational description of the tasks (including use of eye tracking for data collection) was seen as a key ingredient to achieve better requirements specifications and how to enhance the human performance of the operators by increasing their situational awareness on the shop floor. As a detailed example, the AI algorithm can provide information about the times when the operator does not need to directly supervise the milling machine and suggest a scheduling for other simultaneous activities that the operator can perform, thus aiding the operator's workload.</p>
<p><b>References</b></p>	<p><a href="https://rpsonline.com.sg/rps2prod/esrel22-epro/html/S33-08-671.xml">https://rpsonline.com.sg/rps2prod/esrel22-epro/html/S33-08-671.xml</a></p>
<p><b>Additional Material</b></p>	<p>Project Deliverables (see D1.3): <a href="https://www.teamingai-project.eu/project-deliverables">https://www.teamingai-project.eu/project-deliverables</a>  Video: <a href="https://youtu.be/vwHa_nD8Qbo">https://youtu.be/vwHa_nD8Qbo</a></p>

<p><b>Title</b></p>	<p><b>TRANSIT</b> Travel Information Management for Seamless Intermodal Transport</p>
<p><b>Parent Programme</b></p>	<p>SESAR</p>
<p><b>Website</b></p>	<p><a href="https://www.transit-h2020.eu/">https://www.transit-h2020.eu/</a></p>
<p><b>Description</b></p>	<p>The goal of TRANSIT was to develop a set of <b>multimodal key performance indicators</b>, mobility data analysis methods and transport simulation tools allowing the evaluation of the impact of a set of innovative <b>intermodal transport solutions</b> on the quality, efficiency and resilience of the door-to-door passenger journey.  Project ended on 31/10/2022</p>
<p><b>Achievements</b></p>	<p><b>Intermodality Assessment Framework</b>, a tool for evaluating how a specific transport solution would impact the overall passenger journey. The main data sources were geolocation data from mobile devices and ticketing information, feeding into a multimodal transport framework model. This framework includes <b>a set of multimodal, passenger-centric, door-to-door performance indicators</b> that can be used to look at travel time, travel time reliability, affordability, environmental impact and resilience.</p>

	 <p>Key results were:</p> <ul style="list-style-type: none"> <li>● an <b>open-source tool for simulating long-distance travel demand and airport access</b> in an integrated manner,</li> <li>● an <b>Intermodal Timetable Synchronisation tool</b> enabling the design of synchronised timetables between air and ground transport modes, and an</li> <li>● <b>Intermodal Disruption Management Tool</b> designed to facilitate information sharing between air traffic management and ground transport suppliers as a means of mitigating unplanned disruptions.</li> </ul>
<p><b>References</b></p>	<p>Burrieza, J., Jordá, R., Gregg, A., Ruiz, P., Rodríguez, R., Sala, M.J., Torres, J., García-Albertos, P., Cantú Ros, O.G., Herranz, R. (2022). <i>A methodology for understanding passenger flows combining mobile phone records and airport surveys: Application to Madrid-Barajas Airport after the COVID-19 outbreak</i>. Journal of Air Transport Management, Volume 100.</p> <p>Scozzaro, G., Mancel, C., Delahaye, D., &amp; Feron, E. (2022). <i>Optimising security screening resources during airport access mode disruptions</i>. 12th SESAR Innovation Days (SIDs 2022).</p> <p>5 full references available here: <a href="https://www.transit-h2020.eu/resources">https://www.transit-h2020.eu/resources</a></p>
<p><b>Additional Material</b></p>	<p>Article in Journal of Air Transport Management:  <a href="#">A methodology for understanding passenger flows combining mobile phone records and airport surveys: Application to Madrid-Barajas Airport after the COVID-19 outbreak - ScienceDirect</a></p>

## Annex D: Identified HAIT Constructs, and a Preliminary Mapping to Assessment Methods

	Self-report	Query	Checklist	Observation	Behaviour	System performance	Analytic	Physiological
Acceptance	X			X	X	X		
Accessibility			X	X			X	
Accountability			X				X	
Accuracy				X	X	X		
Adversarial training techniques								
Agent capability mismatch								
AI bias			X				X	
Auditability			X				X	
Authority								
Automation acceptance	X			X	X	X		
Automation reliability								
Automation use								
Automation visibility	X	X	X	X	X			
Automations reliability						X		
Autonomy								
Bias against automation	X	X						X
Bias in AI decision-making			X				X	

Brittleness	X		X	X		X	X	
Calibrated trust	X		X	X	X			X
Certification			X					
Classification performance				X		X	X	
Cognitive processes	X		X	X	X		X	X
Collaboration	X		X	X	X			
Communicate goals			X	X				
Communication				X				
Complacency and over/under reliance			X	X		X	X	
Complexity, perceived	X							
Complexity, task				X		X	X	
Comprehensibility	X	X	X	X	X			
Comprehension	X		X	X	X			
Confidence in AI performance	X		X	X	X			
Confidence in operator manual ability	X		X	X	X			
Consistency				X	X			
Cooperation				X	X			
Coordination	X		X	X	X			
Costs								

Data availability				X			X	
Data governance			X				X	
Data integrity			X				X	
Decision making effectiveness				X	X		X	
Decision-making biases, AI			X				X	
Dereferal procedures				X	X			
Dispositional trust	X							
Engagement	X			X	X			X
Environmental constraints								
Error trapping and handling	X			X	X	X		
Errors	X			X	X	X	X	
Ethics			X				X	
Explainability	X	X	X	X	X			
Failure mode model							X	
Fairness			X				X	
Fault tolerance						X	X	
Function allocation							X	
Goal compatibility	X	X	X	X				
Human error probabilities							X	
Human-AI interaction methods	X	X		X			X	

Individual differences	X	X		X	X			
Intelligibility	X	X	X	X	X			
Intent	X	X		X	X			
Interfaces								
Interpretability	X	X	X	X	X			
Intervention supporting								
Job satisfaction	X	X						
Joint human-AI system performance					X			
Mental model	X	X		X	X			
Misuse (overuse) or disuse	X	X	X	X	X	X		
Mode salience								
Monitoring								
Mutual task coordination								
Mutual trust								
Objective performance								
Observability	X	X	X	X				
Operator experience	X	X						
Out-of-the-loop	X	X		X	X			
Pedigree	X	X		X	X	X		
Performance					X	X		

Physical coherency				X				
Planned actions	X	X						
Predictability of future actions	X	X	X	X				
Predicted consequences	X	X						
Purpose and goals	X							
Pursuit of shared goals	X	X						
Quality								
Quantity								
Reasoning for a recommendation								
Reasoning,								
Reliability						X		
Reliance, over / under						X		
Response time						X		
Responsibility			X				X	
Return-to-manual control	X	X		X	X	X		
Robustness								
Safety					X	X		
Security								
Shared intent	X	X						
Shared situation awareness	X	X	X	X				
Shared understanding	X	X	X	X	X			
Situation awareness	X	X	X	X				X
Skill retention	X	X	X					
Social justice maintenance			X				X	

Strategies								
Strategy mismatch / non-conformance	X	X		X	X			
Subjective metrics								
System efficiency,								
Task uncertainty	X	X	X					
Team biases								
Team cognitive coherence								
Team decision making								
Team performance								X
Team situation awareness	X	X	X	X				
Team training								
Team trust	X	X	X					X
Teambuilding								
Teamwork processes	X	X	X					X
Test intrusiveness								
Test reliability								
Time								
Time pressure	X	X	X	X	X			
Traceability								
Trade-offs								
Training, new training requirements								
Training, perturbation training								
Transparency	X	X	X	X				
Trust	X	X		X	X			

Trust, calibrated	X	X		X	X			
Trust, dispositional	X	X						X
Trustworthiness			X				X	
Uncertainty	X	X						
Understandability	X	X	X	X	X			
Unexpected automation transitions	X	X	X	X	X			
Workload	X	X		X	X		X	X
Workload extremes	X	X		X	X		X	X
Workload management	X	X		X	X		X	X

## Annex E: The Assessment List for Trustworthy AI (ALTAI) checklist

This Annex extracts the ALTAI self-evaluation checklist items for each of the seven key requirements of trustworthy AI. Much more detail about the ALTAI methodology can be found in the High-Level Expert Group on Artificial Intelligence (AI HLEG) recent report (European Commission, 2020).

### Requirement 1: Human Agency and Oversight

- ✓ Please determine whether the AI system (choose as many as appropriate):
  - o Is a self-learning or autonomous system
  - o Is overseen by a Human-in-the-Loop
  - o Is overseen by a Human-on-the-Loop
  - o Is overseen by a Human-in-Command
- ✓ Have the humans (human-in-the-loop, human-on-the-loop, human-in-command) been given specific training on how to exercise oversight?
- ✓ Did you establish any detection and response mechanisms for undesirable adverse effects of the AI system for the end-user or subject?
- ✓ Did you ensure a 'stop button' or procedure to safely abort an operation when needed?
- ✓ Did you take any specific oversight and control measures to reflect the self-learning or autonomous nature of the AI system?

### Requirement 2: Technical Robustness and Safety

#### 2A: Resilience to attack and security

- ✓ Could the AI system have adversarial, critical or damaging effects (e.g. to human or societal safety) in case of risks or threats such as design or technical faults, defects, outages, attacks, misuse, inappropriate or malicious use?
- ✓ Is the AI system certified for cybersecurity (e.g. the certification scheme created by the Cybersecurity Act in Europe) or is it compliant with specific security standards?
- ✓ How exposed is the AI system to cyber-attacks?
  - o Did you assess potential forms of attacks to which the AI system could be vulnerable?
  - o Did you consider different types of vulnerabilities and potential entry points for attacks such as:
    - Data poisoning (i.e. manipulation of training data)
    - Model evasion (i.e. classifying the data according to the attacker's will)
    - Model inversion (i.e. infer the model parameters)
- ✓ Did you put measures in place to ensure the integrity, robustness and overall security of the AI system against potential attacks over its lifecycle?
- ✓ Did you red-team/pen test the system?
- ✓ Did you inform end-users of the duration of security coverage and updates?
  - o What length is the expected timeframe within which you provide security updates for the AI system?

