Deliverable N. 2.1

Vision and scenarios

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Abstract:

This deliverable documents the activities and the results achieved within HAIKU Tasks 2.1, "Vision for Human-Centric Intelligent Assistance", and 2.2, "Definition of reference-forward looking scenarios".
Task 2.1 identified a set of high-level **Human-Centred AI principles**, aiming at ensuring that human-centred, value-based considerations will be considered in the AI-based Intelligent Assistants design. Furthermore, it defined **HAIKU's vision**.
Task 2.2 worked on the aviation 2030s landscape for the HAIKU Intelligent Assistants and provided a high-level vision of how aviation may look like in 2050.
The conclusions highlight the main findings and focus on the **key challenges** that aviation is expected to face in the forthcoming years.

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List of Acronyms

Acronym	Definition
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
AR	Augmented Reality
ART	Adaptive Radiation Therapy
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
FPV	Floating PhotoVoltaics
GHG	GreenHouse Gas
HAIKU	Human-AI Teaming Knowledge and Understanding for aviation safety
HF	Human Factors
IA	Intelligent Assistant
IoT	Internet of Things
IFTF	Institute for the Future, Deutsches Forschungszentrum für Künstliche Intelligenz
LBPV	Land-Based PhotoVoltaics
MaaS	Mobility-as-a-Service
ML	Machine Learning
MR	Mixed Reality
PEC	Privacy-Enhancing Computation
PII	Personally Identifiable Information
SASE	Secure Access Service Edge

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SLAM	Simultaneous Localization and Mapping
SaaS	Software-as-a-Service
SME	Subject-Matter Expert
SVO	Simplified Vehicle Operations
UAM	Urban Air Mobility
UATM	Urban Air Traffic Management
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
XR	eXtended Reality

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Executive Summary

Deliverable 2.1 aims at defining the key AI principles and vision for HAIKU (Task 2.1), and a set of landscapes to be used as a reference in the design of the intelligent assistants for each Use Case (Task 2.2).

Task 2.1 identified a set of high-level **Human-Centred AI principles**, aiming at ensuring that human-centred, value-based considerations will be considered in the AI-based Intelligent Assistants design. Furthermore, it defined **HAIKU's vision**.
Task 2.2 worked on the aviation 2030s landscape for the HAIKU Intelligent Assistants and provided a high-level vision of how aviation may look like in 2050.

Section 1 (Principles and Vision) details the process that led to the definition of HAIKU Human-Centred AI guiding principles and vision. The principles are the result of a state-of-the-art review, end-user interviews and a co-design workshop with members of the consortium.

The principles are:

- Human-AI Teaming: For HAIKU, Human-AI Teaming is achieved when the intelligent assistant is dynamic, capable of adapting to users' mental states and specific needs, and actually delivers a clear benefit to the end-users.
- Human-Centred AI: For HAIKU, Human-Centred AI is achieved when human-machine interactions are designed starting from stakeholders' needs, human abilities and limitations, ensuring a compatible fit with technological possibilities. Stakeholders may be primary users (e.g. pilots and controllers) but also other people directly interacting with AI (e.g. system designers, trainers, supervisors and line managers).
- Trustworthiness: For HAIKU, trustworthiness is achieved when safety, security, robustness and transparency are ensured, clear indications of system limitations and information on potential side effects are provided, and responsibilities are well defined.
- Societal Benefits: The success of HAIKU's Intelligent Assistants is strongly connected with a clear understanding and consideration of possible societal concerns and acceptance issues - since the early design stages - as well as with the definition of desired societal benefits.

On the basis of these principles, the following vision statement was drafted: *Developing Human-Centred AI-based Intelligent Assistants for safe, secure, trustworthy and effective Human-AI partnerships in aviation systems.*

Section 2 (Scenarios) describes the creation of segment-specific landscapes for the years 2030 and 2050, which are meant to be used as a reference for designing the assistants. The landscapes were built through desk research, subject-matter experts interviews and a co-design workshop. Each landscape describes the general technological, operational and societal trends and their potential impact on aviation in the coming decades, for each HAIKU target segment: *Airport, Air Traffic Management, Cockpit, Urban Air Mobility.*

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The **Conclusions** part is a reflection on the results captured in the previous sections. Starting from the envisaged significant increase in operational complexity, it identifies four main dominant features characterising the evolution of the coming years - "*Increased traffic*", "*Heterogeneous traffic*", "*Sustainability*", and "*Integrated multi-modal transport systems*" - and depicts the **main challenges** the aviation industry is expected to face in the near (2030) and more distant (2050) future. Furthermore, it acknowledges the potential of AI to offer effective solutions to the above-mentioned challenges. It also highlights how the introduction of AI in aviation operations opens the door for other specific challenges that need to be addressed to allow successful AI deployment in this safety-critical industry.

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Introduction

The main purpose of this document is to present the activities and results achieved within HAIKU Tasks 2.1 “Vision for Human-Centric Intelligent Assistance” (Section 1) and 2.2 “Definition of reference forward-looking scenarios” (Section 2).

Section 1 defines **HAIKU’s own Vision** and **set of guiding principles**. The ultimate goal of this part of the project is to embed human-centred, value-based considerations into the design of each AI-based Intelligent Assistant (IA) since the early design stages.

Section 2 looks far ahead, showing the **HAIKU vision for the future of aviation**. For each aviation segment (Airports, Air Traffic Management ATM, UATM, and Cockpit), it presents both the 2030 and 2050 landscapes. The 2030 landscapes are further detailed for each of the HAIKU use cases.

The vision, set of guiding principles and future landscapes are intended to be key inputs for the whole HAIKU Consortium, a necessary **foundation** to ensure **consistency** in all project outcomes.

The conclusions part is a reflection on the results captured in the previous sections. Starting from the envisaged significant increase in operational complexity, it identifies the **main challenges** the aviation industry is expected to face in the near (2030) and more distant (2050) future.

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SECTION 1: Principles and Vision

1. Scope and structure of the section

The main purpose of this section is to present the activities and results achieved within Task 2.1 "Vision for Human-Centric Intelligent Assistance".

Task 2.1 aims at reviewing existing vision documents and defining HAIKU's own Vision and set of guiding principles. It starts from the "Ethics Guidance for trustworthy AI" (European Commission, 2019), following the suggestion to adapt those guidelines to the specific context and AI application. Its ultimate goal is to embed human-centred, value-based considerations into the next step of AI-based Intelligent Assistants, informing design choices with social and ethical aspects since the early design stages. Indeed, this is expected to be a key high-level input for the whole project.

The section is structured into 5 chapters:

- Chapter 1 is the current one;
- Chapter 2 describes the ways of working and the applied 3-steps approach. Each step is further explained in the following chapters;
- Chapter 3 presents the State-of-the-Art review (step 1) and its main findings;
- Chapter 4 shows the results of a preliminary internal survey (step 2) where the HAIKU Consortium members' views on key principles were collected;
- Chapter 5 shows the results of step 3, a workshop where the HAIKU guiding principles and the project vision were co-designed.

2. Ways of working

The definition of HAIKU's own vision and its set of Human-Centred AI guiding principles requires an in-depth understanding of the point of view of worldwide key players on the Human-centric AI subject. Discussion and coordination within the Consortium are also fundamental, to ensure the applicability and suitability of the high-level principles to both the whole aviation context and the more specific HAIKU use cases.

The work on this task is driven by three key questions:

1. What AI principles are currently driving the work of worldwide key players?
2. What principles are key and consistent with the foundational values of aviation?
3. What foundational principles should HAIKU adopt to design and deliver better Human-Centred Solutions?

To answer these questions, a 3-step approach is applied:

1. Step 1 - State-of-the-Art review: desk review of existing literature and vision documents regarding the principles that are guiding the design and development of Human-Centred AI systems, together with a set of end-user interviews;

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2. Step 2 - Poll: a survey to have a preliminary understanding of what the HAIKU Consortium thinks and thus to identify the most relevant principles for the aviation domain and the HAIKU project;
3. Step 3 - Workshop: a co-design activity to select and define the HAIKU principles and draft the project vision.

All three steps, and related results, are detailed in the remaining part of this section.

3. Step 1: State-of-the-Art review

This first step aims at providing an overview of worldwide key players' points of view on the Human-centric AI subject, with a view to providing an answer to question number 1: ***Which AI principles are currently driving the work of worldwide key-players?***

3.1. Review scope

The review was performed on a variety of sectors and domains, including aviation, resulting in a selection of **36 relevant players** (including 3 players who are disclosing partial information only). A few more relevant aviation key players have been considered but excluded from the review because they did not disclose any information.

The information, presented in Table 1, is extracted from the companies' websites and/or relevant documents available on the web.

Table 1: Review Scope - List of players considered

Domain	Category	Players
Non-aviation specific	Tech Companies	1) IBM 2) Microsoft 3) Google 4) Adobe 5) Siemens 6) META 7) Engineering (*)
	Consulting Companies	8) Accenture 9) Deloitte 10) PWC 11) KPMG 12) Boston Consulting Group
	Research Centres	13) IFTF 14) Future of Life 15) Harvard

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		16) Beijing Academy of AI 17) Partnership On AI
	Research Projects	18) TAILOR
	Other	19) The New York Times
	Institutions	20) European Commission 21) OECD 22) AI Industry Alliance 23) New Generation AI Governance Expert Committee 24) Council for Social Principles of Human-Centric AI 25) Australian Department of Industry, Science and Resources
Aviation specific	Manufacturers	26) Thales 27) Leonardo 28) Lockheed Martin 29) Northrop Grumman 30) Rolls Royce
	Air Traffic Management	31) EUROCONTROL 32) FAA (*)
	Airborne	33) Airbus 34) Embraer
	Drones	35) Percepto (*)

(*) Player disclosing partial information

Moreover, four end-user interviews were performed to collect the operational point of view and enrich the research: two air-traffic controllers (tower) and two pilots (captains). The interview grid is available in Annex A.

3.2. Results

The review resulted in a total of **16 AI principles** (see Annex B for more details on each principle):

1. Accountability

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2. Explainability
3. Fairness
4. Human Values
5. Human-AI Partnership
6. Human-centric AI
7. Inclusiveness
8. Lawfulness
9. Multidisciplinary teams
10. Privacy
11. Reliability
12. Robustness
13. Safety
14. Security
15. Social Benefit
16. Transparency

Figure 1 shows the overall landscape, expressing the number of players (in percentage) referring to the 16 principles.

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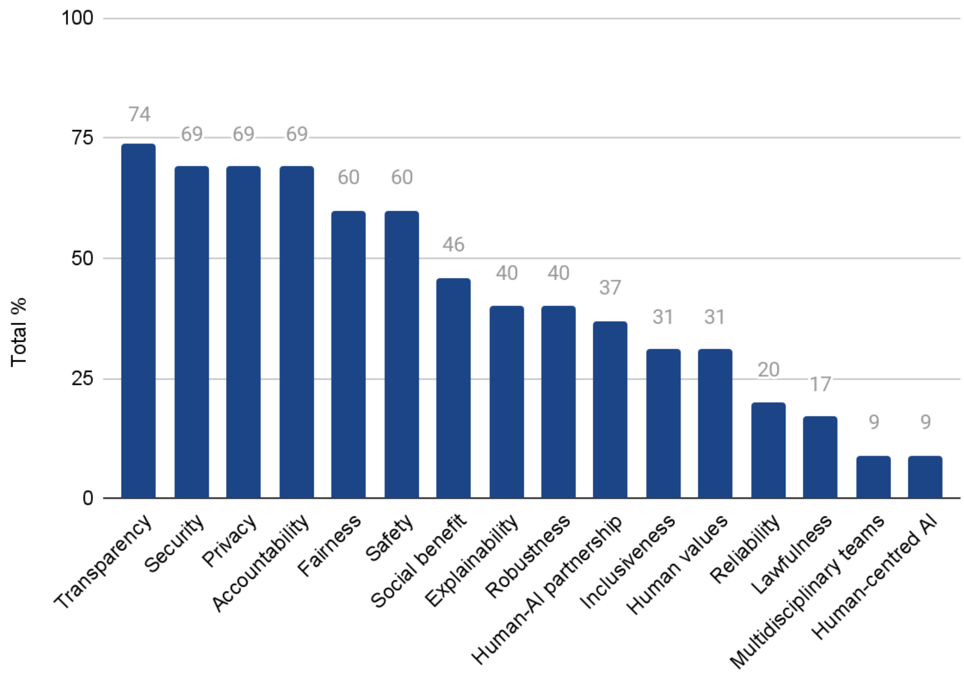

Figure 1: AI principles - Overall landscape (all sectors)

The most mentioned principle is **transparency** (74%), followed by **security**, **privacy**, **accountability** and **safety**. It is also observed that the principles of **Human-AI partnership** and **Human-Centred AI** are rarely mentioned, considering that the majority of mentions come from end-users interviews. Overall, it can be argued that, in the AI community at large, there seems to be **no alignment** and **agreement** on the most relevant principles for designing Human-Centred AI solutions.

Figures 2 to 5 show the distribution at the sectoral level (non-aviation).