#### 2B: General safety

- ✓ Did you define risks, risk metrics and risk levels of the AI system in each specific use case?
  - o Did you put in place a process to continuously measure and assess risks?
  - o Did you inform end-users and subjects of existing or potential risks?
- ✓ Did you identify the possible threats to the AI system (design faults, technical faults, environmental threats) and the possible consequences?
  - o Did you assess the risk of possible malicious use, misuse or inappropriate use of the AI system?
  - o Did you define safety criticality levels (e.g. related to human integrity) of the possible consequences of faults or misuse of the AI system?
- ✓ Did you assess the dependency of a critical AI system's decisions on its stable and reliable behaviour?
  - o Did you align the reliability/testing requirements to the appropriate levels of stability and reliability?
- ✓ Did you plan fault tolerance via, e.g. a duplicated system or another parallel system (AI-based or 'conventional')?
- ✓ Did you develop a mechanism to evaluate when the AI system has been changed to merit a new review of its technical robustness and safety?

#### 2C: Accuracy

- ✓ Could a low level of accuracy of the AI system result in critical, adversarial or

damaging consequences?

- ✓ Did you put in place measures to ensure that the data (including training data) used to develop the AI system is up-to-date, of high quality, complete and representative of the environment the system will be deployed in?
- ✓ Did you put in place a series of steps to monitor, and document the AI system's accuracy?
- ✓ Did you consider whether the AI system's operation can invalidate the data or assumptions it was trained on, and how this might lead to adversarial effects?
- ✓ Did you put processes in place to ensure that the level of accuracy of the AI system to be expected by end-users and/or subjects is properly communicated?

## 2D: Fall-back plans and reproducibility

- ✓ Could the AI system cause critical, adversarial, or damaging consequences (e.g. pertaining to human safety) in case of low reliability and/or reproducibility?
  - Did you put in place a well-defined process to monitor if the AI system is meeting the intended goals?
  - Did you test whether specific contexts or conditions need to be taken into account to ensure reproducibility?
- ✓ Did you put in place verification and validation methods and documentation (e.g. logging) to evaluate and ensure different aspects of the AI system's reliability and reproducibility?
  - Did you clearly document and operationalise processes for the testing and verification of the reliability and reproducibility of the AI system?
- ✓ Did you define tested failsafe fallback plans to address AI system errors of whatever origin and put governance procedures in place to trigger them?
- ✓ Did you put in place a proper procedure for handling the cases where the AI system yields results with a low confidence score?
- ✓ Is your AI system using (online) continual learning?
  - Did you consider potential negative consequences from the AI system learning novel or unusual methods to score well on its objective function?

## **Requirement 3: Privacy and Data Governance**

### 3A: Privacy

- ✓ Did you consider the impact of the AI system on the right to privacy, the right to physical, mental and/or moral integrity and the right to data protection?
- ✓ Depending on the use case, did you establish mechanisms that allow flagging issues related to privacy concerning the AI system?

### 3B: Data governance

- ✓ Is your AI system being trained, or was it developed, by using or processing personal data (including special categories of personal data)?
- ✓ Did you put in place any of the following measures some of which are mandatory under the General Data Protection Regulation (GDPR), or a non-European equivalent?
  - Data Protection Impact Assessment (DPIA)
  - Designate a Data Protection Officer (DPO) and include them at an early state in the development, procurement or use phase of the AI system;
  - Oversight mechanisms for data processing (including limiting access to qualified personnel, mechanisms for logging data access and making modifications);
  - Measures to achieve privacy-by-design and default (e.g. encryption, pseudonymisation, aggregation, anonymisation);
  - Data minimisation, in particular personal data (including special categories of data);
  - Did you implement the right to withdraw consent, the right to object and the right to be forgotten into the development of the AI system?
  - Did you consider the privacy and data protection implications of data collected, generated or processed over the course of the AI system's life cycle?
- ✓ Did you consider the privacy and data protection implications of the AI system's non-personal training-data or other processed non-personal data?
- ✓ Did you align the AI system with relevant standards (e.g. ISO, IEEE) or widely adopted protocols for (daily) data management and governance?

## **Requirement 4: Transparency**

#### 4A: Traceability

- ✓ Did you put in place measures that address the traceability of the AI system during its entire lifecycle?
  - o Did you put in place measures to continuously assess the quality of the input data to the AI system?
  - o Can you trace back which data was used by the AI system to make a certain decision(s) or recommendation(s)?
  - o Can you trace back which AI model or rules led to the decision(s) or recommendation(s) of the AI system?
  - o Did you put in place measures to continuously assess the quality of the output(s) of the AI system?
  - o Did you put adequate logging practices in place to record the decision(s) or recommendation(s) of the AI system?

#### 4B: Explainability

- ✓ Did you explain the decision(s) of the AI system to the users?
- ✓ Do you continuously survey the users if they understand the decision(s) of the AI system?

#### 4C: Communication

- ✓ In cases of interactive AI systems (e.g., chatbots, robo-lawyers), do you communicate to users that they are interacting with an AI system instead of a human?
- ✓ Did you establish mechanisms to inform users about the purpose, criteria and limitations of the decision(s) generated by the AI system?
  - o Did you communicate the benefits of the AI system to users?
  - o Did you communicate the technical limitations and potential risks of the AI system to users, such as its level of accuracy and/ or error rates?
  - o Did you provide appropriate training material and disclaimers to users on how to adequately use the AI system?

### **Requirement 5: Diversity, Non-discrimination and Fairness**

#### 5A: Avoidance of unfair bias

- ✓ Did you establish a strategy or a set of procedures to avoid creating or reinforcing unfair bias in the AI system, both regarding the use of input data as well as for the algorithm design?
- ✓ Did you consider diversity and representativeness of end-users and/or subjects in the data?
  - o Did you test for specific target groups or problematic use cases?
  - o Did you research and use publicly available technical tools, that are state-of-the-art, to improve your understanding of the data, model and performance?
  - o Did you assess and put in place processes to test and monitor for potential biases during the entire lifecycle of the AI system (e.g. biases due to possible limitations stemming from the composition of the used data sets (lack of diversity, non-representativeness))?
  - o Where relevant, did you consider diversity and representativeness of end-users and or subjects in the data?
- ✓ Did you put in place educational and awareness initiatives to help AI designers and AI developers be more aware of the possible bias they can inject in designing and developing the AI system?
- ✓ Did you ensure a mechanism that allows for the flagging of issues related to bias, discrimination or poor performance of the AI system?
  - o Did you establish clear steps and ways of communicating on how and to whom such issues can be raised?
  - o Did you identify the subjects that could potentially be (in)directly affected by the AI system, in addition to the (end-)users and/or subjects?
- ✓ Is your definition of fairness commonly used and implemented in any phase of the process of setting up the AI system?
  - o Did you consider other definitions of fairness before choosing this one?
  - o Did you consult with the impacted communities about the correct definition of fairness, i.e. representatives of elderly persons or persons with disabilities?
  - o Did you ensure a quantitative analysis or metrics to measure and test the applied definition of fairness?
  - o Did you establish mechanisms to ensure fairness in your AI system?

#### 5B: Accessibility and universal design

- ✓ Did you ensure that the AI system corresponds to the variety of preferences and abilities in society?
- ✓ Did you assess whether the AI system's user interface is usable by those with special needs or disabilities or those at risk of exclusion?
  - o Did you ensure that information about, and the AI system's user interface of, the AI system is accessible and usable also to users of assistive technologies (such as screen readers)?

- o Did you involve or consult with end-users or subjects in need for assistive technology during the planning and development phase of the AI system?
- ✓ Did you ensure that Universal Design principles are taken into account during every step of the planning and development process, if applicable?
- ✓ Did you take the impact of the AI system on the potential end-users and/or subjects into account?
  - o Did you assess whether the team involved in building the AI system engaged with the possible target end-users and/or subjects?
  - o Did you assess whether there could be groups who might be disproportionately affected by the outcomes of the AI system?
  - o Did you assess the risk of the possible unfairness of the system onto the end-user's or subject's communities?

### 5C: Stakeholder participation

- ✓ Did you consider a mechanism to include the participation of the widest range of possible stakeholders in the AI system's design and development?

## **Requirement 6: Societal and Environmental Well-bearing**

### 6A: Environmental well-being

- ✓ Are there potential negative impacts of the AI system on the environment?
  - o Which potential impact(s) do you identify?
- ✓ Where possible, did you establish mechanisms to evaluate the environmental impact of the AI system's development, deployment and/or use (for example, the amount of energy used and carbon emissions)?
  - o Did you define measures to reduce the environmental impact of the AI system throughout its lifecycle?

### 6B: Impact on work and skills

- ✓ Does the AI system impact human work and work arrangements?
- ✓ Did you pave the way for the introduction of the AI system in your organisation by informing and consulting with impacted workers and their representatives (trade unions, (European) work councils) in advance?
- ✓ Did you adopt measures to ensure that the impacts of the AI system on human work are well understood?
  - o Did you ensure that workers understand how the AI system operates, which capabilities it has and which it does not have?
- ✓ Could the AI system create the risk of de-skilling of the workforce?
  - o Did you take measures to counteract de-skilling risks?
- ✓ Does the system promote or require new (digital) skills?
  - o Did you provide training opportunities and materials for re- and up-skilling?

### 6C: Impact on society at large or democracy

- ✓ Could the AI system have a negative impact on society at large or democracy?
  - o Did you assess the societal impact of the AI system's use beyond the (end-)user and subject, such as potentially indirectly affected stakeholders or society at large?
  - o Did you take action to minimize potential societal harm of the AI system?
  - o Did you take measures that ensure that the AI system does not negatively impact democracy?

## **Requirement 7: Accountability**

### 7A: Auditability

- ✓ Did you establish mechanisms that facilitate the AI system's auditability (e.g. traceability of the development process, the sourcing of training data and the logging of the AI system's processes, outcomes, positive and negative impact)?
- ✓ Did you ensure that the AI system can be audited by independent third parties?

### 7B: Risk management

- ✓ Did you foresee any kind of external guidance or third-party auditing processes to oversee ethical concerns and accountability measures?
  - o Does the involvement of these third parties go beyond the development phase?

- ✓ Did you organise risk training and, if so, does this also inform about the potential legal framework applicable to the AI system?
- ✓ Did you consider establishing an AI ethics review board or a similar mechanism to discuss the overall accountability and ethics practices, including potential unclear grey areas?
- ✓ Did you establish a process to discuss and continuously monitor and assess the AI system's adherence to this Assessment List for Trustworthy AI (ALTAI)?
  - o Does this process include identification and documentation of conflicts between the 6 aforementioned requirements or between different ethical principles and explanation of the 'trade-off' decisions made?
  - o Did you provide appropriate training to those involved in such a process and does this also cover the legal framework applicable to the AI system?
- ✓ Did you establish a process for third parties (e.g. suppliers, end-users, subjects, distributors/vendors or workers) to report potential vulnerabilities, risks or biases in the AI system?
  - o Does this process foster revision of the risk management process?
- ✓ For applications that can adversely affect individuals, have redress by design mechanisms been put in place?

## Annex F: Microsoft AI Impact Assessment

For questions about specific sections within the Impact Assessment, please refer to the Impact Assessment Guide.

### Section 1: System Information

#### System profile

1.1 Complete the system information below.

System name	
Team name	

Track revision history below.

Authors	
Last updated	

Identify the individuals who will review your Impact Assessment when it is completed.

Reviewers	
-----------	--

## System lifecycle stage

1.2 Indicate the dates of planned releases for the system.

Date	Lifecycle stage
	Planning & analysis
	Design
	Development
	Testing
	Implementation & deployment
	Maintenance
	Retired

## System description

1.3 Briefly explain, in plain language, what you're building. This will give reviewers the necessary context to understand

the system and the environment in which it operates.

System description

If you have links to any supplementary information on the system such as demonstrations, functional specifications, slide decks, or system architecture diagrams, please include links below.

Description of supplementary information	Link

## System purpose

**1.4** Briefly describe the purpose of the system and system features, focusing on how the system will address the needs of the people who use it. Explain how the AI technology contributes to achieving these objectives.

System purpose

## System features

**1.5** Focusing on the whole system, briefly describe the system features or high-level feature areas that already exist and those planned for the upcoming release.

Existing system features	System features planned for the upcoming release

Briefly describe how this system relates to other systems or products. For example, describe if the system includes models from other systems.

Relation to other systems/products

## Geographic areas and languages

**1.6** Describe the geographic areas where the system will or might be deployed to identify special considerations for language, laws, and culture.

The system is currently deployed to:	
In the upcoming release, the system will be deployed to:	
In the future, the system might be deployed to:	

*For natural language processing systems, describe supported languages:*

The system currently supports:	
In the upcoming release, the system will support:	
In the future, the system might support:	

## Deployment mode

1.7 Document each way that this system might be deployed.

How is the system currently deployed?	
Will the deployment mode change in the upcoming release? If so, how?	

## Intended uses

1.8 Intended uses are the uses of the system your team is designing and testing for. An intended use is a description of who will use the system, for what task or purpose, and where they are when using the system. They are not the same as system features, as any number of features could be part of an intended use. Fill in the table with a description of the system's intended use(s).

Name of intended use(s)	Description of intended use(s)
1.	
2.	
3.	

## Section 2: Intended uses

**Intended use #1: [Name of intended use] – repeat for each intended use**

Copy and paste the Intended Use #1 section and repeat questions 2.1 – 2.8 for each intended use you identified above

### Assessment of fitness for purpose

**2.1** Assess how the system's use will solve the problem posed by each intended use, recognizing that there may be multiple valid ways in which to solve the problem.

Assessment of fitness for purpose

### Stakeholders, potential benefits, and potential harms

**2.2** Identify the system's stakeholders for this intended use. Then, for each stakeholder, document the potential benefits

and potential harms. For more information, including prompts, see the *Impact Assessment Guide*.

Stakeholders	Potential system benefits	Potential system harms
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

9.		
10.		

## Stakeholders for Goal-driven requirements from the Responsible AI Standard

**2.3** Certain Goals in the Responsible AI Standard require you to identify specific types of stakeholders. You may have included them in the stakeholder table above. For the Goals below that apply to the system, identify the specific stakeholder(s) for this intended use. If a Goal does not apply to the system, enter "N/A" in the table.

### Goal A5: Human oversight and control

*This Goal applies to all AI systems. Complete the table below.*

Who is responsible for troubleshooting, managing, operating, overseeing, and controlling the system during and after deployment?	For these stakeholders, identify their oversight and control responsibilities.

### Goal T1: System intelligibility for decision making

*This Goal applies to AI systems when the intended use of the generated outputs is to inform decision making by or about people. If this Goal applies to the system, complete the table below.*

Who will use the outputs of the system to make decisions?	Who will decisions be made about?

### Goal T2: Communication to stakeholders

*This Goal applies to all AI systems. Complete the table below.*

Who will make decisions about whether to employ the system for particular tasks?	Who develops or deploys systems that integrate with this system?

### Goal T3: Disclosure of AI interaction

*This Goal applies to AI systems that impersonate interactions with humans, unless it is obvious from the circumstances or context of use that an AI system is in use, and AI systems that generate or manipulate image,*

audio, or video content that could falsely appear to be authentic. If this Goal applies to the system, complete the table below.

## Fairness considerations

**2.4** For each Fairness Goal that applies to the system, 1) identify the relevant stakeholder(s) (e.g., system user, person impacted by the system); 2) identify any demographic groups, including marginalized groups, that may require fairness considerations; and 3) prioritize these groups for fairness consideration and explain how the fairness consideration applies. If the Fairness Goal does not apply to the system, enter “N/A” in the first column.

### Goal F1: Quality of service

*This Goal applies to AI systems when system users or people impacted by the system with different demographic characteristics might experience differences in quality of service that can be remedied by building the system differently. If this Goal applies to the system, complete the table below describing the appropriate stakeholders for this intended use.*

Which stakeholder(s) will be affected?	For affected stakeholder(s) which demographic groups are you prioritizing for this Goal?	Explain how each demographic group might be affected.

### Goal F2: Allocation of resources and opportunities

*This Goal applies to AI systems that generate outputs that directly affect the allocation of resources or opportunities relating to finance, education, employment, healthcare, housing, insurance, or social welfare. If this Goal applies to the system, complete the table below describing the appropriate stakeholders for this intended use.*

Which stakeholder(s) will be affected?	For affected stakeholder(s) which demographic groups are you prioritizing for this Goal?	Explain how each demographic group might be affected.

### Goal F3: Minimization of stereotyping, demeaning, and erasing outputs

*This Goal applies to AI systems when system outputs include descriptions, depictions, or other representations of people, cultures, or society. If this Goal applies to the system, complete the table below describing the appropriate stakeholders for this intended use.*

Which stakeholder(s) will be affected?	For affected stakeholder(s) which demographic groups are you prioritizing for this Goal?	Explain how each demographic group might be affected.

## Technology readiness assessment

2.5 Indicate with an "X" the description that best represents the system regarding this intended use.

Select one	Technology Readiness
	<b>The system includes AI supported by basic research</b> and has not yet been deployed to production systems at scale for similar uses.
	<b>The system includes AI supported by evidence</b> demonstrating feasibility for uses similar to this intended use in production systems.
	<b>This is the first time that one or more system component(s) are to be validated in relevant environment(s)</b> for the intended use. Operational conditions that can be supported have not yet been completely defined and evaluated.
	<b>This is the first time the whole system will be validated in relevant environment(s)</b> for the intended use. Operational conditions that can be supported will also be validated. Alternatively, nearly similar systems or nearly similar methods have been applied by other organizations with defined success.
	<b>The whole system has been deployed for all intended uses</b> , and operational conditions have been qualified through testing and uses in production.

## Task complexity

2.6 Indicate with an "X" the description that best represents the system regarding this intended use.

Select One	Task Complexity
	<b>Simple tasks</b> , such as classification based on few features into a few categories with clear boundaries. For such decisions, humans could easily agree on the correct answer, and identify mistakes made by the system. For example, a natural language processing system that checks spelling in documents.
	<b>Moderately complex tasks</b> , such as classification into a few categories that are subjective. Typically, ground truth is defined by most evaluators arriving at the same answer. For example, a natural language processing system that autocompletes a word or phrase as the user is typing.

	<p><b>Complex tasks</b>, such as models based on many features, not easily interpretable by humans, resulting in highly variable predictions without clear boundaries between decision criteria. For such decisions, humans would have a difficult time agreeing on the best answer, and there may be no clearly incorrect answer. For example, a natural language processing system that generates prose based on user input prompts.</p>
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## Role of humans

2.7 Indicate with an "X" the description that best represents the system regarding this intended use.

Select One	Role of humans
	<b>People will be responsible for troubleshooting</b> triggered by system alerts but will not otherwise oversee system operation. For example, an AI system that generates keywords from unstructured text alerts the operator of errors, such as improper format of submission files.
	<b>The system will support effective hand-off</b> to people but will be designed to automate most use. For example, an AI system that generates keywords from unstructured text that can be configured by system admins to alert the operator when keyword generation falls below a certain confidence threshold.
	<b>The system will require effective hand-off</b> to people but will be designed to automate most use. For example, an AI system that generates keywords from unstructured text alerts the operator when keyword generation falls below a certain confidence threshold (regardless of system admin configuration).
	<b>People will evaluate system outputs</b> and can intervene before any action is taken: the system will proceed unless the reviewer intervenes. For example, an AI system that generates keywords from unstructured text will deliver the generated keywords for operator review but will finalize the results unless the operator intervenes.
	<b>People will make decisions based on output</b> provided by the system: the system will not proceed unless a person approves. For example, an AI system that generates keywords from unstructured text but does not finalize the results without review and approval from the operator.

## Deployment environment complexity

2.8 Indicate with an "X" the description that best represents the system regarding this intended use.

Select One	Deployment environment complexity
	<b>Simple environment</b> , such as when the deployment environment is static, possible input options are limited, and there are few unexpected situations that the system must deal with gracefully. For example, a natural language processing system used in a controlled research environment.
	<b>Moderately complex environment</b> , such as when the deployment environment varies, unexpected situations the system must deal with gracefully may occur, but when they do, there is little risk to people, and it is clear how to effectively mitigate issues. For example, a natural language processing system used in a corporate workplace where language is professional and communication norms change slowly.