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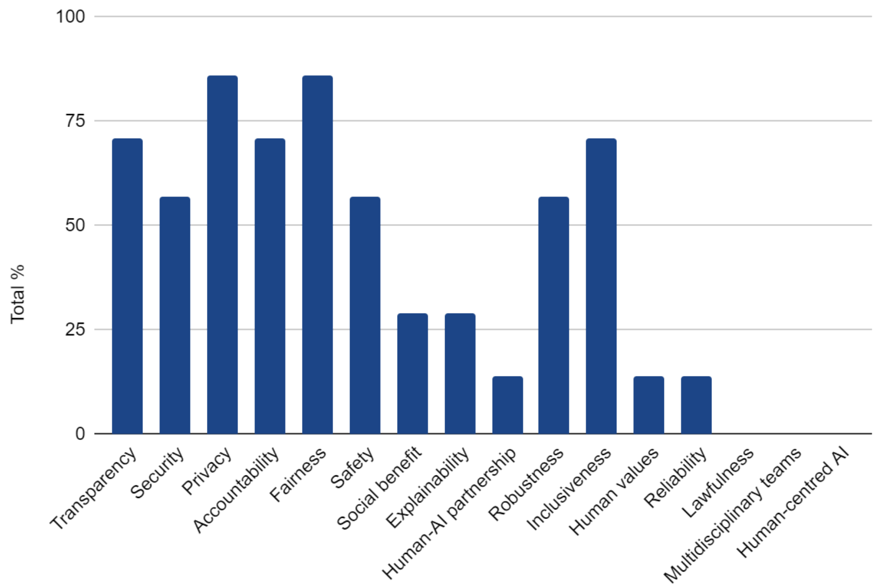

Figure 2: AI principles - Tech companies
(number of actors - in percentage - referring to the principles)

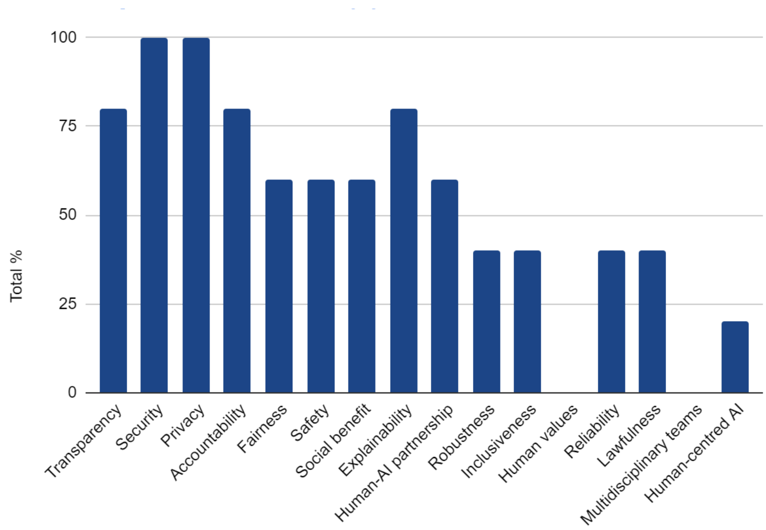

Figure 3: AI principles - Consultancy companies
(number of actors - in percentage - referring to the principles)

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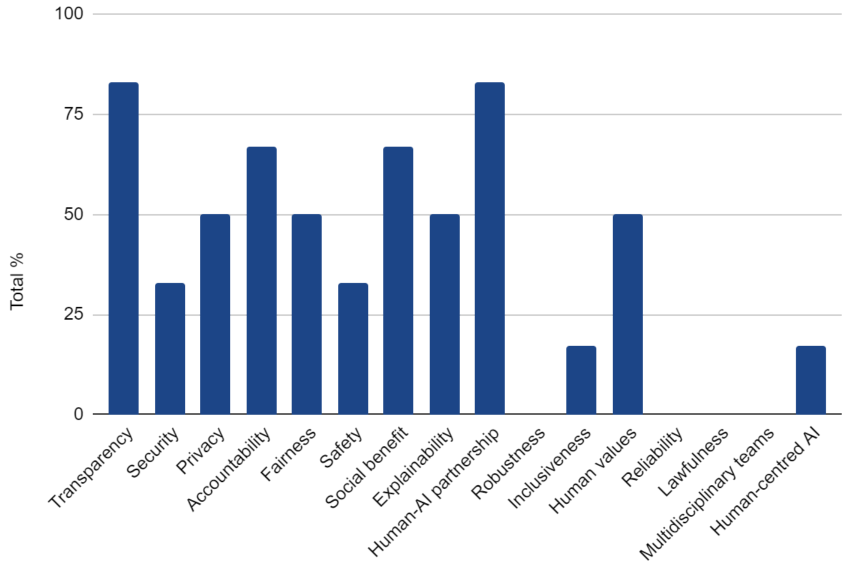

Figure 4: AI principles - Research centres
(number of actors - in percentage - referring to the principles)

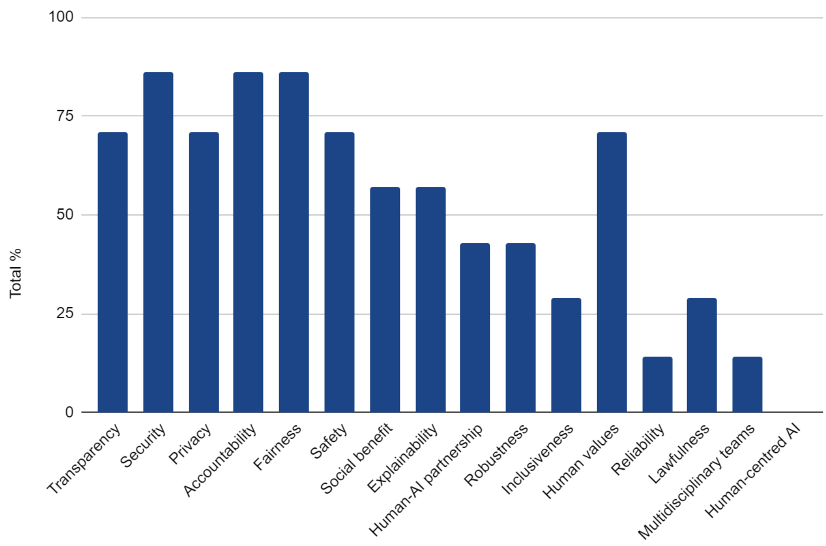

Figure 5: AI principles - Institutions
(number of actors - in percentage - referring to the principles)

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These charts show that:

- The different sectors are giving different relevance to the principles. More specifically:
    - Tech companies give more relevance to robustness and inclusiveness (>50%);
    - Consulting companies give more relevance to explainability (>75%)
    - For Research Centres, no evidence of consideration regarding Robustness, Reliability and Lawfulness was found.
    - Consulting companies, Institutions and Research centres seem to attribute particular relevance to societal benefits, differently from Tech companies.
- Focusing on Human aspects, it can be noted that:
    - Tech companies tend to not mention the Human-centred AI principle, differently from Research centres and Consulting companies. However, this may not mean that Tech companies are not considering Human-centred aspects when designing AI solutions, and it can probably be a pure matter of semantics. Indeed, tech companies seem to give relevance to other principles, such as Transparency and Inclusiveness, which can be somehow attributed to Human-centred AI;
    - Institutions attribute high relevance to Human values but do not refer at all to Human-centred AI.
- A key result emerges when comparing Tech companies and Research centres: Human-AI partnership seems to be a key principle for the Research centres (>75%) while it seems not to be relevant for Tech companies. Robustness emerges as a key principle for Tech companies (>50%) while it is not even mentioned by Research centres. This difference is consistent with one of the bottlenecks identified by OPTICS2 (OPTICS2, 2021), i.e. the low level of industrial uptake of AI research outcomes.
- Outside the aviation domain, it seems that there is not a high level of agreement on the Human-Centred AI principle, especially if comparing the point of view of Tech companies and Research centres.

Figure 6 shows the results related to the aviation domain, including also the findings captured through the four end-user interviews.

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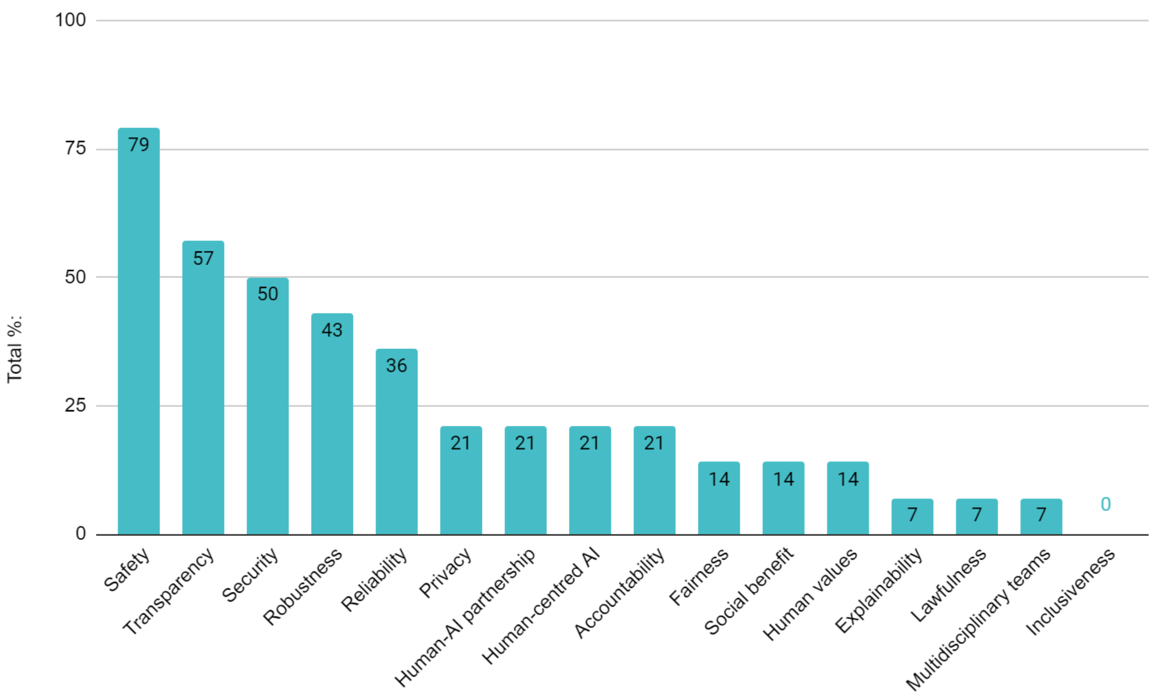

Figure 6: AI principles - Aviation industry
(number of actors - in percentage - referring to the principles)

This chart shows that:

- The aviation-specific results are quite misaligned compared to the general landscape;
- There is not a very high level of agreement within the aviation community, except for **safety**, **transparency**, and **security** which are considered fundamental principles by the majority of the actors considered. In particular, end-users consider safety to be the ultimate and most relevant goal for aviation;
- The results seem to indicate that the aviation industry does not pay much attention to the principle of inclusiveness. Also, the principle of explainability has received relatively low attention. However, explainability is a crucial topic in aviation, and all four interviewed end-users emphasised the need for systems that are understandable and explainable, keeping the human in the loop to ensure operators comprehend the reasoning behind suggested actions or machine decisions. It is worth mentioning that there are overlapping aspects between these concepts and other concepts cited, such as Transparency, Human-AI partnership and Human-centred AI (for Explainability) and Fairness (for Inclusiveness);
- The industrial players also seem to attribute very low relevance to Human-Centred AI, Human-AI partnership and societal benefits. However, the

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end-user perspective sees the "Human-centred design" principle as a key driver to developing successful systems, highlighting the relevance of involving operators since the early stages of design. Furthermore, the need for simple and user-friendly systems and HMIs were highlighted and defined as the key to ensuring a smooth and effective collaboration between humans and machines.

On the basis of this review, the HAIKU Consortium concluded that:

- Both globally and at the specific aviation level, there is **no alignment and agreement** on either **key principles** or the **related definitions**;
- The **concept of human-centric** AI is still nascent and thus, is not yet mature and consolidated.

4. Step 2: HAIKU survey

The second step towards the identification of the HAIKU Human-Centred AI principles was an internal survey to collect all HAIKU Consortium members' views. Figure 7 shows the results of the survey.

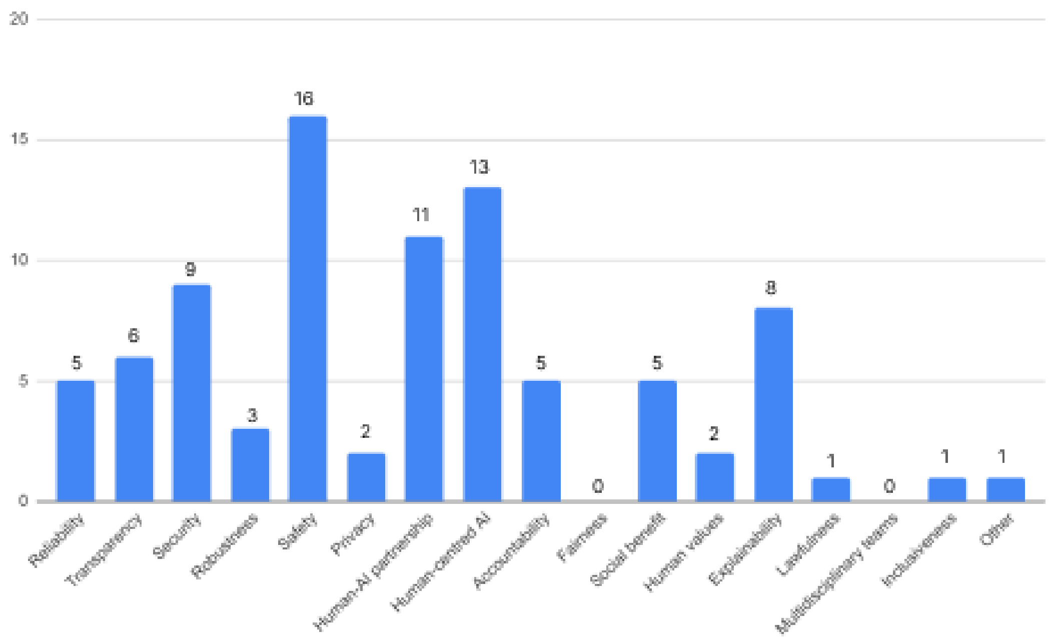

Figure 7: Number of votes for each principle in the HAIKU consortium

The survey resulted in the identification of three key principles with a high level of agreement inside the consortium ...