	<p><b>Complex environment</b>, such as when the deployment environment is dynamic, the system will be deployed in an open and unpredictable environment or may be subject to drifts in input distributions over time. There are many possible types of inputs, and inputs may significantly vary in quality. Time and attention may be at a premium in making decisions and it can be difficult to mitigate issues. For example, a natural language processing system used on a social media platform where language and communication norms change rapidly.</p>
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## Section 3: Adverse impact

### Restricted Uses

**3.1** *If any uses of the system are subject to a legal or internal policy restriction, list them here, and follow the requirements for those uses.*

#### Restricted Uses

### Unsupported uses

**3.2** *Uses for which the system was not designed or evaluated or that should be avoided.*

#### Unsupported uses

### Known limitations

**3.3** *Describe the known limitations of the system. This could include scenarios where the system will not perform well, environmental factors to consider, or other operating factors to be aware of.*

#### Known limitations

### Potential impact of failure on stakeholders

**3.4** *Define predictable failures, including false positive and false negative results for the system as a whole and how they would impact stakeholders for each intended use.*

#### Potential impact of failure on stakeholders

## Potential impact of misuse on stakeholders

**3.5** Define system misuse, whether intentional or unintentional, and how misuse could negatively impact each stakeholder. Identify and document whether the consequences of misuse differ for marginalized groups. When serious

impacts of misuse are identified, note them in the summary of impact as a potential harm.

Potential impact of misuse on stakeholders

## Sensitive Uses

**3.6** Consider whether the use or misuse of the system could meet any of the Microsoft Sensitive Use triggers below.

Yes or No	Sensitive Use triggers
	<p><b>Consequential impact on legal position or life opportunities</b></p> <p>The use or misuse of the AI system could affect an individual's: legal status, legal rights, access to credit, education, employment, healthcare, housing, insurance, and social welfare benefits, services, or opportunities, or the terms on which they are provided.</p>
	<p><b>Risk of physical or psychological injury</b></p> <p>The use or misuse of the AI system could result in significant physical or psychological injury to an individual.</p>
	<p><b>Threat to human rights</b></p> <p>The use or misuse of the AI system could restrict, infringe upon, or undermine the ability to realize an individual's human rights. Because human rights are interdependent and interrelated, AI can affect nearly every internationally recognized human right.</p>

## Section 4: Data Requirements

### Data requirements

**4.1** Define and document data requirements with respect to the system's intended uses, stakeholders, and the geographic areas where the system will be deployed.

Data requirements

### Existing data sets

**4.2** If you plan to use existing data sets to train the system, assess the quantity and suitability of available data sets that will be needed by the system in relation to the data requirements defined above. If you do not plan to use pre-defined data sets, enter "N/A" in the response area.

Existing data sets

## Section 5: Summary of Impact

### Potential harms and preliminary mitigations

**5.1** Gather the potential harms you identified earlier in the Impact Assessment in this table (check the stakeholder table, fairness considerations, adverse impact section, and any other place where you may have described potential harms). Use the mitigations prompts in the Impact Assessment Guide to understand if the Responsible AI Standard can mitigate some of the harms you identified. Discuss the harms that remain unmitigated with your team and potential reviewers.

Describe the potential harm	Corresponding Goal from the Responsible AI Standard (if applicable)	Describe your initial ideas for mitigations or explain how you might implement the corresponding Goal in the design of the system

### Goal Applicability

**5.2** To assess which Goals apply to this system, use the tables below. When a Goal applies to only specific types of AI systems, indicate if the Goal applies to the system being evaluated in this Impact Assessment by indicating “Yes” or “No.” If you indicate that a Goal does not apply to the system, explain why in the response area. If a Goal applies to the system, you must complete the requirements associated with that Goal while developing the system.

#### Accountability Goals

Goals	Does this Goal apply to the system? (Yes or No)
<b>A1: Impact assessment</b> <i>Applies to:</i> All AI systems.	
<b>A2: Oversight of significant adverse impacts</b> <i>Applies to:</i> All AI systems.	

<b>A3: Fit for purpose</b> <i>Applies to: All AI systems.</i>	
<b>A4: Data governance and management</b> <i>Applies to: All AI systems.</i>	
<b>A5: Human oversight and control</b> <i>Applies to: All AI systems.</i>	

## Transparency Goals

Goals	Does this Goal apply to the system? (Yes or No)
<p><b>T1: System intelligibility for decision making</b></p> <p><i>Applies to:</i> AI systems when the intended use of the generated outputs is to inform decision making by or about people.</p>	
<p><b>T2: Communication to stakeholders</b></p> <p><i>Applies to:</i> All AI systems.</p>	
<p><b>T3: Disclosure of AI interaction</b></p> <p><i>Applies to:</i> AI systems that impersonate interactions with humans, unless it is obvious from the circumstances or context of use that an AI system is in use, and AI systems that generate or manipulate image, audio, or video content that could falsely appear to be authentic.</p>	

If you selected "No" for any of the Transparency Goals, explain why the Goal does not apply to the system.

## Fairness Goals

Goals	Does this Goal apply to the system? (Yes or No)
<p><b>F1: Quality of service</b></p> <p><i>Applies to:</i> AI systems when system users or people impacted by the system with different demographic characteristics might experience differences in quality of service that can be remedied by building the system differently.</p>	
<p><b>F2: Allocation of resources and opportunities</b></p> <p><i>Applies to:</i> AI systems that generate outputs that directly affect the allocation of resources or opportunities relating to finance, education, employment, healthcare, housing, insurance, or social welfare.</p>	

**F3: Minimization of stereotyping, demeaning, and erasing outputs**

*Applies to:* AI systems when system outputs include descriptions, depictions, or other representations of people, cultures, or society.

If you selected “No” for any of the Fairness Goals, explain why the Goal does not apply to the system below.

## Reliability & Safety Goals

Goals	Does this Goal apply to the system? (Yes or No)
<b>RS1: Reliability and safety guidance</b> <i>Applies to: All AI systems.</i>	
<b>RS2: Failures and remediations</b> <i>Applies to: All AI systems.</i>	
<b>RS3: Ongoing monitoring, feedback, and evaluation</b> <i>Applies to: All AI systems.</i>	

## Privacy & Security Goals

Goals	Does this Goal apply to the system? (Yes or No)
<b>PS1: Privacy Standard compliance</b> <i>Applies when the Microsoft Privacy Standard applies.</i>	
<b>PS2: Security Policy compliance</b> <i>Applies when the Microsoft Security Policy applies.</i>	

## Inclusiveness Goal

Goals	Does this Goal apply to the system? (Yes or No)
<b>I1: Accessibility Standards compliance</b> <i>Applies when the Microsoft Accessibility Standards apply.</i>	

## Signing off on the Impact Assessment

**5.3** Before you continue with next steps, complete the appropriate reviews and sign off on the Impact Assessment. At minimum, the PM should verify that the Impact Assessment is complete. In this case, ensure you complete the appropriate reviews and secure all approvals as required by your organization before beginning development.

Reviewer role and name	I can confirm that the document benefitted from collaborative work and different expertise within the team (e.g., engineers, designers, data scientists, etc.)	Date reviewed	Comments

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*Update and review the Impact Assessment at least annually, when new intended uses are added, and before advancing*

*to a new release stage. The Impact Assessment will remain a key reference document as you work toward compliance with the remaining Goals of the Responsible AI Standard*


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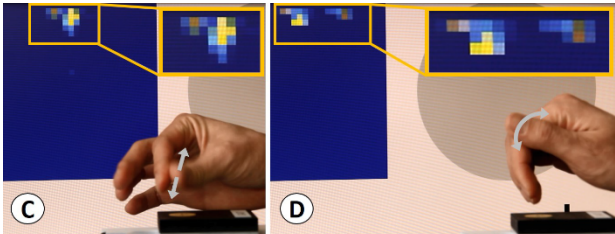
## Annex G: Human Performance Sensors and Technologies

### Mindtooth

<b>Technology:</b> EEG headset		
Manufacturer/s: BrainSigns Srl	Readiness: 2 - In experimental phase	Consortium expertise: Deep Blue
<b>Technical</b>		
Equipment/Sensor Type: wearable EEG	Associated Software: Algorithm-based neurometrics software which accompanies the technology. Real-time analysis.	
<b>Human Factors concept</b>		
Data being measured: Brain activity (additional sensors can be combined e.g. Heart Rate, Skin Conductance, Body Temperature, but aren't part of the system currently)	Physical and cognitive states being observed (from the data): Attention, Interest, Stress, Workload, Fatigue and Emotion.	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: high temporal resolution	Limitations: headset preparation by the user (gel, headset application, power), long-term suitability of the headset
Cost: ~€6.000		
<b>Context of use</b>		
Industries: aviation, automotive, manufacturing, marketing		
 <p><b>Image &amp; References</b>  <a href="https://pubmed.ncbi.nlm.nih.gov/35911603/">https://pubmed.ncbi.nlm.nih.gov/35911603/</a>  <a href="https://www.mindtooth.com/">https://www.mindtooth.com/</a>  <a href="https://www.brainsigns.com/en/">https://www.brainsigns.com/en/</a>  <a href="https://cordis.europa.eu/project/id/950998">https://cordis.europa.eu/project/id/950998</a></p>		

### Soli Gesture Recognition

**Technology:** Soli - Miniaturised Radar Sensor

Manufacturer/s: Google (Advanced Technology & Projects)	Readiness: 2 - In experimental phase	Consortium expertise: None
<b>Technical</b>		
Equipment/Sensor Type: Radar (emits electromagnetic waves in a broad beam. Objects, such as a human hand, within the beam scatter this energy, reflecting some portion back towards the radar antenna)	Associated Software: Uses RadarNet, an algorithm that recognizes gestures	
<b>Human Factors concept</b>		
Data being measured: Motion and gestures	Physical and cognitive states being observed (from the data): Workload, arousal, non-verbal interactions, intention, behaviour, sleep	
<b>Characteristics</b>		
Invasiveness: Low	Temporal / Spatial resolution: Medium. 180 degrees field of view. Uses the 60GHz mmWave frequency band	Limitations: Have to manage integration on some transport platforms e.g. air platforms as radar can interfere with other instrumentation. The signal cannot reconstruct the spatial structure or the shape of objects. However, the signal does capture motion even of very small magnitude and it is possible to discriminate very subtle and precise hand motions and gestures.
Cost: unknown		
<b>Context of use</b>		
Industries: Domestic-Ambient computing interactions, opening the opportunity to design interactions that are eye-free and allow the user to continue with their primary tasks.		
<b>Image &amp; References</b> <a href="https://blog.google/products/atap/how-computers-can-use-radar-to-understand-nonverbal-cues/">https://blog.google/products/atap/how-computers-can-use-radar-to-understand-nonverbal-cues/</a>  Eiji Hayashi, E et al (2021) RadarNet: Efficient Gesture Recognition Technique Utilizing a Miniature Radar Sensor. Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan. ACM, New York, NY, USA, 14 pages.		

Wang, S et al (2016) Interacting with Soli: Exploring Fine-Grained Dynamic Gesture Recognition in the Radio-Frequency Spectrum. UIST '16: Proceedings of the 29th Annual Symposium on User Interface Software and Technology October 2016 Pages 851–860.

### Jacquard

#### Technology: Jacquard Interactive Tag and Textiles

Manufacturer/s: Google (Advanced Technology & Projects)	Readiness: 1 - Available on the market	Consortium expertise: None
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#### Technical

Equipment/Sensor Type: Touch sensitive textiles using a conductive yarn and small 'tag' (computer) that translates interactions into commands.	Associated Software: Jacquard 'App'
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#### Human Factors concept

Data being measured: Tactile/touch interactions.	Physical and cognitive states being observed (from the data): Workload, situational awareness, intention, behaviour.
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#### Characteristics

Invasiveness: High	Temporal / Spatial resolution: Unknown	Limitations: requires a phone or similar device to install the Jacquard app.
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Cost: unknown

#### Context of use

Industries: Domestic - *Potential of application in aviation*


#### Image & References

<https://atap.google.com/jacquard/technology/>

Poupyrev, I. et al (2016) Project Jacquard: Interactive Digital Textiles at Scale. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). Association for Computing Machinery, New York, NY, USA, 4216–4227.




### Tobii glasses v2

Technology:		
Manufacturer/s: Tobii	Readiness: 1 - Available on the market	Consortium expertise: ENAC
Technical		
Equipment/Sensor Type: Wearable eye tracker (glasses)	Associated Software: Tobii Pro Lab, Home made software from ENAC	
Human Factors concept		
Data being measured: gaze position, fixation duration, saccade amplitude, ratio exploit/explore, AOI fixation, scanpath, heatmaps, blink rate, pupil diameter, accelerometers	Physical and cognitive states being observed (from the data): workload, attention, abnormal scanpath, fatigue	
Characteristics		
Invasiveness: High	Temporal / Spatial resolution: medium/medium precision 0.1°, accuracy 1°	Limitations: Light environment has to be controlled, battery life is #1hour, fragile, 100Hz is a bit low for pupil diameter analysis
Cost: #12k€		
Context of use		
Industries: air traffic control, aviation, automotive, manufacturing, marketing		
Image & References : <a href="https://connect.tobii.com/s/g2-downloads?language=en_US">https://connect.tobii.com/s/g2-downloads?language=en_US</a>		
		


### Tobii Spectrum

Technology:		
Manufacturer/s: Tobii	Readiness: 1 - Available on the market	Consortium expertise: ENAC
Technical		
Equipment/Sensor Type:	Associated Software:	

screen based eye tracker		Tobii Pro Lab, Home made software from ENAC
<b>Human Factors concept</b>		
Data being measured: gaze position, fixation duration, saccade amplitude, ratio exploit/explore, AOI fixation, scanpath, heatmaps, blink rate, pupil diameter		Physical and cognitive states being observed (from the data): workload, attention, abnormal scanpath, fatigue
<b>Characteristics</b>		
Invasiveness: Low	Temporal / Spatial resolution: High/High precision 0.01°, accuracy 0.3°	Limitations: Light environment has to be controlled, Eye tracker dedicated to a single screen up to 40"
Cost: 50k€		
<b>Context of use</b>		
Industries: air traffic control, web marketing, design		
<b>Image &amp; References:</b> <a href="https://www.tobii.com/products/eye-trackers/screen-based/tobii-pro-spectrum">https://www.tobii.com/products/eye-trackers/screen-based/tobii-pro-spectrum</a>		
		


### *Tobii gaming*

<b>Technology:</b>		
Manufacturer/s: Tobii	Readiness: 1 - Available on the market	Consortium expertise: ENAC
<b>Technical</b>		
Equipment/Sensor Type: screen based eye tracker	Associated Software: Tobii Pro Lab, Home made software from ENAC	
<b>Human Factors concept</b>		
Data being measured: gaze position, fixation duration, saccade amplitude, ratio exploit/explore, AOI fixation, scanpath, heatmaps, blink rate,	Physical and cognitive states being observed (from the data): attention, abnormal scanpath, fatigue	
<b>Characteristics</b>		

Invasiveness: Low	Temporal / Spatial resolution: High/High	Limitations: Light environment has to be controlled, Eye tracker dedicated to a single screen up to 30", special licence needed for research purposes, no pupil diameter
Cost: 270€ + 2200€ licence		
<b>Context of use</b>		
Industries: air traffic control, web marketing, design		
<b>Image &amp; References:</b>		
		
<a href="https://gaming.tobii.com/product/eye-tracker-5/">https://gaming.tobii.com/product/eye-tracker-5/</a>		

### *Pupil Labs Core*

<b>Technology:</b>		
Manufacturer/s: Pupil Labs	Readiness: 1 - Available on the market	Consortium expertise: BdxINP
<b>Technical</b>		
Equipment/Sensor Type: Wearable eye tracker (glasses)	Associated Software: Pupil lab dedicated software	
<b>Human Factors concept</b>		
Data being measured: gaze position, fixation duration, saccade amplitude,	Physical and cognitive states being observed (from the data): workload, attention, abnormal scanpath, fatigue	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: Accuracy : 0.60° Precision : 0.02 Eye Camera : 200Hz @ 192×192px World Camera : 30Hz@1080p	Limitations: calibration needed, learning the sdk to have advanced functions (time synchronisation, realtime world mapping...), to be connected to the computer.

	60Hz@720p 120Hz@480p	
Cost: 3500€		
<b>Context of use</b>		
Industries: research, manufacturing, transportation,		
<b>Image &amp; References:</b>		
		
<a href="https://pupil-labs.com/products/core/">https://pupil-labs.com/products/core/</a>		
API : <a href="https://github.com/pupil-labs/pupil">https://github.com/pupil-labs/pupil</a>		

*Polar H10*

<b>Technology:</b>		
Manufacturer/s: Polar	Readiness: 1 - Available on the market	Consortium expertise: BdxINP
<b>Technical</b>		
Equipment/Sensor Type: Heart Rate Sensor	Associated Software: Via the Polar Beat or Polar Flow mobile app	
<b>Human Factors concept</b>		
Data being measured: heart rate, HRV time-domain measures, frequency-domain measures, non-linear measures, RR intervals, 3 axis accelerometer	Physical and cognitive states being observed (from the data): stress, fatigue	

Characteristics		
Invasiveness: High	Temporal / Spatial resolution: RR : 1000Hz sampling accelerometer : 100Hz sampling rate and 4g sampling resolution	Limitations: BLE connection, cognitive activity could be analyse only without physical activity, need a minimum 5 min sample to see the effect of cognitive activity
Cost: 90€		
Context of use		
Industries: research, sport, medical		
Image & References:		
		
<a href="https://support.polar.com/e_manuals/h10-heart-rate-sensor/polar-h10-user-manual-english/manual.pdf">https://support.polar.com/e_manuals/h10-heart-rate-sensor/polar-h10-user-manual-english/manual.pdf</a> <a href="https://www.polar.com/en/sensors/h10-heart-rate-sensor">https://www.polar.com/en/sensors/h10-heart-rate-sensor</a>		

### Pilot State Monitoring Systems (REPS)

Technology: Pilot State Monitoring		
Manufacturer/s: Honeywell	Readiness: 2 - In experimental phase	Consortium expertise: HAIKU Partner familiar with the technology
Technical		
Equipment/Sensor Type:	Associated Software:	

Uses eye and head tracking cameras, Near-IR lights, a computational unit and a wristband. Pressure sensors on the seat.	Microsoft Surface Pro 7 is used in the Computation Unit (CU)
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### Human Factors concept

Data being measured: Video: used to extract facial expressions (yawning, eye lid blinking, eye closing rate) Trends can be generated out of cumulated anonymized data. Wristband: Activity, supplementary heart-rate related features, electro-dermal activity, state related features (e.g. movement activity, EDA). Pressure sensors: Long-range movements, e.g. left & right, body posture and movement activity.	Physical and cognitive states being observed (from the data): Psychophysiological, behavioural and health states: Sleep, drowsiness and fatigue. Presence, attention and conflict. Heart attack, Stroke, Loss of consciousness, Epileptic seizure, Hypoxia, Death.
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### Characteristics

Invasiveness: High	Temporal / Spatial resolution: Sampling rate: 60 Hz NIR light at 850 nm	Limitations: Consider anonymity of data collection and handling. Possible extra cables in the cockpit/ around the pilot.
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Cost: unknown

### Context of use




Industries: Aviation

### Image & References


Sandgaard, J et al. Transportation Research Procedia (2022) Not yet published. Transport Research Arena (TRA) Conference. Wakefulness monitoring in a real life cockpit environment.

**CURRENT EXPERIMENTAL SET**

The diagram illustrates the experimental setup with three main components: Vision system, Processing, and Wristband. Arrows indicate the flow of data from the Vision system to the Processing unit, and from the Wristband to the Processing unit.