1. **Safety**

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2. **Human-Centred AI**
3. **Human-AI partnership**

... Followed by other 7 principles which are considered relevant by a good number of consortium members:

4. Security
5. Explainability
6. Transparency
7. Reliability
8. Accountability
9. Societal benefits
10. Robustness

5. Step 3: Co-design workshop

Starting from the preliminary Step 1 and 2 results, HAIKU carried out a co-design workshop to define the **HAIKU guiding principles** and, on the basis of them, draft the **project vision**. The principles will be taken as a foundation for the whole project, guiding the development of all HAIKU Intelligent Assistants from the early stages of design. The project vision will serve as a basis for the project activities, discussions and dissemination efforts.

The workshop took place in Rome on November 3rd, 2022, and involved six consortium members from DBL, ECTL and LiU. It was structured in three phases:

- Phase 1: Prioritisation and selection of the key principles that HAIKU wants to adopt to address aspects typically left aside in other AI projects;
- Phase 2: Definition of the HAIKU principles, focusing on the HAIKU use cases and leveraging on the **Lotus Blossom methodology** (The Innovation Tools Handbook, 2016);
- Phase 3: Draft of HAIKU's vision.

5.1. Phase 1: selected key principles

The activity started with a brainstorming phase based on the list of principles built in Step 1 and ranked in Step 2. The participants agreed almost immediately that the principles needed more detailing and clustering in order to be aligned at the same conceptual level. More specifically:

- **Safety** emerged to be more than a principle but an absolute cornerstone, the ultimate goal for aviation and, thus, for HAIKU. Therefore, it was not included in the principles;
- **Lawfulness** and **Human values** emerged to be more than principles but overarching high-level ethical aspects to be aligned with. As for safety, these were not included in the principles;

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- **Human-centred AI**, **Transparency** and **Explainability** were considered to be part of the same phenomenon, and they were merged into a single category;

- The idea of ***trustworthiness*** was also introduced and included in the same cluster with **robustness**, **accountability** and **reliability**.

The brainstorming and prioritisation activities resulted in the selection of 4 key principles:

- Human-AI Partnership
- Human-Centred AI (which includes Explainability and Transparency)
- Trustworthiness (which includes Accountability, Robustness and Reliability)
- Societal benefits

5.2. Phase 2: key principles definition

Each key principle selected in Phase 1 was discussed and defined in Phase 2. To this end, the Lotus Blossom methodology was applied and the HAIKU Use Cases were used as the main reference in order to ensure a comprehensive definition.

Each principle is further detailed in the following tables (2, 3, 4 and 5). The tables contain a generic definition of the principle within the context of HAIKU and two examples of application to the HAIKU use cases. The full application of the four principles to HAIKU use cases is available in Annex C.

Human-AI Teaming

Table 2: Human-AI Teaming principle: definition and examples.

For HAIKU, Human-AI Teaming is achieved when the intelligent assistant is **dynamic, capable of adapting** to users' mental states and specific needs, and actually delivers a clear benefit to the end-users.	
Ad-hoc interaction modalities should be designed for each use case in order to ensure **shared situational awareness,** shared situational awareness and an **effective learning loop** (human-AI and vice versa), as well as a **smooth partnership** between AI, its users and other relevant actors potentially impacted. **Personalised interactions** could be also considered for some of HAIKU's AI applications.	
Use Case #1: Flight deck startle response	
Directing Situational Awareness (SA)	• If a startle event is triggered, the intelligent assistant has to recognise it, partner up with the pilots and direct their situational awareness towards appropriate actions. The IA should be able to adapt and switch

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	between different types of partnerships that consider either the case in which only one pilot is under startle effect, or both pilots are at the same time.
Dynamic Guidance	• The control is expected to be continuously and smoothly shifted from the pilot to the AI and vice versa. In case of a startling event, the intelligent assistant should take over and guide the pilot in responding to the problem in the most appropriate and fast way. The control should be shifted back to the pilot once sufficient awareness is reached.

Human-Centred AI

Table 3: Human-Centred AI principle: definition and examples.

For HAIKU, Human-Centred AI is achieved when **human-machine interactions** are designed starting from **stakeholders' needs**, human **abilities** and **limitations**, ensuring a compatible fit with technological possibilities. Stakeholders may be primary users (e.g. pilots and controllers) but also other people directly interacting with AI (e.g. system designers, trainers, supervisors and line managers).	
Ad-hoc explainability strategies need to be designed for each AI application, supporting **workload managemen**t and ensuring **adaptability to users' mental** states and models and overall **transparency**.	
Use Case #2: Flightdeck route planning and re-planning	
Explanations available in the most adequate format	• Explanations must be available for users at the depth level they need to reach a good understanding of the situation and/or the reasoning the AI presents. The user also must be able to understand if the AI performance is degraded and is thus impairing decision-making instead of supporting it. • The need for explanations to ensure transparency to other stakeholders during the assistant lifecycle shall also be mapped and taken into account during the development. • The intelligent assistant should be also designed to optimise workload. This means that the system

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	should only intervene when appropriate, and should never be perceived as an annoyance by either pilots and ATCOs. For example, the assistant should not constantly provide updates and suggestions, as well as it should take the whole picture into account to avoid generating side effects.
Use Case #6: Monitoring and prevention of COVID-19 spreading in airports	
Tailor-made experience	• The intelligent assistant should offer a tailor-made experience to passengers. It is expected to start from data collected and predicted at a system level (e.g. the number of people currently at the airport, flight schedules, etc.) which should be crossed with individual needs, characteristics and preferences in order to suggest tailor-made solutions. • The passengers should be able to understand how their individual needs, characteristics and preferences connect to the intelligent assistant suggestions.

Trustworthiness

Table 4: Trustworthiness principle: definition and examples.

For HAIKU, trustworthiness is achieved when **safety**, **security**, **robustness** and **transparency** are ensured, **clear indications of system limitations** and information on potential side effects are provided, and **responsibilities** are well defined.	
Training to provide the right level of knowledge on how the intelligent assistant works is also key to achieving trustworthiness and **addressing any users' acceptance resistance**. Furthermore, intelligent assistants have to work collaboratively with the user, being **aligned with users' goals**, priorities and values.	
Use Case #4: Digital Towers	
Ability to manage exceptions with the support of the system	• The intelligent assistant should be designed to handle regular operations, but it is also expected to support and suggest solutions in case of exceptional events. This will increase trustworthiness.

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Use Case #5: Airport Safety Watch	
Bias prevention	• Safety data captures only specific events, not the normal behaviour and operations of the system. For this reason, training an intelligent assistant on a safety data set may introduce undesired biases. These effects must be understood and mitigated. Identified limitations of the assistant derived from biases must be clearly stated to stakeholders. Corrective mechanisms and clear governance should be in place.

Societal Benefits

Table 5: Societal Benefits principle: definition and examples.

The success of HAIKU's Intelligent Assistants is strongly connected with a **clear understanding and consideration** of possible **societal concerns** and **acceptance issues** - since the early design stages - as well as with the definition of **desired societal benefits**. Apart from self-evident aspects like **safety** and **security**, HAIKU is addressing **cultural aspects** (e.g. the preservation and enhancement of safety culture across all stakeholders), the **human role** in future AI systems, and **sustainability**.	
Use Case #3: Urban Air Mobility	
Safety enhancement	• The introduction of the IA should be seen as an introduction of an additional safety layer. Given a safety level that must be ensured, the assistant will enable the feasibility of complex operations that will address the growing demands of society.
Service equality	• The intelligent assistant should enable effective management of intense UAM traffic, ensuring equal service to all airspace users and, in case of emergencies, adequate prioritisation.

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5.3. Phase 3: HAIKU vision

On the basis of the principles discussed and defined in the previous step, the HAIKU vision was drafted:

> Developing **Human-Centred AI-based Intelligent Assistants** for **safe**, **secure**, **trustworthy** and **effective Human-AI partnerships** in **aviation** systems.

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SECTION 2: Scenarios

6. Scope and structure of section

The main purpose of this section is to present the activities and results achieved within Task 2.2 "Definition of reference forward-looking scenarios".

Task 2.2 aims to design the aviation 2030s scenarios (called landscape, from now on) for the HAIKU Intelligent Assistants, as well as to provide a high-level vision of how aviation may look like in 2050.

The section is structured into 3 chapters:

- Chapter 1 is the current one;
- Chapter 2 describes the methodology chosen to develop the 2030 and 2050 landscapes;
- Chapter 3 presents the 2030 and 2050 landscapes for each aviation segment (Airports, Air Traffic Management (ATM), Urban Air Traffic Management (UATM), and Cockpit). The 2030 landscapes are also further detailed for each of the HAIKU use cases.

7. Methodology

The design of the 2030 landscapes required an in-depth knowledge of the future trends and views concerning technology, operations, society and workforce. To collect all relevant information, a 3-step methodology was applied:

- Step 1: desk review to build a preliminary overview of the future of aviation by looking at future technology trends and business models for aviation. Many documents were analysed, including current reports from key tech and consulting companies (e.g. Gartner, Accenture, IBM, Microsoft, Meta, etc.) as well as relevant documents developed by aviation key players (e.g. Airbus, Thales, etc.), European bodies (e.g. EUROCONTROL, ACARE, SESAR JU, EASA, etc.) and past and on-going research projects (e.g. Skill-UP and Mobility4EU). The full list of documents is available in the bibliography;

- Step 2: a set of semi-structured interviews to deep dive into key aspects, mostly related to operations and workforce (the interview grid is available in Annex D). Eleven aviation Subject-Matter Experts (SME) with managerial or executive roles were interviewed:
  - Four experts from the ATM segment (EUROCONTROL, SkyGuide) with in-depth expertise in operations, HF, safety and digital transformation, one of whom has also significant expertise in UATM;
  - Three experts from the UATM segment (EMBRT, EveAirMobility, DroneRadar) who brought a broad and deep overview on this area by covering operational, HF, technological and regulatory aspects;

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- Three experts from the Cockpit segment (European Cockpit Association, EMBRT) with their significant expertise in operations, product development and technical aspects;
- One expert from Schiphol Airport with his in-depth expertise in aviation safety.

- Step 3: a co-design workshop within the Consortium to further detail the general landscape for each of the HAIKU use cases and define the related benefits, challenges, opportunities and risks. The workshop took place on February 1st 2023 in Brussels (ECTL premises) and involved 21 participants. It was structured into 2 main activities: activity 1 dedicated to drafting specific landscapes for each use case starting from the more general landscape, and activity 2 aimed at developing a SWOT analysis on the newly created landscapes, thus identifying the main benefits, challenges, opportunities, and risks associated with each use case. More details of the workshop's activities are available in Annex E.

Differently, the 2050 landscapes are the result of a dedicated co-design workshop which took place in Lisbon on September 7th, 2022 and involved all HAIKU partners (40 people), followed by a variety of internal offline iterations. Therefore, the 2050 landscapes reflect the HAIKU vision of how aviation may be in 30 years.

8. Landscapes

The landscapes aim to present a high-level view of how aviation is expected to change in the 2030s and 2050, covering all its segments: ATM, Airport, Cockpit and UATM. The 2030 landscapes are also further detailed for each of the HAIKU use cases.

The full information used to build the landscapes is presented in Annex F.

8.1. Air Traffic Management (ATM)

8.1.1. ATM 2030 Landscape

Looking ahead to 2030, ATM operations are not expected to be much different compared to today as the innovation cycle to introduce new approaches and technologies usually takes 8 to 15 years. Many of the innovations currently under experimentation are expected to come into force during the 2030s, including some U-Space and UATM technologies and operational concepts potentially transferable to the ATM segment.

Digitalisation is a trend expected to have a significant impact on ATM (SESAR JU, 2020). By 2030, the whole infrastructure is expected to be more and more digitised (consistent investments have already been allocated worldwide). The more advanced ANSPs will probably have digitalised CNS (Communications, Navigation and Surveillance) systems. The whole ATM infrastructure will probably be improved by creating a form of digital layers on top of the current analogue one. A shift towards cloud-based services is also expected. Thanks to this digitised infrastructure, more real-time information will be made available to passengers but also, and most importantly, ATM will be able to manage the envisaged higher airspace complexity.

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The expectation is to have a **significant increase in operations** over the next few years, reaching around **50.000 flights on a peak day in Europe** (approximately +50% compared with the 2019 traffic demand) (EUROCONTROL, 2022). Airbus expects demand to be dominated by single-aisle aircraft (~80%, mainly short and medium-haul) compared to widebody aircraft (~20%, mainly long-haul(Airbus, 2022). Regional airports, often in or near cities, will have difficulty expanding, so efficient traffic management will be necessary to meet growing demand. **UATM operations** will also be started by 2030, which will rapidly increase during the 30s. It is acknowledged that with the current system and infrastructure, it may be very difficult to maintain the current level of safety in this scenario unless technologies and processes are re-designed. For instance, to face the UATM demand, **segregated airspace** will be used at the beginning with a view to quickly shift towards an **integrated traffic management system** leveraging new advanced digital technologies and AI systems for highly heterogeneous traffic management.

As we move into 2030, we can also expect a significant increase in the number of **digital Towers (TWR)**. **More remote TWR (rTWR)** will be operating and some **multiple rTWR** will be put into operation (SKYbrary, 2020; SESAR JU, 2020), for instance for small airports with very low traffic. However, from a Human Factors point of view, the multiple rTWR concept creates new cognitive challenges for the human that need to be carefully assessed and addressed. A few **AI-based Intelligent Assistants** will also be operating in the OPS rooms to support ATCOs in managing the envisaged increased complexity, sustaining traffic demand while ensuring a **low carbon footprint**.

This landscape may have an **impact on the human role**, requiring new skills, competencies and strategies.

HAIKU Use Case #4: Digital Tower

Use Case #4 aims to design and deliver an **AI-based Intelligent Assistant for tower (and remote tower) controllers to assist in routine and repetitive tasks for aircraft on approach**, targeting to generate the following high-level benefits:

- **Operational efficiency**: this assistant is expected to suggest to ATCOs the most effective sequence of aircraft, maximising the number of planes using the runway;
- **Cost reduction**: by optimising the usage of the runway, this assistant is expected to have an indirect positive impact on costs for the whole aviation ecosystem (fuel consumption, delays, etc.);
- **Environmental safeguard**: by suggesting the most effective sequence of aircraft, this assistant will prevent avoidable waste of fuel. Furthermore, the sustainability principle may even be embedded into the design of this assistant, allowing for consideration of the environmental impact of each aircraft directly in the calculation of sequence;
- **Reduction in ATCOs stress**: this assistant is also expected to have a positive impact on operator well-being. Indeed, while suggesting the most effective sequence of aircraft, the stress due to constant decision-making will be reduced and the risk of errors will be minimised;
- **Safety enhancement**: this assistant is meant to be an additional safety layer.

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The Use Case #4 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 6.

Table 6: Use Case 4: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		USE CASE SPECIFICATIONS	IMPLICATIONS FOR THE IA DESIGN
OPERATIONAL	Increase in the number of Digital, Remote and Multiple Remote Towers	Human-AI teaming	• The traffic will be managed by the ATCO together with the IA. • The IA will suggest to the ATCO the most effective sequence of aircraft. • The ATCO will approve the suggested sequence or inject some changes and instruct the aircraft accordingly. ○ *Open point to be addressed: will the system automatically communicate the instructions to aircraft?* • In the case of Multiple Remote Towers, multiple airports will be managed as a single one. • Looking further, the IA may gradually take on the majority of standard and repetitive tasks, shifting the ATCO role to supervision and emergency management. This upgrade would require robust contingency procedures.
	Reduction of CO2 emissions	Emissions tuning	• The IA may also consider the aircraft power information in the definition of the suggested sequence of aircraft. This would allow not only to maximise the usage of the runway but also to minimise the emissions. *The feasibility of this feature will be further assessed.*
	ATM & UATM integration	Multi-actors coordination for emergency situations	• In case of a UATM emergency, the ATCO is expected to be digitally contacted by the UATM Coordinator who will propose an emergency route. ATCO is expected to digitally approve or provide alternative instructions. • The IA is expected to support the ATCO in these kinds of situations, ensuring a fast response. Potentially, in these

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			cases, the IA may take on the traffic management task to allow the ATCO to focus on the emergency request. ○ *Open point to be addressed: how to ensure a safe and effective response in case of a multiple remote tower ATCO dealing with one or more UATM coordination requests for emergency purposes?*
TECHNOLOGICAL	Cybersecurity	Cybersecurity by design	• Appropriate level of security must be defined from the early design stage. ○ *Open point to be addressed: how the IA will access data if everything is highly secured?*
	Digitalisation	Meteorological data feed	• The IA is expected to be digitally fed by meteorological data (wind, visibility, humidity, precipitations).
		Capturing airline behaviours	• The IA envisages analysing, identifying and categorising airline behaviours. Indeed, these tend to vary depending on the airline company (e.g. some airlines immediately react upon receiving authorizations, while others take some more seconds before acting). The IA will learn these behaviours by constantly studying and analysing aircraft data and reusing this information to provide more accurate and effective sequence suggestions to ATCOs.
SOCIETAL	Impact on the human role	Human on-the-loop	• ATCOs are expected to have a more active role at the initial stages where they will be able to accept, change or reject the suggestions provided by the IA. • In case of emergency situations, the IA may take over the traffic management role to allow the ATCO to focus on the emergency. • Looking further, the IA may gradually take on the majority of standard and repetitive tasks, shifting the ATCO role to supervision and emergency management. • In all cases, the IA will ensure that the

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			ATCO will be always kept on-the-loop ○ *Open point to be addressed: responsibility - Who is responsible?*
		Fatigue and fitness monitoring	• The IA may assess the fatigue level and fitness status of the ATCO. • The IA may adapt according to the ATCO mental state. • The IA may provide individual alerts and recommendations. • Privacy would be ensured. • *The feasibility and acceptability of this feature will be further assessed.*
	Societal acceptance	Risk of job loss	• The IA assistant may find operators' resistance due to the perceived risk of job loss. This is a key factor that needs to be taken into consideration in the early design stages.
		The Multiple Remote Tower concept may not be easily acceptable by society. This is a key factor that needs to be taken into consideration in the early design stages.	-

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8.1.2. ATM 2050 Landscape

Figure 8 summarises the HAIKU consortium vision of the Air Traffic Management (ATM) segment in 2050.

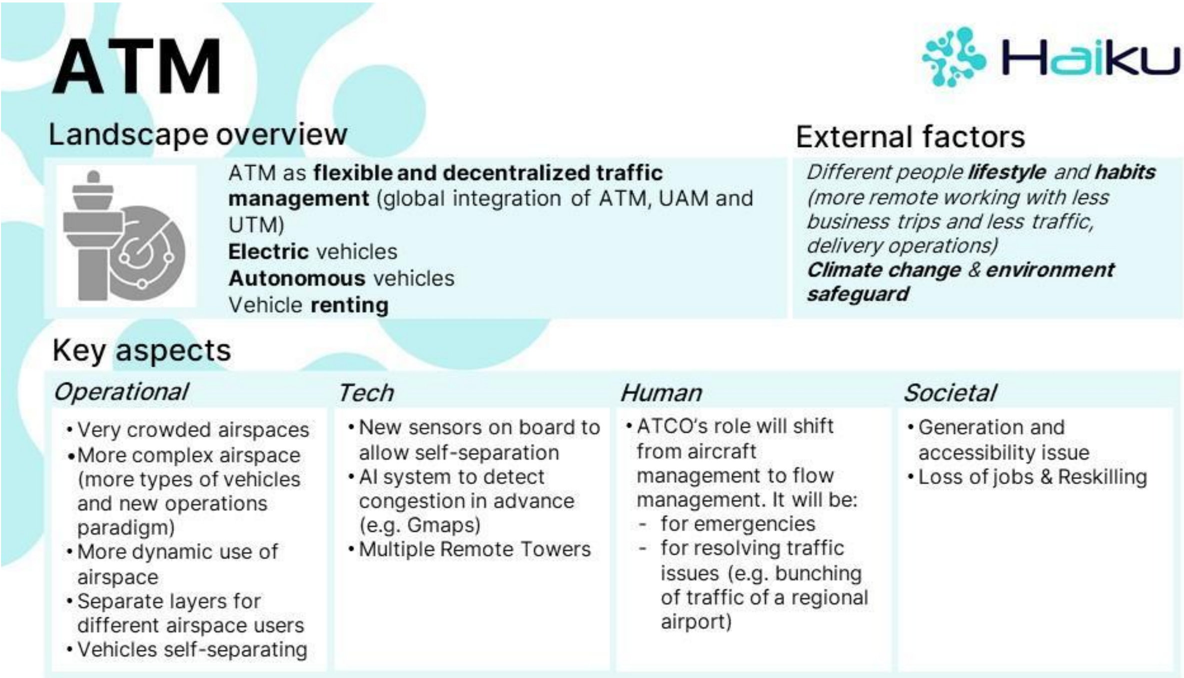

Figure 8: An overview of the ATM segment landscape in 2050.

Looking ahead to 2050, the envisaged **changes in people's lifestyles and habits** are expected to have a significant impact on ATM. First of all, the number of business trips is expected to significantly drop in the next 25 years as people may be mostly working remotely, leading also to a drop in road traffic. In general, people will probably use public transportation to move from one place to another rather than using owned vehicles, envisaging a fully integrated transport system for all the major cities in the world. Despite the decrease in business trips, the airspace is expected to be much more **crowded** compared to 2030 due to an increase in leisure trips and, primarily, to an **intense usage of UAM delivery services**. Furthermore, **more severe and extreme weather events** may cause more disruptions.

The increase in airspace complexity is not only linked to traffic growth and environmental aspects, but also to the co-presence of **many more types of vehicles and air space users**. With the introduction of UATM, a **new operational paradigm** needs to be developed.

Global integration of ATM, UTM and UAM is envisaged by 2050, transforming the ATM world into a **more flexible and decentralised traffic management system**. Separate layers for different airspace users are expected, but, as previously said, with an integrated management system. A significant number of **Multiple Remote Towers** should be operating by 2050.

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Vehicles are expected to be equipped with new sensors and technologies to allow **self-separation**. New **AI assistants for ATCOs to predict and prevent congestion** are envisaged.

As a result, a significant **change in the ATCO role** is foreseen, with a shift from aircraft management to flow management. AI is expected to autonomously manage traffic; the ATCO role will be mostly key in case of emergencies and important traffic issues. This will probably generate **strong acceptance issues** and concerns which need to be carefully addressed.

Finally, the envisaged system should take **inclusiveness** as a primary target, and ensure that it will be **easily accessible** to everybody, including elders and people with disabilities.

8.2. Airport

8.2.1. Airport 2030 Landscape

Airports are foreseen to start a transformation process in order to support **mixed-traffic interoperability** and to become part of an **end-to-end transport network**, operating and integrating with other transport modes and infrastructures (UKRI, 2021). Therefore, airports will be required to be more resilient, have a more robust network and **enhanced connectivity**. Furthermore, it is expected that small regional airports with easy local access will mostly become big transport hubs with a key role in the envisaged highly connected transport system (UKRI, 2021).

To move towards "an **integrated European multimodal transport network**" (Ibid., p.10), airports are looking to place passengers at the core centre of their services and business by 2030. This will increase the **user's satisfaction**, improving the user's experience, from the booking to arrival, and offering them tailored solutions.

Access to tickets and information will be much easier thanks to a **mobility-as-a-service approach**. The **booking** will be more **integrated** and **multimodal**, suggesting the most efficient, eco-friendly and cost-effective options for travel. More options will be available to reach the airport. At the airports, passengers will be provided with a complete self-service bag drop and self-service kiosk. Thanks to new technologies, access controls and security checks will also be improved in order to ensure a smoother journey for passengers (e.g. corridor with fully automated checks). Furthermore, **charging stations** for electric vehicles will be available to ensure that all electrical equipment can be charged. In the 2040s, it is expected that baggage checks, check-ins, and security control will be moved away from the airport and done at the start of the journey in the city environment. AI will also be in place in the airports. For instance, it is expected to be beneficial for:

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- **Flow management**: AI-based intelligent assistants may be helpful in balancing the flow of passengers to avoid overcrowding. These will help operators in managing it. Information and directions will also be directly provided to passengers. Indeed, nowadays people tend to show up at the airport earlier to avoid missing their flights. If AI could support flow management, the service would be faster and more reliable, raising passenger trust, avoiding early arrivals and thus reducing the risk of overcrowding. By reducing overcrowding situations, the risk of spreading viruses inside the airports will also be reduced.
- **Gate planning**: AI-based intelligent assistants may also support the gate planning and re-planning tasks that are currently being performed by airport operators, raising efficiency.
- **Safety management**: AI-based intelligent assistants monitoring and analysing safety data will be in operation to support airport safety experts. These will be capable of processing big amounts of data, offering real-time risk prediction and identification, identifying trends and risky patterns, and proactively suggesting corrective measures

This landscape may have an **impact on the way airports' operators are currently organised and structured**, requiring new roles, skills and competencies.

HAIKU Use Case #5: Airport Safety Watch

Use Case #5 aims to design and deliver an **AI-Based Intelligent Assistant (IA) to assist Airport personnel in improving safety through data analysis**, targeting to generate the following high-level benefits:

- **Safety enhancement**: this assistant is meant to collect and analyse a comprehensive set of data to improve safety-critical operations;
- **Human support:** this assistant is meant to analyse a comprehensive set of historical data to provide predictive opportunities and aid decision-making avoiding safety hazards.

The Use Case #5 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 7.