Vision system	Processing	Wristband
 <p><b>EYE AND HEAD TRACKING CAMERAS</b></p> <ul style="list-style-type: none"> <li>• Sampling rate: 60 Hz</li> <li>• Size: 17x31x31mm</li> <li>• Camera weight: 20g</li> <li>• NIR light at 850 nm</li> </ul>	 <p><b>COMPUTATION UNIT</b></p> <ul style="list-style-type: none"> <li>• <b>No image of pilot is being stored!</b></li> <li>• <b>Data are anonymized, impossible to track the data back to the pilot</b></li> <li>• Video used to extract facial expressions (yawning, eye lid blinking, eye closing rate, etc.)</li> <li>• Trends can be generated out of cumulated anonymized data</li> </ul>	 <p><b>WRISTBAND</b></p> <ul style="list-style-type: none"> <li>• Activity, supplementary heart-rate related features, electro-dermal activity</li> <li>• State related features (e.g. movement activity, EDA)</li> </ul>


## Neurometrics Toolbox

Technology Neuro- and Cardio- Sensors		
Manufacturer/s: Deep Blue Srl	Readiness: 2 - In experimental phase (almost ready for the market)	Consortium expertise: Deep Blue
Technical		
Equipment/Sensor Type: EDA, heart rate, EEG <i>Note: Neurometrics Toolbox is linked with Mindtooth</i>	Associated Software: - Algorithm-based neurometrics software	
Human Factors concept		
Data being measured: Brain activity (EEG evoked potentials, using Mindtooth), HRV, Galvanic skin response	Physical and cognitive states being observed (from the data): Attention, workload, stress	
Characteristics		
Invasiveness: High	Temporal / Spatial resolution: n/a	Limitations: Necessary to calibrate the baseline of each user
Cost: unknown		
Context of use		
Industries: Aviation, Automotive		
Image & References		
<a href="https://dblue.it/consultings/mental-states-measurement/">https://dblue.it/consultings/mental-states-measurement/</a>		
		
Aricò et al., 2014		

## HARMAN In-Cabin Monitoring Systems

Technology: Driver Monitoring Systems		
Manufacturer/s: Harman International (subsidiary of Samsung Electronics Co., Ltd)	Readiness: 2 - In experimental phase	Consortium expertise: none

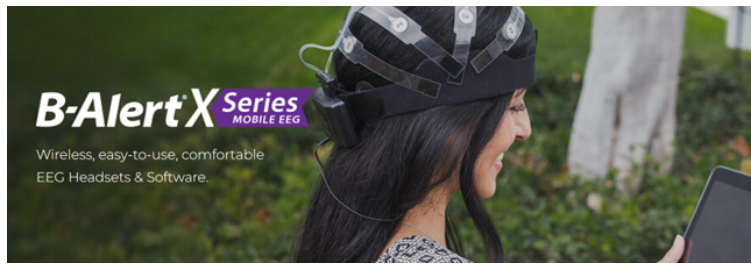
Technical		
Equipment/Sensor Type: Sensors behind the driving wheel. A camera records fluctuations of the pupil. In-cabin radar sensor (previously CAAESYS technology).		Associated Software: Calculation of the cognitive workload with a proprietary software algorithm that analyses the pupil reflex using advanced filtering and signal processing.
Human Factors concept		
Data being measured: Facial features, speech, vital signs: Eye gaze direction, eyelid position, head orientation, facial features, voice features, heart rate, respiratory rate and HRV.		Physical and cognitive states being observed (from the data): Cognitive load, stress, attention, distraction and drowsiness, emotional load.
Characteristics		
Invasiveness: Low	Temporal / Spatial resolution: Not known	Limitations: Not known
Cost: unknown		
Context of use		
Industries: Automotive		
Image & References		
<a href="https://car.harman.com/solutions/adas/in-cabin-monitoring-systems">https://car.harman.com/solutions/adas/in-cabin-monitoring-systems</a>  <a href="https://info.car.harman.com/l/606031/2021-12-28/4zzvq/606031/1645611263wvGeSyIM/FactSheet_In_Cabin_Monitoring_Systems.pdf">https://info.car.harman.com/l/606031/2021-12-28/4zzvq/606031/1645611263wvGeSyIM/FactSheet_In_Cabin_Monitoring_Systems.pdf</a>		
		

<b>Technology: Smartwatch</b>		
Manufacturer/s: Google	Readiness: 1 - Available on the market	Consortium expertise: Yes
<b>Technical</b>		
Equipment/Sensor Type: Altimeter, Haptic motor, Optical heart rate sensor, Accelerometer, Gyroscope Ambient light sensor, Built-in microphone, Built-in speaker, GPS + GLONASS, Multipurpose electrical sensors compatible with ECG app, Bluetooth and Wifi	Associated Software: Proprietary. Real time.	
<b>Human Factors concept</b>		
Data being measured: HRV, Breathing rate, heart rate, sleep tracking, GPS, accelerometry - activity tracking, ECG.	Physical and cognitive states being observed (from the data): Activity, health, fall detection, stress, sleep.	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: unknown	Limitations: software and hardware proprietary and not configurable
Cost: \$399		
<b>Context of use</b>		
Industries: All, but currently used in the domestic market for health monitoring and fitness.		
<b>Image &amp; References</b>		
<a href="https://www.fitbit.com/global/us/products/smartwatches/google-pixel-watch?sku=GA03BKBK">https://www.fitbit.com/global/us/products/smartwatches/google-pixel-watch?sku=GA03BKBK</a>		
		

### *B-Alert X series*

<b>Technology: mobile EEG headset</b>		
Manufacturer/s: Advanced Brain Monitoring	Readiness: 1 - Available on the market	Consortium expertise: None

<b>Technical</b>		
Equipment/Sensor Type: Mobile EEG-9 or 20 channels of EEG plus one optional ECG, EOG, EMG, ECG channel.  On-board accelerometer	Associated Software: Proprietary software capable of: Real-time and off -line processing and analysis. Collection, storage and display of raw data signals. Data quality assessment including identification of artefacts. Impedance checks on demand. Capability for manual event marking and annotation of files. Integration with third party event markers using the External Syncing Unit. Automated delivery of resting state tasks eye open and eyes closed. Files saved in European Data Format (EDF). Full SDK to facilitate programming access to all software functions. Supports MP4 video recording / remote video monitoring.	
<b>Human Factors concept</b>		
Data being measured: Brain Activity	Physical and cognitive states being observed (from the data): Real-time Cognitive State Metrics for measuring subject's engagement & drowsiness levels. Real-time Cognitive Workload Metric for measuring subject's mental effort.	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: Unknown	Limitations: Unknown
Cost: 500€		
<b>Context of use</b>		
Industries: All e.g. Biomarkers for a number of neurological and psychiatric disorders; Neuromarketing; Team Neurodynamics; Human Performance Enhancement; and Fatigue Management and Safety.		
<b>Image &amp; References</b>		
<a href="https://www.advancedbrainmonitoring.com/products/b-alert-x-series">https://www.advancedbrainmonitoring.com/products/b-alert-x-series</a>		



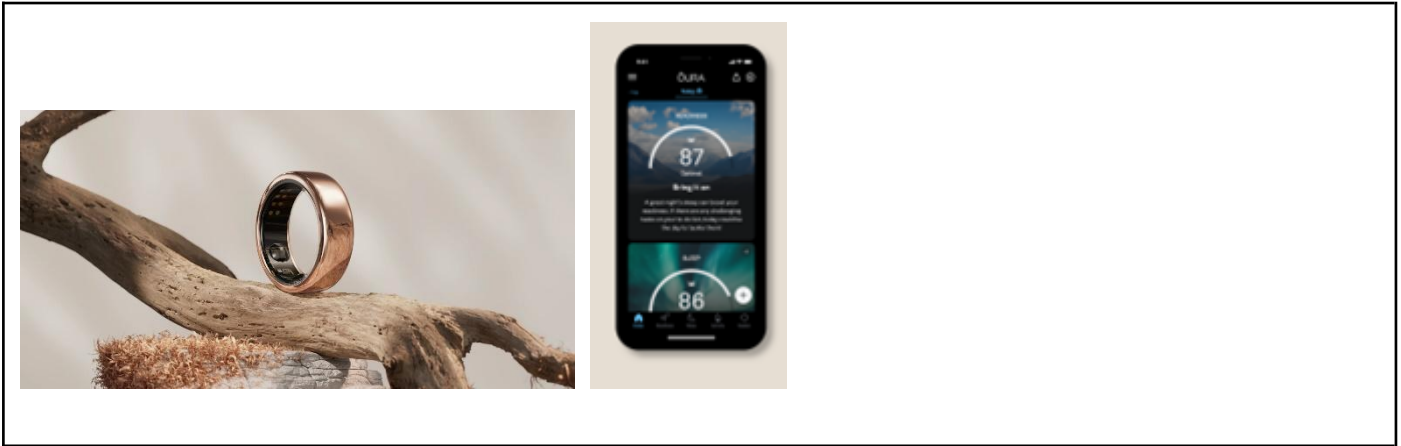
## SUEmpathy100

Technology:		
Manufacturer/s: Technische Universität Chemnitz	Readiness: 2 - In experimental phase	Consortium expertise: None
Technical		
Equipment/Sensor Type: ECG, Skin conductance, Electromyogram (EMG) and blood pressure.	Associated Software: Proprietary	
Human Factors concept		
Data being measured: Measuring device for functional diagnostics of the autonomic nervous system.	Physical and cognitive states being observed (from the data): mental workload, physical activity, arousal.	
Characteristics		
Invasiveness: High	Temporal / Spatial resolution: unknown	Limitations: Potentially old technology
Cost: unknown		
Context of use		
Industries: All - Experimental tool		
Image & References		
<a href="https://www.tu-chemnitz.de/hsw/psychologie/professuren/allpsy2/Forschung/Labor/Labor_SUEmpathy.php.en">https://www.tu-chemnitz.de/hsw/psychologie/professuren/allpsy2/Forschung/Labor/Labor_SUEmpathy.php.en</a>		
<a href="https://www.hfes-europe.org/wp-content/uploads/2017/10/Schmalfluss2017.pdf">https://www.hfes-europe.org/wp-content/uploads/2017/10/Schmalfluss2017.pdf</a>		



*The ŌURA ring*

<b>Technology:</b> Sleep tracking device		
Manufacturer/s: Oura	Readiness: 1 - available on the market	Consortium expertise: None
<b>Technical</b>		
Equipment/Sensor Type: Blood oxygen sensor Infrared Photoplethysmography (PPG) sensors, optical heart rate sensor, skin temperature sensors (negative temperature coefficient sensors) Photodiodes, 3D Accelerometer.	Associated Software: Proprietary Mobile phone app.	
<b>Human Factors concept</b>		
Data being measured: "sleep tracker" measuring and processing information from several bio-signals.	Physical and cognitive states being observed (from the data): Activity and rest, sleeping in different stages, blood oxygen sensing, HR and HRV, menstruation tracking (temperature)	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: unknown	Limitations: Battery limited to three days
Cost: 300-500 euros		
<b>Context of use</b>		
Industries: All, currently used in the domestic industry for health and fitness monitoring.		
<b>Image &amp; References</b> <a href="https://ouraring.com/">https://ouraring.com/</a>		



## FaceReader

Technology: Facial Expression Identification system		
Manufacturer/s: Noldus Information Technology	Readiness: 1 - Available on the market	Consortium expertise: Deep Blue
Technical		
Equipment/Sensor Type: Software for facial analysis through a camera. Photoplethysmography (PPG) unit optional.	Associated Software: Proprietary. Real time. Uses a facial modelling technique based on deep neural networks. Classification of facial expressions is done by a trained deep artificial neural network to recognize patterns in the face.	
Human Factors concept		
Data being measured: Facial expressions.	Physical and cognitive states being observed (from the data): Facial expression classification Valence calculation (emotional state of the subject is positive or negative) Facial arousal calculation Action Unit classification (muscle groups in the face). Subject characteristics analysis. Can analyse the facial expressions of a group of participants.	
Characteristics		
Invasiveness: Low	Temporal / Spatial resolution: unknown	Limitations: Calibrate FaceReader to correct for these person-specific biases.
Cost:		
Context of use		

Industries: All, currently used in experimental research on behaviour.