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Table 7: Use Case 5: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		USE CASE SPECIFICATIONS	IMPLICATIONS FOR THE IA DESIGN
OPERATIONAL	Growth in traffic and airspace complexity. New concepts of operations: SPIC, UATM.	Better management of a more complex environment	• The IA is expected to generate relevant insights to improve operations, especially looking at the envisaged landscape which is characterised by a significant increase in traffic complexity and potential new concepts of operations. • The IA, with its prediction abilities, has the potential to reduce safety hazards and actively support the transition towards a more complex airspace and SPIC operations.
TECHNOLOGICAL	Digitalisation	Autonomous Intelligence	• The IA is expected to benefit from the automation and digitisation of operations. For instance, for ground movements, the IA is expected to benefit from the shift towards digital towers which implies data digitisation.
		Cloud services to store large data sets	• The IA needs to be trained through historical data. Access to large data sets is a high-priority requirement.
		XR Technologies for Training	• The IA could be matched with an enhanced vision system to be used for training purposes.
		Balancing quantitative and qualitative data	• The IA will focus on quantitative data sets. However, the inclusion of qualitative data in the analysis would be highly beneficial to better explore individual and organisational causes impacting safety. Its feasibility will be further assessed. • More generally, the main challenge of Use Case 5 is to set AI with adequate and targeted instructions, either only with quantitative or also with qualitative data as input.
	Cybersecurity	Robust	• Cybersecurity attacks could:

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		cybersecurity measures	○ Feed corrupted data into the IA, mining the effectiveness of the system and generating safety risks; ○ Lead to personal data breach, generating privacy issues; Both risks will be further assessed in order to ensure robust cybersecurity defences.
SOCIETAL	Impact on the human role	Changes in role	• The introduction of the IA may lead to changes in human roles. This aspect will be carefully addressed by this use case and considered in the IA design from the early stages.
		Ad-hoc design of Human-AI teaming interactions	• Humans play a fundamental role in the development and future evolution of the IA. They are a key source of qualitative data which are fundamental to identifying hot spots and analysing safety occurrences. Therefore, the operators' role is considered key to further training the AI system on a comprehensive data set. To this end, Human-AI teaming interactions will be carefully designed.
		Over-reliance and skill loss	• The IA aims at preventing hazards, but, on the other hand, exposes to the risk of over-reliance on automation and potential skill loss. This risk will be carefully considered in the IA design.
	Data privacy	Sensitive data management	• The IA will probably collect operational data from the crew. Therefore, the problem of data privacy will be carefully considered. GDPR should be required. ○ *Open point to be addressed: Will competing companies agree on sharing their data? If yes, just locally or worldwide?*

HAIKU Use Case #6: Airport prevention of virus spreading

The Use Case #6 aims to design and deliver an **AI-Based Intelligent Assistant (IA) to assist the Airport in the monitoring of risk factor conditions associated with indoor spread of infectious diseases**, targeting to generate the following high-level benefits:

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- **Better and safer passengers' flow management**: the Intelligent Assistant is meant to monitor and manage the affluence of people in the airport, preventing and mitigating crowds through contingency strategies;
- **Improved users' experience**: the Intelligent Assistant is meant to provide passengers with a smoother, less stressful and safer travelling experience by predicting a more accurate and reliable waiting and travelling time, as well as by dynamically guiding them inside the airport minimising the risk of crowded situations.

The Use Case #6 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 8.

Table 8: Use Case 6: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		USE CASE SPECIFICATIONS	IMPLICATIONS FOR THE IA DESIGN
OPS	Growth in air traffic	Better management of more crowded airports	• The IA is envisaged to mostly support large airports by providing crowd management solutions. • *Open point to be addressed:* ○ *What happens if a large airport needs to be closed for an emergency? How to support in this kind of situation?*
TECHNOLOGICAL	Digitisation	IoT & The use of personal devices to feed data into the DA	• The use of personal devices and their sensors (i.e., GPS) could be potentially used to collect and track data instead of fixed cameras. This would avoid the facial recognition issue; • The IA will work on rigorous, specific, and detailed data sets. The necessary information will be carefully defined. • The IA may also provide passengers with personalised suggestions. This would support travellers in defining their experience in the airport (e.g. finding the best route/restaurants/store with the lower level of crowdedness).
		Cloud services to store large datasets	• The IA needs to be supported by cloud services able to store a large amount of data. This is a high-priority requirement.

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		Advancement in automation reducing crowds	• The IA is expected to be impacted by the envisaged automatic airport services (e.g. automatic check-in automatic security lanes, etc.).
	Cybersecurity	Robust cybersecurity measures	• Cybersecurity attacks in themselves might trigger the gathering of a crowd. if through a cyberattack corrupted data were to be inserted into the system, people might be directed into crowds rather than be dispersed in the environment. This could cause significant risk factors that should be taken into consideration for the safety and security of both people and the infrastructure. The IA needs to be robust enough to avoid such attacks.
SOCIETAL	Impact on the human role	Design of ad-hoc Human-AI Teaming interactions	• The IA will support the airport staff in managing the airport capacity during different peak hours. To this end, Human-AI teaming interactions will be carefully designed.
	Data privacy	Real-time processing of personal data	• Certification and approvals related to GDPR will be required to allow data gathering and analysis. This use case will further assess this aspect.
	Societal concerns		• Potential ethical issues related to the constant monitoring and tracing of people will be further assessed and considered from the early stages of design.
	Multimodal and integrated transport system		• The IA is expected to enhance the overall transport system effectiveness and safety. It will match indoor crowd data with the flow of the passengers travelling through the whole transport system.

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8.2.2. Airport 2050 Landscape

Figure 9 summarises the HAIKU consortium vision of the Airport segment in 2050.

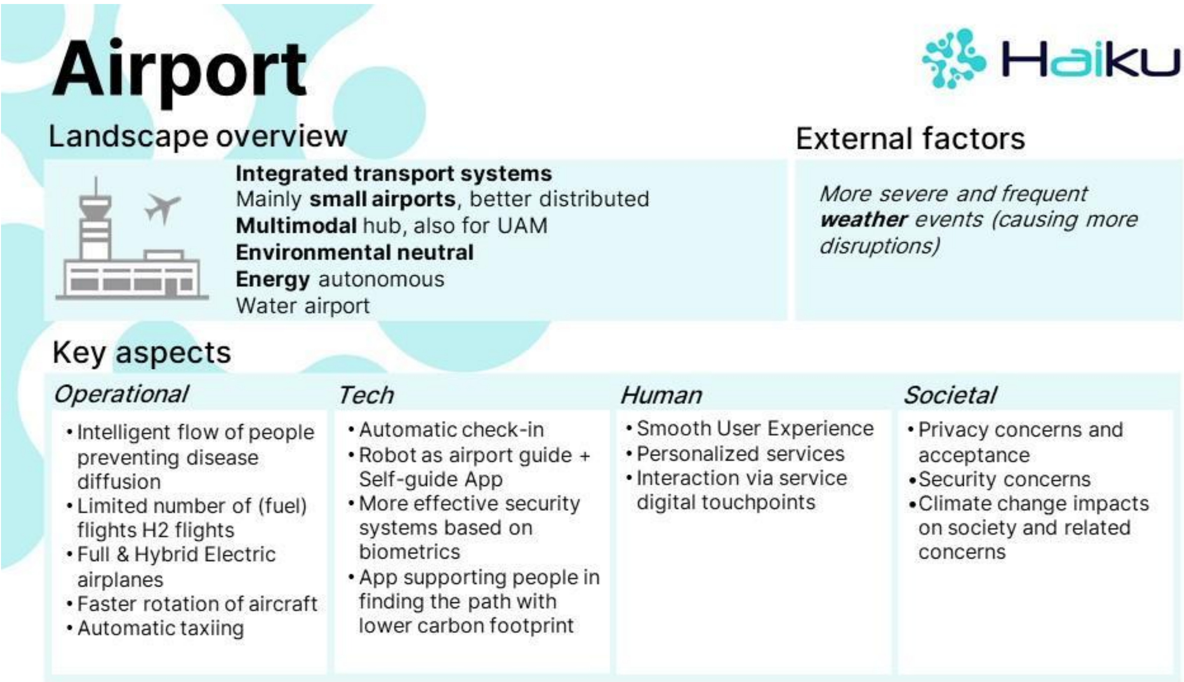

Figure 9: An overview of the Airport segment landscape in 2050.

A **fully integrated multimodal transport system** is expected to be in place by 2050. **Multimodal hubs** are envisaged for both commercial and UATM operations.

The whole transport service is expected to be **user-centric** and highly **personalised**. The current airport concept may change, with a shift towards **smaller, better distributed airports** on the territory in order to increase capillarity and ease passengers' movements. **Intelligent systems to manage the flow of passengers** to and inside airports will be in place with a view to ensure a smoother journey and prevent the risk of disease diffusion. **Baggage checks**, **check-ins**, and **security control** are envisaged to be **fully automated**, moved **away from the airport** and done at the start of the journey in the city environment. Inside the airports, the availability of **robotic airport guides**, **digital touchpoints** and **self-guide apps** is expected.

Airports are also predicted to be much more **sustainable**. By 2050, airports aim to be **energy autonomous** and to mostly manage **full-electric and hybrid electric vehicles**, limiting the number of fuel flights. **Aircraft taxiing systems** may be **fully automated** and **faster rotation of aircraft** is expected.

The transition to multimodal transportation and this new airport concept must consider societal concerns such as privacy, security, and the impact on climate change. The **involvement and empowerment of passengers in the design** of the whole service is

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considered key to addressing these concerns and maximising benefits for the end-users.

8.3. Cockpit

8.3.1. Cockpit 2030 Landscape

Aircraft manufacturers and airlines are expected to gradually evolve in the coming decades, also aiming to face the already mentioned envisaged increase in traffic and the predicted more critical weather conditions. As avionics systems continue to improve, it is expected that the number of crew members on board the aircraft will decrease. In the 2030s, or sooner, the **Single Pilot in Cruise (SPIC)** concept is very likely to be applied in operations for freight flights. SPIC refers to a reduction in the number of pilots required for a long-haul flight during the cruise phase: one pilot in command during the cruising phase while the second can rest and then take over, but both pilots are present for the preparation, taxiing, take-off, descent and landing phases. EASA and Airbus, in partnership with Cathay Pacific airline, plan to introduce SPIC on an A350 Freight around 2025. SPIC is expected to be the first step towards Single Pilot Operations (SPO), which concept is expected to come into operation during the 40s, if not slightly sooner for freight flights.

Sensor-based technology and **augmented reality** are also expected to support pilots in communication, navigation and surveillance through **multi-touch displays. AI-based assistants** and **automation** are expected to become more prevalent in the cockpit, helping pilots with a range of tasks, ensuring optimization of workload and increasing safety. For instance, in the coming years, the **Electronic Flight Bag** (EFB) is expected to be equipped with AI functionalities to help and guide the pilots' decision-making process during critical situations while keeping them in the loop of events (Kirwan, Charles, Jones, Li, Page, et al., 2020). AI-based assistants are also envisaged for space keeping on the ILS and for risk assessment purposes in live operations.

Furthermore, in the next decades, systems such as **Automatic recovery** (Garmin) and **flight** (ATTOL) are projected to become effective and reach the safety, reliability and resilience level required for certification. For instance, the Garmin Autoland system has been certified by EASA and the FAA for single-engine aircraft. Similarly, Airbus' **Autonomous Taxi, Take-Off & Landing** (ATTOL) project demonstrates taxi, take-off, and landing using image recognition without the need for satellite or ground systems. These systems can be applied to unmanned aircraft and as a backup system for large passenger aircraft in case of pilot incapacitation.

Moving to the main challenges envisaged for aircraft manufacturers and airlines in the next few years, **sustainability** comes up first. **Optimised operations** is a primary solution envisaged to address this challenge and it will probably require changes to operational procedures and, thus, impact the way work is done. **New technologies and alternative fuels** for aircraft are also expected to tackle this challenge, including **hybrid-electric, pure electric, and hydrogen-powered aircraft** as well as alternative fuels. By 2030, the following solutions are expected to be launched:

- **Sustainable Aviation Fuel (SAF)** for majority of flights;

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- **Pure electric air vehicles** for smaller flights and Passenger Air Vehicle (PAV) (up to 19 passengers);
- **Hybrid-electric air vehicles** introduced in some routes for some regional flights.
- **Hydrogen-fuelled gas turbine engines** first operations (or demonstrations) for some regional flights and above;

By 2035, the introduction of a medium-sized, hydrogen-powered aircraft is also expected. However, all of these are long-term solutions that will take several decades to be fully implemented.

Low-noise aircraft technologies are also expected to improve the environmental footprint considering noise emissions and thus improving the quality of life for residents living in the vicinity of airports.

With the introduction of new technologies and AI solutions, **Cybersecurity** is another challenge envisaged to become more and more relevant for airlines. Indeed, as aircraft strongly relies on real-time data and electronic equipment, it is crucial to implement robust measures to protect against malicious attack. Spoofing and jamming are two major concerns as they directly interfere with communications and electronic systems such as GPS. The implementation of robust anti-spoofing and anti-jamming technologies and secure communication protocols are required, as well as crew members' training to recognize and respond to potential threats will be crucial.

Gradual **changes** in **pilots' roles** and **required skills** are envisaged. A shift to a more supervisory and management role is expected. From a Human Factors point of view, the introduction of more automation and AI-based intelligent assistants leads to the **risks of skill loss** and **impaired situational awareness**. It is indeed essential to design systems that keep humans involved in the decision-making process at all times (Kirwan, Charles, Jones, Li, Page, et al., 2020). The **Simplified Vehicle Operations (SVO)** concept (Furuzawa, J., Fegnani, J., 2022) could be a way to address this risk as it consists in using automation along with HF best practices to optimise the overall quantity of trained skills, knowledge, and attitudes required for pilots or operators to safely operate an aircraft.

HAIKU Use Case #1: Startle Effect

HAIKU's Use Case 1 aims at building an IA to **support pilots in case of startle effects**. This use case targets the following high-level benefits:

- **Human support**: The IA aims to be flexible enough to effectively support humans in dealing with a number of different high-stress, safety-critical situations that might lead to startling events;
- **Safety enhancement:** the IA aims to be able to detect startle effects and assist pilots to recover from them. Therefore, it will improve flight safety;
- **Operational support**: the IA aims to ease the shift towards SPO by enabling single pilots to safely deal with startle events.

The Use Case #1 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 9.

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Table 9: Use Case 1: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		USE CASE SPECIFICATIONS	IMPLICATIONS FOR THE IA DESIGN
OPERATIONAL	Increase in traffic and airspace complexity	Proactive assistance	• The IA is expected to constantly monitor the situation and pinpoint potential risks of startle effects, supporting pilots in managing such a complex environment. • In case of startle events, the IA will efficiently and effectively interact with pilots, and guide them to safely overcome those risky situations. • To sustain pilots SA, the IA should always be transparent on what it is doing and its status.
	SPIC operations	Human-AI Teaming	• In view of the transaction towards SPIC operations, the design of the IA should be capable of interacting also with the resting pilot to address the situation of the startled pilot flying.
TECHNOLOGICAL	Digitalisation	XR Technologies	• The IA might be supported by XR technologies when displaying information to the crew during a startling event. It is expected to present the information in an overlaid layer above the cockpit to allow the reduction of sensorial confusion and to facilitate relevant information retrieval. • The IA might also leverage VR for training purposes.
		Autonomous Intelligence	• The IA will gather data independently, without specific user-initiated interactions, aiming to anticipate startling events.
		Advancements in Automation	• The IA will consider the case of startle effects triggered by automated system failures. Therefore, it should receive data from all cockpit automated systems and also be trained on them.
	Cybersecurity	Robust cybersecurity measures	• The IA will consider the case of startle effects triggered by cyberattacks. • The IA is expected to be robust enough

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			not to be compromised by cyber attacks.
	More frequent and extreme weather events	More accurate weather forecast	• The IA will need access to accurate weather information to allow safe planning and avoid unpleasant unpredicted events that may trigger startling.
SOCIETAL	End-users acceptance	Sensitive data management	• The IA will monitor the pilot status, collecting and analysing sensitive information. Pilots' resistances and acceptance issues are indeed envisaged. This potential issue will be taken into consideration from the early stages of design.
		Change in the human role	• The introduction of the IA in the cockpit is expected to change the human role in startling scenarios. Pilots will be requested to accept and trust the IA, and to rely on it in case of startle events. Building trust and ensuring acceptance is a key challenge that Use Case 1 aims to tackle. • The IA is expected to be flexible enough to adapt to different roles and team dynamics.
	Societal concerns	Over-reliance and skill loss	• The IA design will take the over-reliance and skill loss issues into account from the early stages of design to avoid safety repercussions.

HAIKU Use Case #2: Route planning and replanning

HAIKU's Use Case 2 aims at building an IA **to assist pilots in route planning/replanning.** It will target the following high-level benefits:

- **Human support:** the IA will assist the pilots' planning/replanning decision-making process.
- **Workload reduction**: the IA will reduce pilots' cognitive workload, freeing up cognitive resources to allocate to other tasks.
- **Operational efficiency and effectiveness**: the IA aims to improve the synchronicity between the workflows of pilots and ATCOs by enabling real-time communications between them. Thus, it will improve the overall efficiency and effectiveness of operations.

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The Use Case #2 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 10.

Table 10: Use Case 2: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		USE CASE SPECIFICATIONS	IMPLICATIONS FOR THE IA DESIGN
OPERATIONAL	Increase in traffic and airspace complexity SPIC operations	Human-AI Teaming	• The IA is expected to suggest route changes to pilots, mediating the communication between them and ATCOs. It will then support flight operations in such a complex environment, while also easing the transaction towards SPIC. • The IA will adequately explain its route change suggestions to pilots.
	Sustainability	Use of environmental data	• The IA is expected to take power and emission data (such as CO_2 and NO_2) as input. • The IA will therefore consider the environmental impact on its algorithms, suggesting routes associated with the lower carbon footprint possible.
TECHNOLOGICAL	Digitalisation	Optimisation of resources	• The IA is expected to play as an integrator of systems, helping manage technological variability in the cockpit. It should aid pilots in optimising flight planning, allowing for parallel optimisation across the technological infrastructure.
		IoT	• The IA will leverage an IoT layer to receive and send data with other systems/devices.
		Cloud services	• The IA needs access to cloud services to ensure the flow of data through the system.
		XR Technologies	• The IA could make use of XR technologies to improve the usability of the HMI.

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		Advancements in automation	• The IA is expected to be featured by autonomous functions. Furthermore, it might leverage other automated parts of the cockpit. • Moreover, the IA should in some cases be used to manage autonomous systems in the cockpit.
		Personalisation	• The IA might be personalised, tailoring its behaviours and suggestions on the basis of specific characteristics of pilots. This possibility will be further evaluated.
	Cybersecurity	Robust cybersecurity measures	• The IA risk of being compromised by cyber attacks is high, especially due to its communication channel with ATCOs. Secure communication flows and lines and contingency will be assessed and designed.
SOCIETAL	Impact on human role	Adaptability	• In view of the envisaged changes in the human role, the IA system and HMI is expected to be easily adaptable without altering its level of reliability and safety.
	Societal concerns	Over-reliance and over-complacency	• Over-reliance and over-complacency with the DA's suggestions may lead to safety risks. The IA design will take these aspects into account from the early stages of design.

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8.3.2. Cockpit 2050 Landscape

Figure 10 summarises the HAIKU consortium vision of the Cockpit segment in 2050.

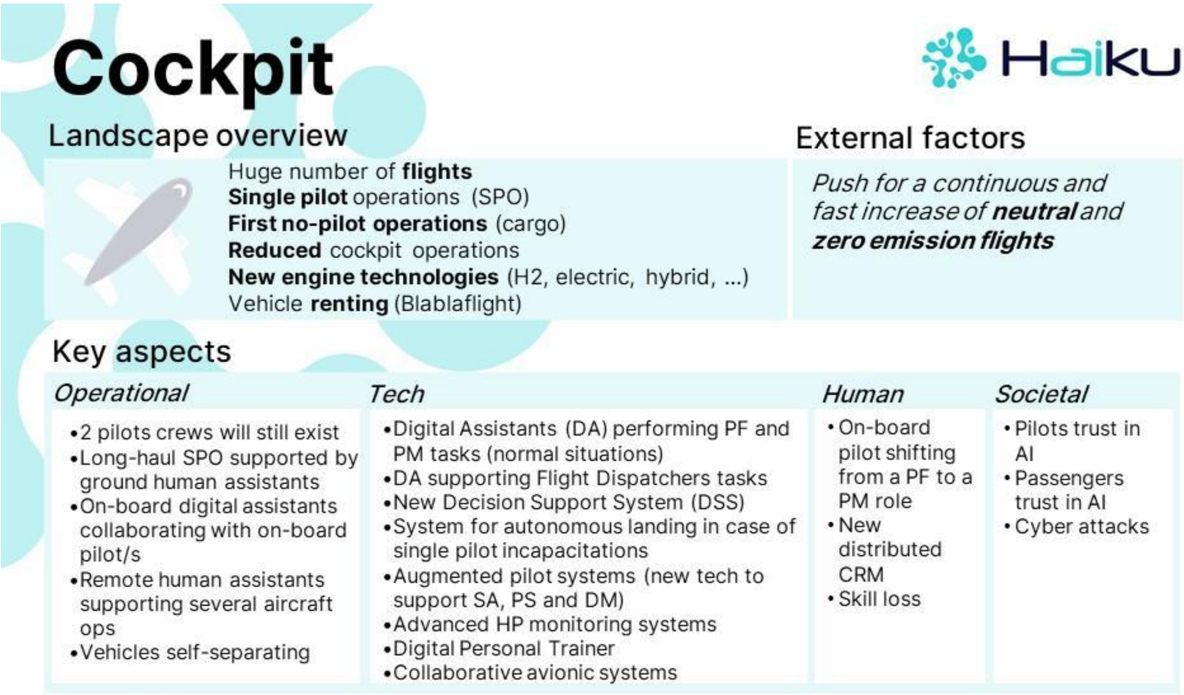

Figure 10: An overview of the Cockpit segment landscape in 2050

As mentioned in the ATM 2050 landscape, a **huge increase in traffic** is forecasted. In the next 25 years, airlines and aircraft manufacturers are expected to face a significant challenge as requested to meet a **constantly growing operational demand** while, at the same time, shifting to **neutral and zero-emission operations**. Indeed, as shown in Figure 12, **new engine technologies** will be gradually deployed while moving towards 2050, aiming to reach zero Net CO2 emissions by then.

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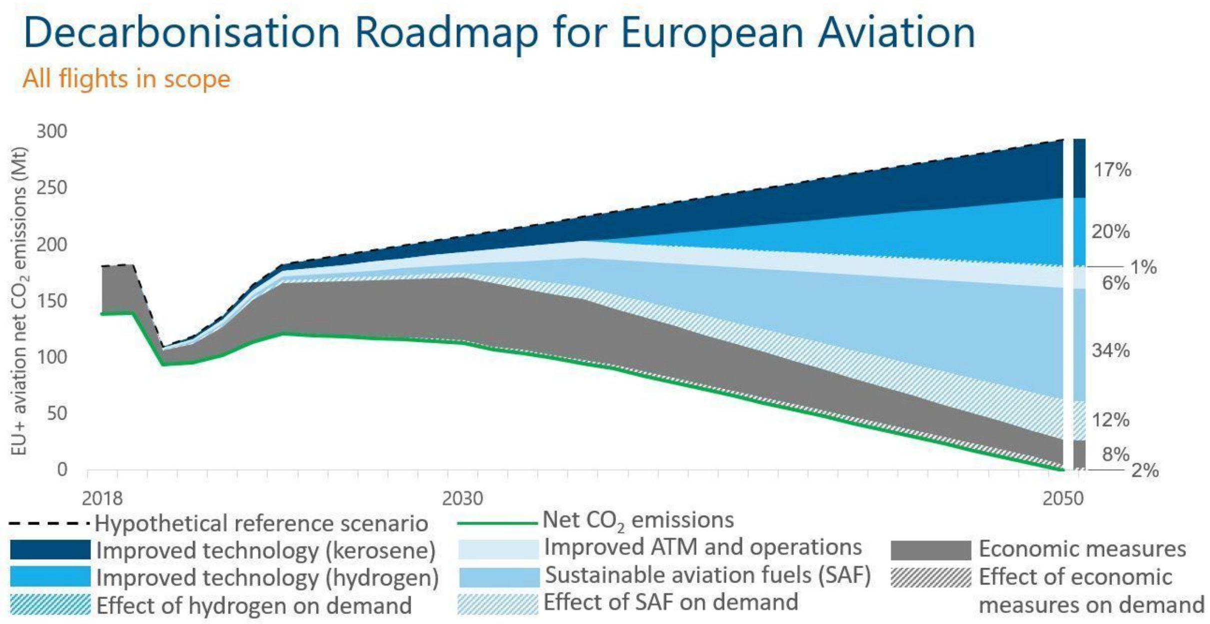

Figure 11: Decarbonisation Roadmap 2050 (source: https://www.destination2050.eu/)

The shift from two-pilots in the cockpit, SPIC and **SPO (Single-Pilot Operations)** is expected to be accomplished by 2050 for long-haul flights. During operations, single pilots will be supported by **onboard intelligent assistants**. **Remote human assistants** managing several aircraft are also envisaged. **Two-pilot crew** will still operate. Furthermore, by 2050 the **first no-pilots operations** are envisaged for freight flights. **Vehicle sharing services** (concept similar to car sharing, but for aircraft) may be also provided to passengers.

A variety of intelligent assistants are expected to be deployed by 2050 in order to support pilots. Both the **Pilot Flying and Monitoring tasks** may be **automatically managed** in normal situations. To support pilots' Situational Awareness, problem-solving and decision-making, **augmented pilot systems** are envisaged. A **new Decision Support System** will be needed. **Advanced Human Performance monitoring systems** will be available. In case of single pilot incapacitation, a **system for autonomous landing** will intervene. Furthermore, a sort of a **Digital Personal Trainer** may be available for pilots, aiming to support and partner with them from the start of their careers, learn from them and evolve over time. Intelligent Assistants to support **Flight Dispatchers** are also expected.

As a result, a significant **change in the pilot role** is foreseen, with a shift towards a more supervisory and emergency management role. AI is expected to autonomously fly the aircraft, leading to the **risk of skill loss** that should be carefully tackled and prevented. A **new CRM concept** should be designed considering the envisaged changes in the pilot role and the introduction of new figures in the team: Intelligent Assistants as a sort of a digital on-board crew member and Remote human assistants. Overall, a **safe Human-AI teaming** must be ensured.