**Image & References**

<https://www.noldus.com/>

[https://info.noldus.com/hubfs/resources/noldus-white-paper-facereader-methodology.pdf?utm\\_campaign=Downloads&utm\\_medium=email&utm\\_content=59367721&utm\\_source=hs\\_automation](https://info.noldus.com/hubfs/resources/noldus-white-paper-facereader-methodology.pdf?utm_campaign=Downloads&utm_medium=email&utm_content=59367721&utm_source=hs_automation)



*Vocavio*

**Technology: Speech Analysis**

Manufacturer/s:  
Vocavio Technologies

Readiness:  
1 - Available on the market

Consortium expertise:  
Deep Blue

**Technical**

Equipment/Sensor Type:  
Uses voice recordings

Associated Software:  
Proprietary software.  
The Vocavio engine outputs json files or .tsv format.

**Human Factors concept**

Data being measured:  
Non-verbal cues from speech communication, e.g. tone of voice.

Physical and cognitive states being observed (from the data):  
Communication performance.  
Balance/Effort levels (crew gradient).  
Speaker Ratio.  
Turn taking.  
Engagement levels.  
Workload flags.  
Crew Resource Management event flags.

**Characteristics**

Invasiveness:  
Low

Temporal / Spatial resolution:  
unknown

Limitations:  
unknown

Cost: unknown

**Context of use**

Industries: Aviation (pilot training, multi-actors training, scientific research, virtual reality training).

**Image & References**

<https://vocavio.com/>



**NIRSIT**

**Technology:** Portable functional near-infrared (fNIR) imaging

Manufacturer/s:  
Soterix Medical

Readiness:  
1 - Available on the market

Consortium expertise:  
none

**Technical**

Equipment/Sensor Type:  
Functional Near Infrared Spectroscopy System.  
Photogrammetry for localization and 6-axis  
gyroscope.

Associated Software:  
Proprietary algorithm for motion artefact  
removal, save, retrieve and play back data  
using tablet or computer.

**Human Factors concept**

Data being measured:  
Measuring cerebral hemodynamics within the  
prefrontal cortex in response to sensory, motor,  
or cognitive activation.

Physical and cognitive states being observed  
(from the data):  
Mental workload

**Characteristics**

Invasiveness:  
High  
Light (500 grams), compact, and  
portable. No wires.

Temporal / Spatial resolution:  
millimetre-level spatial resolution and  
high temporal resolution (125 ms / 8  
Hz).  
Implements real-time Diffuse Optical  
Tomography (DOT) resulting in 204  
channels that provide 4mm x 4mm  
spatial resolution.

Limitations:

Cost: unknown

**Context of use**

Industries: Medical: Neuro-Rehabilitation, depression and PTSD, concussion, education (Monitor progress by checking cognitive performance when performing cognitive and behavioural tasks).

**Image & References**





<https://soterixmedical.com/research/nirsit>

Ayaz, H., Shewokis, P. A., Bunce, S., Izzetoglu, K., Willems, B., & Onaral, B. (2012). Optical brain monitoring for operator training and mental workload assessment. *NeuroImage*, 59(1), 36-47. doi:<https://doi.org/10.1016/j.neuroimage.2011.06.023>

*Real Time Pilot Activity Monitoring (IAI)*

Technology:		
Manufacturer/s: Israel Aerospace Industries Ltd.	Readiness: 2 - System is in an experimental phase	Consortium expertise: none
Technical		
Equipment/Sensor Type: All sensors are embedded in the seat (IAIs Golan Ind seat) - heart rate and respiration monitor. Possible use of eye tracking for redundancy (more invasive).	Associated Software: Real time with filtering to reduce false alarms. Filters noise, vibration, acceleration, artefacts etc.	
Human Factors concept		
Data being measured: HR and respiratory rate.	Physical and cognitive states being observed (from the data): Monitor the health and alertness of the pilot for incapacitation. Alerts when abnormal or cessation of breathing.	

Characteristics		
Invasiveness: Seat 1 - Low With eye tracker 3 - High	Temporal / Spatial resolution: unknown	Limitations: Unknown
Cost: prototype - unknown		
Context of use		
Industries: Aviation, automotive, control stations etc		
Image & References		
<a href="https://www.iai.co.il/">https://www.iai.co.il/</a>		
 <ul style="list-style-type: none"> <li>❖ No limited interfaces – warning light, aural, avionics etc.</li> <li>❖ No limited uses – aircrafts, cars, control stations etc.</li> <li>❖ Certifiable &amp; safe for use</li> <li>❖ Not affect seat comfortable</li> <li>❖ All sensors are imbedded in the seat</li> </ul> <div style="display: flex; align-items: center;"> <div style="margin-right: 20px;"> <p>Using AirPods di Garminia</p> </div>  </div>		

### Delphi adaptive cruise control

Technology:		
Manufacturer/s: Delphi	Readiness: On Market	Consortium expertise: no
Technical		
Equipment/Sensor Type: RADAR	Associated Software: unknown	
Human Factors concept		
Data being measured: Radial range	Parameter being observed (from the data): Vehicle detection/tracking	
Characteristics		
Invasiveness: n/a	Temporal / Spatial resolution: n/a	Limitations: Classification issues, more power consumption ,range
Cost: up to ~500\$		
Context of use		
Industries: automotive		

## Image & References

<https://www.delphiautoparts.com/gbr/en>



## HDL-32E

### Technology:

Manufacturer/s: Velodyne

Readiness: On Market

Consortium expertise: no

### Technical

Equipment/Sensor Type: LIDAR - high definition 3-dimensional information about the surrounding environment using laser technology.

Associated Software: LIDAR software

### Human Factors concept

Data being measured: Range/distance

Physical and cognitive states being observed (from the data):  
Vehicle detection/tracking

### Characteristics

Invasiveness: n/a

Temporal / Spatial resolution: unknown

Limitations: Range, road infrastructure dependency

Cost: up to unknown

### Context of use

Industries: automotive

### Image & References

<https://velodynelidar.com/products/hdl-32e/>



*625B-Infrared camera*

<b>Technology:</b>		
Manufacturer/s: Safety Vision	Readiness: Market	On Consortium expertise:no
<b>Technical</b>		
Equipment/Sensor Infrared camera	Type:	Associated Software: provided commercial software
<b>Human Factors concept</b>		
Data being measured: images (day/night)	Physical and cognitive states being observed (from the data): Vehicle detection/tracking	
<b>Characteristics</b>		
Invasiveness: n/a	Temporal / Spatial resolution: n/a	Limitations: Requires more resource for computing, image quality dependent on lighting conditions
Cost: up to unknown		
<b>Context of use</b>		
Industries: automotive		
<b>Image &amp; References</b> <a href="https://www.safetyvision.com/products/detail/625B/41">https://www.safetyvision.com/products/detail/625B/41</a>		



**OMRON**


<b>Technology:</b>		
Manufacturer/s: Omron corp.	Readiness: On Market	Consortium expertise:no
<b>Technical</b>		
Equipment/Sensor Type: ECG	Associated Software: unknown	
<b>Human Factors concept</b>		
Data being measured: heart rhythm and electricity	Physical and cognitive states being observed (from the data): Fatigue detection	
<b>Characteristics</b>		
Invasiveness: High	Temporal / Spatial resolution: unknown	Limitations: none known
Cost: up to ~300\$		
<b>Context of use</b>		
Industries: automotive, aviation, medical		
<b>Image &amp; References</b>		
<a href="https://omronhealthcare.com/ekg/">https://omronhealthcare.com/ekg/</a>		



*MindWave Mobile*

<b>Technology:</b>		
Manufacturer/s: NeuroSky	Readiness: On Market	Consortium expertise:no
<b>Technical</b>		
Equipment/Sensor Type: EEG	Associated Software: MindWave app	
<b>Human Factors concept</b>		
Data being measured: Brainwaves	Physical and cognitive states being observed (from the data): Fatigue and distraction detection	
<b>Characteristics</b>		
Invasiveness: minor to major	Temporal / Spatial resolution: unknown	Limitations: Other electrical activities can effect sensor readings
Cost: up to 110\$		
<b>Context of use</b>		
Industries: Automotive, aviation, medical		
<b>Image &amp; References</b> <a href="https://store.neurosky.com/">https://store.neurosky.com/</a>		

*LogicOne*

Technology:		
Manufacturer/s: EyeLogic	Readiness: Experimental/research	Consortium expertise: no
Technical		
Equipment/Sensor Type: EOG screen-based eye tracking device	Associated Software: SDK/Integration Kit	
Human Factors concept		
Data being measured: blink duration, frequency	Physical and cognitive states being observed (from the data): Detection of alertness	
Characteristics		
Invasiveness: none	Temporal / Spatial resolution: unknown	Limitations: none known
Cost: unknown		
Context of use		
Industries: Automotive, Aviation, Medical, Entertainment and Education		
Image & References		
<a href="https://www.eyelogicsolutions.com/logicone/remote-eye-tracking (gazeintelligence.com)">https://www.eyelogicsolutions.com/logicone/remote-eye-tracking (gazeintelligence.com)</a>		
 <p>The image shows a white rectangular box with the EyeLogic logo (a red dot with a trail) and the text 'eyeLOGIC'. Next to the box is a black, elongated, rectangular device, which is the eye tracking sensor, connected to the box by a thin black cable.</p>		

## Annex H: Measuring HF Constructs

### H.1. Trust

Trust measurement still often relies on proxy measures (like automation use or reported acceptance) but this overlooks the role trust plays as an underlying concept (Westin & Hilburn, 2011; NAS, 2022). Trust can drive acceptance, but trust is not the same thing as acceptance. Other factors, like time pressure, can play a role.