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8.4. Urban Air Traffic Management (UATM)

8.4.1. UATM 2030 Landscape

The UATM concept is considered a safe, secure, and sustainable transportation system for passengers and cargo in urban environments, enabled by new technologies and integrated into multimodal transportation systems. UATM operations will be started by 2030 **and a rapid increase is envisaged during the 30s**, necessitating some form of traffic regulation.

UATM operations are expected to start from specific, time-critical applications such as **medical supply delivery** and **emergency responses**. Other applications might involve a variety of industries and sectors, including goods and services **deliveries, law enforcement, and tourism**. The personal transportation industry, at least initially, is unlikely to become widespread by 2030 but will probably be in place in a few selected cities (USA mostly).

As the number of drone operations and aircraft increases, managing the airspace will become increasingly complex. The integration of different types of aircraft, each with varying levels of automation, will pose significant challenges for air traffic control. To safely manage this complexity, **segregation** is projected to be the most likely solution by 2030, envisaging a shift towards an **integrated airspace** in the next decade. **Urban Air Traffic Management** (UATM) solutions are deemed necessary to manage traffic safely and efficiently in cities, where essential components include optimised airspace usage, adaptable airspace structures, and shared situation awareness for all stakeholders.

Overall, it is envisaged that the UATM system will be **fully automated,** from traffic planning and management, to on-board detection and avoidance systems (Riedel & Rozelkopf, 2022).

New human roles as part of city U-Space Service Providers (USSP) are required to accommodate the link between ground and airborne activities. A **UATM Coordinator** is expected as a new key role entering the aviation industry. It will provide real-time strategic and tactical U-space services to UAS and UATM operators and stakeholders, as well as coordinate with ATM. The UATM Coordinator is expected to be supported by **AI-based intelligent assistants** capable of monitoring the traffic in city urban airspace and identifying ground events and city life with an impact on trajectory planning. Therefore, AI has the potential to assist in traffic management and planning, detecting issues, making decisions, and facilitating communication between air vehicles and ground operations. The assistant is expected to care for the majority of standard, repetitive, normal tasks (e.g., flight authorization, traffic monitoring, flight information, weather information) and to reduce workload, allowing the human to focus on high-level strategic decision-making in oversight of UATM operations.

The implementation of UATM will also present specific challenges from an infrastructural perspective. In order to ensure safe and efficient operations, **landing spots** for UATM aircraft must be identified and made available. To ensure that emergency situations can be handled safely, a **network of emergency landing stations**, as well as **charging infrastructure for electric vehicles**, must be developed and

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implemented. Moreover, it is crucial for governments and regulatory bodies to develop and implement clear legislation for UATM in the near future.

UATM seems to be marking the **beginning of a new era for aviation**: attractive from an economic perspective and widespread in everyday city life.

HAIKU Use Case #3: UAM

Use Case #3 aims to design and deliver an **AI-Based Intelligent Assistant (IA) to assist the Urban Air Mobility coordinator in traffic management**, targeting to generate the following high-level benefits:

- **Safety enhancement**: this assistant is meant to be an additional safety layer;
- **Operational efficiency and effectiveness**: this assistant is expected to enable humans to safely and effectively manage the envisaged high level of UAM traffic, making the UAM concept possible.
- **Human support**: this assistant will process a huge amount of data, providing the coordinator with the right information at the right time, allowing him/her to quickly make better decisions. Furthermore, the consortium will assess the benefits of making it capable of being adaptive to human status and thus supporting the coordinator from a workload, stress management and situational awareness perspective.

The Use Case #3 landscape is built upon the more general 2030 landscapes. Starting from these, a set of key trends and elements have been identified and further discussed in order to better specify the context of reference for this IA and identify potential impacts and implications on its design. These aspects are summarised in Table 11.

Table 11: Use Case 3: key trends and implications.

GENERAL KEY TRENDS /ELEMENTS		**USE CASE SPECIFICATIONS**	**IMPLICATIONS FOR THE IA DESIGN**
OPERATIONAL	Increase in traffic and airspace complexity	Ad-hoc design of Human-AI teaming interactions	• The traffic will be managed by the UAM Coordinator together with the IA. • The IA is expected to care for the majority of standard and repetitive tasks (e.g. traffic monitoring, flight authorisation, etc.). It will also be able to identify ground events with potential impact on trajectory planning. • The IA will therefore prevent humans from being overloaded by traffic information, allowing the coordinator to focus on high-level strategic decision-making.
	ATM & UAM integration	Segregated U-Space	• The IA will only process UAM data. No ATM data feed is requested.

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		In case of emergencies, shift from segregation to negotiation	• The IA will be able to detect emergency situations and suggest emergency plans and routes to the coordinator.
			• The IA will not automatically coordinate with relevant stakeholders (e.g. ATCO); this will be a coordination task.
			• The coordinator will propose emergency routes to ATCOs via the DA; ATCOs will digitally approve or provide alternative instructions.
			• Once the route is approved, the IA will automatically send the clearance to unmanned aircraft.
			• *Open points to be addressed:*
			  ○ *Frequencies: having different ATM and UTM frequencies, exposes to safety risks in case of UAM vehicles passing through an ATM sector for emergency reasons.*
			  ○ *Priority of emergencies: who goes first?*
			  ○ *System connection: ATM & UTM systems would need to be connected in order to allow digital communication and coordination.*
			  ○ *Responsibility: who is responsible?*

	More frequent and extreme weather events	More accurate weather forecast to avoid unpleasant unpredicted disruptions	• Weather data will be fed into the IA. • Weather information is envisaged to be directly collected through drones. Meteo-drones are expected to be operating but also other vehicles may be capable of providing real-time weather information to USSP.
		Clear decision-making process (and responsibilities) for weather events	• In case of weather events, the last decision to continue or stop operating will be taken by the drone operators. • Each drone operator will communicate its decision to the UAM coordinator via the IA.
TECHNO	Cybersecurity	Robust cybersecurity measures	• The IA is expected to be able to self-defend. It will automatically communicate with the operators in case of a cyber attack. • In case of abnormal behaviours or hostile vehicles, military drones are

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LOGICAL			expected to quickly react (scrambling).
		Emergency lanes	• In case of a potential cyber attack, the IA is expected to have the ability to disconnect the hostile drone/s to the system. • The hostile drone/s will shift to emergency mode and will be automatically instructed on a specific emergency lane.
	Digitalisation	Autonomous intelligence	• The UAM traffic is envisaged to be mostly unmanned.
		Cloud services & IoT	• UAM is envisaged as a fully digitised system. • UAM is envisaged to be part of a fully integrated transport system, leveraging IoT.
SOCIETAL	Multimodal and integrated transport system	UAM systems connected with more general transport systems	• The IA aims to be suitable for integration with all other transport systems, to ensure access to all transport data. • Thanks to this integration, the IA aims to be able to support passengers in finding alternative routes in case of UAM disruptions. • *Open points to be addressed:* ○ *Cost coverage: in case of disruptions and related implications for passengers (e.g. delays, missed flights, ...), who will cover this cost? Will it be absorbed by the transport system? Or will the passengers be charged?*
	Impact on the human role	Operators Situational Awareness (SA)	• During the IA development, solutions will be explored to support the UAM coordinator SA, avoid startle effects and thus ensure that the human will be kept in the loop.
		Multi-actor coordination	• The IA is expected to autonomously carry out the majority of standard and routine tasks, proposing solutions to the UAM Coordinator in case of re-planning and emergencies. • In those cases, the UAM Coordinator is

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			expected to make decisions on the basis of the solutions proposed by the IA. ● This decision-making process requires the UAM Coordinator to coordinate with a variety of actors (ATCOs, drone operators, emergency services, etc.), ensuring a fast and smooth response. This is a challenge that will be further explored by this use case.
	Societal concerns	The UAM concept is expected to further explore the societal concerns associated with privacy and trust. These are key factors that need to be taken into consideration from the early design stages.	-

8.4.2. UATM 2050 Landscape

Figure 12 summarises the HAIKU consortium vision of the UATM segment in 2050.

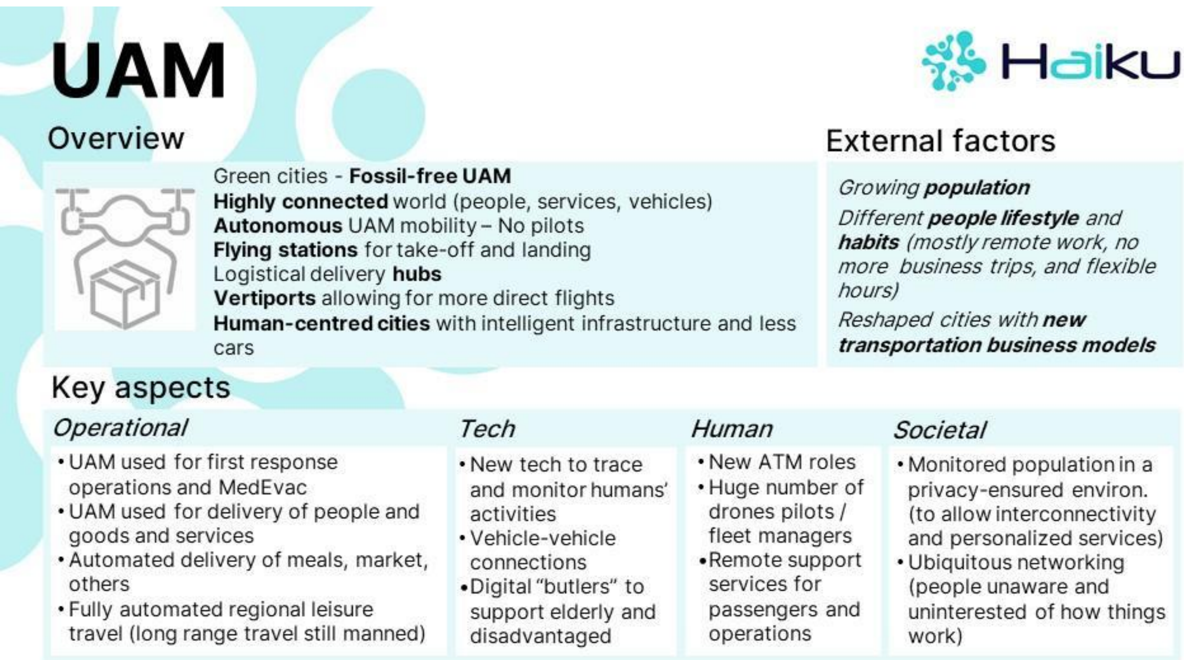

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Figure 12: An overview of the UATM segment landscape in 2050

UATM is expected to be **fully operational by 2050**, expecting UATM high traffic above the major cities in the world to provide a **variety of services** (medical supply delivery, medical evacuation transportation, emergency responses, delivery of goods, meals, people, etc.). Delivery and mobility operations are envisaged to be **fully autonomous** (no pilots on board). Some regional leisure travel may also be fully automated, while long-haul flights will still be manned.

UATM is expected to be a key part of **new transportation business models** that will reshape cities. By 2050, cities must be **green**, thus UATM aims to be **fossil-free**. Within cities, a **highly connected environment** (people, service, vehicles) will be fundamental in order to smoothly and effectively run UATM operations. Related **acceptance concerns and resistances** should be taken into consideration from the early stages of design and a privacy-ensured environment should be guaranteed. Furthermore, **new infrastructures** will be required such as flying stations, logistical hubs and vertiports.

Robust vehicle-vehicle connection technologies are expected to be deployed to ensure operational safety and effectiveness. Inside the vehicles, **new technologies to monitor humans' activities and state** will be available. To ensure accessibility, **digital "butlers"** to support the elderly and disadvantaged should be put in place. **Remote support services for passengers and operations** would also be required.

As mentioned in the ATM 2050 landscape, a **global integration of ATM, UTM and UAM** is envisaged by 2050. A **huge number of drone pilots and fleet managers** will be operating. **New roles** for coordinating and managing UATM traffic may be required.

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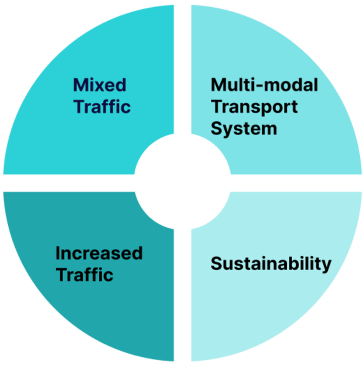
Conclusions

This document shows the HAIKU vision for the future of aviation (Section 2) as well as providing hints on how to successfully embed human-centred, value-based considerations into AI-based Intelligent Assistant design (Section 1).

All the outcomes stated in this document are the results of in-depth research where the contents of relevant documents have been enriched with the visions and points of view of a variety of aviation experts collected through interviews (15), co-design workshops (3), and several iterations amongst the HAIKU partners.

Looking ahead to 2030 and, going even further, 2050, a **continual increase in operational complexity** seems to be one of the major challenges, suggesting a future aviation landscape that is as challenging as it is full of opportunities. "***Increased traffic***", "***Heterogeneous traffic***", "***Sustainability***", and "***Integrated multi-modal transport systems***" are the dominant features characterising the evolution of the coming years.