Broadly speaking, there are three main classes of trust measures: subjective (i.e., self-report), performance-based, and physiological-based. Trust measurement seems to still rely heavily on self-report. In their review of 127 empirical trust studies, Hoff & Bashir (2015) found that 66% used subjective trust questionnaires, 34% behavioral measures, and 62% both. Review seemed to support this finding.

#### Self-reported trust

Self-reports can be easy, cheap, and familiar to respondents. Moreover, if trust is a purely psychological construct then self-report might be the best way to measure it (Hergeth et al., 2016). Candidate self-report instruments include:

- Wojtan et al's (2020) Trust Of Automated Systems Test (TOAST)
- Merritt's (2015) *Trust in Automation* scale
- Jian, Bizantz & Drury's (2000) *Checklist for Trust Between People and Automation*
- Madsen & Gregor's (2000) *Human Computer Trust* (HCT) scale
- Lee & Moray's (1994) *Trust Scale*

Of these, the TOAST (Wojtan et al, 2020) is the most recent, and claims to overcome some of the wording confounds of the earlier (and still widely used) Jian et al instrument. Figure 3-7 shows the self-report instruments).

Examples of each are provided below.

System Purpose	System Performance	Underlying Processes
<ul style="list-style-type: none"> <li>• I understand what the system should do.</li> <li>• I understand the limitations of the system.</li> <li>• I understand the capabilities of the system.</li> </ul>	<ul style="list-style-type: none"> <li>• The system helps me achieve my goals.</li> <li>• The system performs consistently.</li> <li>• The system performs as it should.</li> <li>• I feel comfortable relying on the information provided by the system.</li> <li>• I think I could do a better job than the system.</li> <li>• I am concerned the system is vulnerable to hacking.</li> </ul>	<ul style="list-style-type: none"> <li>• I understand how the system executes tasks.</li> <li>• I wish I had more control over how the system executes tasks.</li> <li>• I am rarely surprised by how the system behaves.</li> <li>• I wish the system gave me more information.</li> <li>• I know when I should trust the system.</li> </ul>

Figure H.1. Wojtan et al's *Trust Of Automated Systems Test* (TOAST).

The system is deceptive  
 The system behaves in an underhanded manner  
 I am suspicious of the system's intent, action, or output  
 I am wary of the system  
 The system's action will have a harmful or injurious outcome  
 I am confident in the system\*  
 The system provides security\*  
 The system has integrity\*  
 The system is dependable\*  
 The system is reliable\*  
 I can trust the system\*  
 I am familiar with the system

Figure H.2. Jian et al's *Checklist for Trust*.

**Trust scale items**

I believe the [system] is a competent performer.  
 I trust the [system].  
 I have confidence in the advice given by the [system].  
 I can depend on the [system].  
 I can rely on the [system] to behave in consistent ways.  
 I can rely on the [system] to do its best every time I take its advice.

**Liking scale items**

I like working with the [system].  
 I wish the [system] weren't around.  
 I dislike the [system].  
 I'm glad I have the option of using the [system].  
 Overall, I feel positively toward using the [system].

Figure H.3. Merritt's *Trust in Automation scale*.

To what extent can the system's behavior be predicted from moment to moment?  
 To what extent can you count on the system to do its job?  
 What degree of faith do you have that the system will be able to cope with all system "states in the future"?  
 Overall, how much do you trust the system?

Figure H.4. Lee & Moray's *Trust Scale*.

<p><b>1. Perceived reliability</b></p> <p>R1. The system always provides the advice I require to make my decision.</p> <p>R2. The system performs reliably.</p> <p>R3. The system responds the same way under the same conditions at different times.</p> <p>R4. I can rely on the system to function properly.</p> <p>R5. The system analyzes problems consistently.</p> <p><b>2. Perceived technical competence</b></p> <p>T1. The system uses appropriate methods to reach decisions.</p> <p>T2. The system has sound knowledge about this type of problem built into it.</p> <p>T3. The advice the system produces is as good as that which a highly competent person could produce.</p> <p>T4. The system correctly uses the information I enter.</p> <p>T5. The system uses all the knowledge and information available to produce its solution.</p> <p><b>3. Perceived understandability</b></p> <p>U1. I know what will happen the next time I use the system because I understand how it behaves.</p> <p>U2. I understand how the system will assist me with decisions I have to make.</p> <p>U3. Although I may not know exactly how the system works, I know how to use it to make decisions about the problem.</p> <p>U4. It is easy to follow what the system does.</p> <p>U5. I recognize what I should do to get the advice I need from the system the next time I use it.</p> <p><b>4. Faith</b></p> <p>F1. I believe advice from the system even when I don't know for certain that it is correct.</p> <p>F2. When I am uncertain about a decision I believe the system rather than myself.</p> <p>F3. If I am not sure about a decision, I have faith that the system will provide the best solution.</p> <p>F4. When the system gives unusual advice I am confident that the advice is correct.</p> <p>F5. Even if I have no reason to expect the system will be able to solve a difficult problem, I still feel certain that it will.</p> <p><b>5. Personal attachment</b></p> <p>P1. I would feel a sense of loss if the system was unavailable and I could no longer use it.</p> <p>P2. I feel a sense of attachment to using the system.</p> <p>P3. I find the system suitable to my style of decision-making.</p> <p>P4. I like using the system for decision-making.</p> <p>P5. I have a personal preference for making decisions with the system.</p>
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Figure H.5. Madsen & Gregor's *Human Computer Trust* scale.

### Performance measures of trust

Trust has also been assessed via

- Automation use decision— also known as reliance, this refers to the acceptance of automation and the decision to engage automaton, and is often taken as an indication of underlying trust. As noted, this can introduce confounds (Westin & Hilburn, 2011; NAS, 2022).
- Trust “resolution”— refers to how well an operator calibrates trust to automation performance (Lee & See, 2004). Low resolution means that an operator maps large reliability changes onto small trust changes.
- Other proxy measures of trust and acceptance—such as tool use or secondary task performance (ibid).

### Physiological measures of trust

Cognitive processes underlying decision-making (e.g. problem representation, evidence evaluation, value comparison) can show physiological markers (Drnec et al., 2016). EEG, ECG, fMRI, and eye tracking measures have all been applied (Engell, Haxby & Todorov (in Hoff & Bashir, 2015). Visual scan frequency has been shown to vary inversely with reported automation trust (Hergeth et al, 2016; Moray, Inagaki & Ito, 2000). Finally, eye movement data can distinguish high- from low trust groups (Lu & Sarter, 2020) but this might not provide sufficient granularity for HAIKU.

## H.2. Transparency and Explainability

Transparency impacts seem to have been assessed in only a few ways:

- self-reported understanding and understandability
- queries of task-specific knowledge
- inferred via task performance measures, or
- via trust measures.

The use of trust measures of transparency measures seems widespread, and underscores the widely held theoretical link between the two (Dubey et al, 2020). However, it is not clear that the two constructs are always linearly related. As the MAHALO project observed, increased transparency only increases trust for reliable automation. That is, it seems that transparency calibrates trust: increasing trust in reliable AI, but decreasing trust in unreliable AI.

### H.3. Situation Awareness

Situation awareness (SA) measurement techniques can be mainly categorized as: subjective measures; real-time probe or freezing measures; and physiological measures (Feng, 2022). Subjective measures can be inexpensive, easy, and have high face validity, whereas physiological measures can be objective, mobile, continuously recorded, and show better time resolution (Charles et al, 2019; Feng, 2022).

#### Subjective / Realtime probe / Freeze measures

- SAGAT (Situation Awareness Global Assessment Technique)-- a freeze + online probe technique for use in real time simulation
- SPAM—(situation present assessment method)-- thought to correct some of the deficiencies with the SAGAT; SPAM uses real-time probe technique to locate information in the environment, rather than recall specific information. It is considered less intrusive than SAGAT.
- Active I checked about a man chef
- SALSA— (situation awareness of en route air traffic controllers in the context of automation) a similar freeze technique to the SAGAT, but tailored to ATC
- SAVANT— a technique developed by the FAA to study ATC, this combines elements of SAGAT and SPAM
- SART (situation awareness rating technique)- a post – trial subjective rating technique originally developed for assessing pilot SA. Uses 10 dimensions, and participants rate each dimension on a seven point scale.
- SASHA (Situation Awareness for SHAPE)-- EUROCONTROL's seven-point scale to assess SA in ATC automation
- SALIANT situation awareness linked indicators adapted to novel tasks)-- specifically focuses on **team situation awareness**. Involves observations of behavioral processes and indicators related to TSA. Uses a behavioral checklist to assess SA in teams.

#### Physiological measures (Feng et al, 2022; de Winter et al., 2019; van de Merwe et al, 2012)

- Electrocardiographic (ECG) heart rate derived measures
- Electrodermal (EDA) skin conductivity measures
- Eye tracking data (fixation rates, dwell times, scan entropy)
- EEG—composite EEG has shown good split half discrimination of SAGAT scores, and ERP can offer good time resolution

### Conclusions

SA measurement still relies primarily on query and performance measures (e.g. freezing a simulation and using real-time problems to test recall or information location ability). Freeze techniques have been criticized as intrusive. All of the performance measures have a theoretical limitation in that they use proxy measures of what is understood to be an underlying concept. At least one observational technique, SALIANT, is designed especially to measure team situation awareness. Laboratory application of physiological measures has shown great progress especially in recent years.

Physiological measures of course have the potential advantages of increased time resolution and objectivity. It is not clear however that most if any of the physiological measures would be practical for the HAIKU UC developments. Finally, it is worth noting that NAS (2022) does not mention SA measurement as a current. The authors are concerned about the need for new techniques to develop SA (e.g. display design ) but not, apparently, for measuring SA. This suggests that current generation SA measurement tools can be reasonably applied in the HAIT context.