"***Increased traffic***" and "***Heterogeneous traffic***" are the first two features. **50.000 flights on a peak day in Europe** (EUROCONTROL, 2022) are expected by 2030, approximately +50% compared with the 2019 traffic demand (EUROCONTROL, 2022). Furthermore, **UATM operations** will start by 2030 and a rapid increase is envisaged during the 2030s. Segregation is projected to be the most likely solution by 2030 for managing such diverse traffic.

But what are the **main challenges** the aviation industry is expected to face in the forthcoming years?

1. **Maintaining high safety standards** comes up first. Resilient, flexible and proportionate safety procedures and approaches for risk management will be necessary, to anticipate and manage emerging risks.
2. **Maintaining a strong safety culture** across the entire aviation system, in particular extending it to new entrants.
3. **Ensuring robustness of new systems**. More automated and autonomous systems are expected to be progressively deployed to support humans in managing flight and traffic management operations. These traffic management systems must be capable of dealing with more extreme and severe weather conditions due to climate change. Integration with existing legacy systems will also be a major challenge.
4. **Enabling regulations to progress as fast as the evolution of operations** to avoid the risk of unregulated actors or situations which could undermine the safety of operations, specifically for UATM.

Looking further ahead to 2040 and 2050, a shift towards a fully **integrated airspace will be essential**. There will be literally more moving parts, more that can go wrong and, with more 'players' controlling traffic, a step-change in the need for smooth and effective traffic coordination. This scenario poses significant additional challenges to be addressed in the mid-term:

5. Development of a **robust global architecture for integrated traffic management, integrating ATM and UATM systems**.

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The third feature is "***Sustainability***", seen by many today as an aspiration, will become a 'given', an essential attribute of future air traffic that is non-negotiable. This raises two further challenges:

6. Enabling the aviation system to **sustain traffic demand, while minimising the carbon footprint** to a level acceptable to society;
7. **Sustainable Aviation Fuel, battery and hydrogen-fuelled gas turbine engines production**.

The fourth feature refers to the **integrated multi-modal transport system** that should be in place well before 2050, offering a user-centric and highly personalised service to passengers and UATM customers. This will definitely enhance the user experience, bringing with it a key challenge:

8. **Enhancing connectivity of transport hubs** and **integrating their systems** to allow mixed-traffic interoperability. Multimodal services, platforms and apps will be necessary, to ensure smooth journeys for passengers and simple usage of UATM delivery services to customers. New multimodal or cross-modal business models are likely to arise, offering simple multimodal ticketing according to user preferences.

Regarding the increasing **digitalisation** and introduction of **AI solutions** - e.g. automatic recovery systems, Autonomous Taxi, Take-Off & Landing, automatic detection and avoidance systems, management of the passenger flow from, to and inside airports - there are certain **specific challenges** that must be addressed as a priority to allow successful AI deployment in this safety-critical industry.

A. **Data availability and accessibility**.
B. Developing **high-performance algorithms** capable of ensuring safe and effective outcomes. More specifically, the most challenging aspects are:
    a. Enabling the system to **constantly learn** and evolve, also **capturing 'tacit' human knowledge**;
    b. Developing a **context-aware system**, capable of understanding when to intervene and when to stay quiet;
    c. Ensuring AI's ability to **deal with human variability**;
    d. Ensuring **applicability and proficiency for different scenarios**.
C. Developing **safe, trustworthy and effective Human-AI teaming models** for each AI application, identifying the most effective **explainability strategy**, ensuring that the operators' situational awareness will be adequately sustained during operations, and preventing risks associated with human over-reliance on AI.
D. **Workforce redesign**, defining new roles, skills and competencies, and training approaches including joint human-AI training.
E. Clear definition of **responsibilities** from a legal point of view, and also acceptable to professional unions.
F. Understand and address both **users'** and **societal concerns** and **reservations** concerning the application of, and reliance on, AI in safety-critical systems such as aviation, including ethical and privacy aspects.

Looking at the envisaged operational complexity, high connectivity, system integration, and introduction of AI in operations, one final challenge of utmost importance is identified:

9. Ensuring **Cyber resilience**. Robust security measures to prevent and avoid attacks and ensure the safety of operations and critical supporting infrastructure must be developed and deployed.

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In conclusion, while AI is acknowledged as a possible solution for addressing the above-mentioned challenges, the deployment of AI systems will transform the aviation landscape, creating new risks, issues and dynamics to be managed. For HAIKU, AI solutions will be successful and effective only if designed starting from **users' and stakeholders' needs.** This means that the **AI systems themselves must value what we value.** The only way we will achieve this is if human-centred, value-based considerations are embedded into the Intelligent Assistants design, literally into its coding. The four core principles identified in HAIKU - **Human-AI Teaming**, **Human-Centred AI**, **Trustworthiness** and **Societal benefits** - will guide the development of HAIKU's Intelligent Assistants and ensure that the ultimate goal is achieved: ***Human-Centred AI-based Intelligent Assistants for safe, secure, trustworthy and effective Human-AI partnerships in aviation systems***.

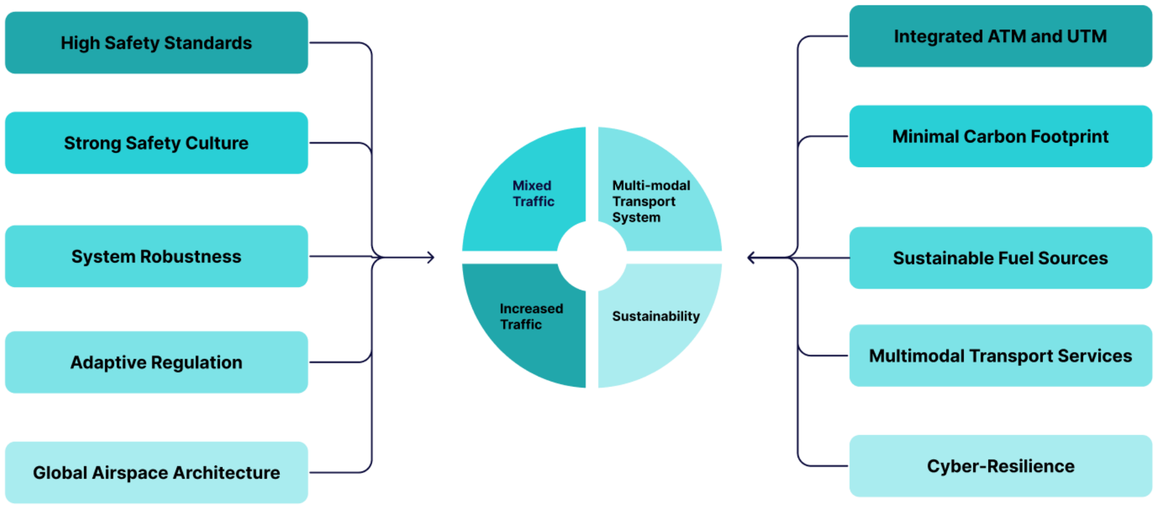

Figure 13: Overview on future challenges

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Annex A

Human-Centred AI Principles - Interview grid

Table 1: interview grid for aviation end-users

N.	Question
Q1	Think about your domain and your work in 2030... When I say, Human-Centred AI, what are the first 3 things that come to your mind?
Q2	To develop a useful and effective human-centric AI-Based Digital Assistant, what are the key principles that should steer its design?
Q3	To ensure a successful deployment of a human-centric AI-Based Digital Assistant, what are the main characteristics that it should have?
Q4	On the basis of the previous answers, define what are, in your point of view, the 3 main pillars for Human-Centric AI. Please list them and provide a short description
Q5	[shows results from the survey] By looking at these results, what is your reaction and opinion?
Q6	[shows results from the survey] By looking at these results, what is your reaction and opinion?
Q7	Now that we have seen what are the principles most mentioned by worldwide and aviation key players, do you confirm the 3 main pillars for Human-Centric AI previously identified? Is there anything that you would like to add/change?

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Annex B

Human-Centred AI principles - High level definition

Premise: the following high-level definitions are a first attempt of mixing many different definitions and points of view. These do not express the HAIKU vision.

- **Accountability**: All stakeholders of AI systems that are responsible for moral and legal implications of their use and misuse must be clearly defined.
- **Explainability**: AI systems should be able to explain their overall decision-making/prediction model to users and other stakeholders, allowing them to understand how the variables affect the predictions in specific cases. Ad-hoc explainability strategies and solutions need to be defined for each AI application.
- **Fairness**: AI should treat individuals in a fair manner, without favouritism or discrimination, and without causing or resulting in harm. AI should also maintain respect for the individuals behind the data and refrain from using datasets that contain discriminatory bias.
- **Human values**: AI systems should be designed and operated to be compatible with values of human dignity, rights and freedom.
- **Human-AI partnership**: Ad-hoc Human-AI partnership/teaming strategies need to be defined for each AI application, to ensure effective and safe collaborations.
- **Human-centred AI**: users must be involved in all stages of design and development.
- **Inclusiveness**: systems must empower and engage people, preventing discrimination.
- **Lawfulness**: AI systems must be compliant with law. All stakeholders of the system must always act in accordance with the law and all relevant regulatory regimes.
- **Multidisciplinary teams**: Multidisciplinary design teams must be engaged in the development of the system to properly capture and address the requirements of all stakeholders.
- **Privacy**: People's privacy must be ensured. People must have the right to access, manage and control the data they generate.
- **Reliability**: AI systems should be developed so that they will operate correctly over long periods of time, using the appropriate models and datasets.
- **Robustness**: the system must be able to cope adequately with errors and deviations in diverse scenarios throughout the operational life.
- **Safety**: AI systems must have different safety layers to guarantee operational safety. People’s physical and mental integrity must be protected.
- **Security**: AI systems must be accompanied by robust security measures, to protect data and defend the system itself from cybersecurity risks.

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- **Social benefit**: AI systems must promote and reflect the common good of the individuals, society and environment, empowering as many people as possible. To be successful, these must generate benefits for society.
- **Transparency**: People have the right to understand how their data is being used and how AI systems drive decisions.

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Annex C

HAIKU's Human-Centred AI principles

Human-AI Teaming

Table 2: Human-AI Teaming principle: application in all Use Cases.

For HAIKU, Human-AI Teaming is achieved when the Intelligent Assistant is **dynamic, capable of adapting** to users' mental states and specific needs, and actually delivers a clear benefit to the end-users.	
Ad-hoc interaction modalities should be designed for each use case in order to ensure **shared situational awareness,** shared situational awareness and an **effective learning loop** (human-AI and vice versa), as well as a **smooth partnership** between AI, its users and other relevant actors potentially impacted. **Personalised interactions** could be also considered for some of the HAIKU's AI applications.	
Use Case #1: Flight deck startle response	
Directing Situational Awareness (SA)	• If a startle event is triggered, the intelligent assistant has to recognise it, partner up with the pilots and direct their situational awareness towards appropriate actions. The IA should be able to adapt and switch between different types of partnerships that consider either the case in which only one pilot is under startle effect, or both pilots are at the same time.
Dynamic Guidance	• The control is expected to be continuously and smoothly shifted from the pilot to the AI and vice versa. In case of a startling event, the intelligent assistant should take over and guide the pilot in responding to the problem in the most appropriate and fast way. The control should be shifted back to the pilot once sufficient awareness is reached.
Mutual understanding	• The Human-AI partnership concept should be built upon mutual understanding. The intelligent assistant should be aware of the pilot's cognitive and emotional state, and conversely, the pilot should be aware of what AI is doing at all times and should be able to effectively interact with it. Their individual interpretations of the ongoing

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	situation must be compatible with each other.
Physiological monitoring and training	• Physiological monitoring might be used by the AI to infer or predict the pilot's state, while the human should be trained to understand how the AI works to better coordinate with it.
Human-Human-AI coordination	• The introduction of AI in the cockpit might lead to new definitions of Crew Resource Management (CRM) processes which might involve not only the partnership between pilots and the assistant, but the entire crew operating the flight.
Interaction Modalities	• Interaction modalities (vision, audition, touch, ...) should be designed to ensure a smooth and effective partnership; • The intelligent assistant should always intervene at the moment in which the user needs it, never too early or too late.
Use Case #2: Flightdeck route planning and re-planning	
Pilots as decision-makers	• The intelligent assistant will support the pilots by detecting relevant information and suggesting solutions. • All decisions about route definition or change will be made by pilots. The pilots may delegate their implementation to the assistant.
Extended Crew Resource Management (CRM)	• With the introduction of AI assistants, the experience of route planning and re-planning can change significantly. As a direct consequence, a revision extension of the traditional CRM processes might be required.
Air Traffic Control (ATC) coordination with pilots	• The Human-AI teaming concept should be extended also to ATCOs to ensure an effective, smooth and safe collaboration. The intelligent assistant may act as a mediator that is able to consider the big picture, and facilitates exchanges of prioritised messages from the pilots to the controllers and vice versa. This might prove

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	particularly valuable in areas of high-complexity routing, like MUAC.
Human-AI dialogue	• The calculations of the algorithm should be translated into understandable language, providing clear information for humans to use. Establishing shared situational awareness will improve the effectiveness of the partnership, especially in safety-critical situations.
Interaction modalities	• Interaction modalities (vision, audition, touch, ...) should be designed to ensure a smooth and effective teaming, taking the human factors into consideration from the early design stages. • The timing of the interaction (user-initiated vs system-initiated) also needs to be defined according to user needs.
Workload management	• Tasks allocation and distribution over time shall relieve the pilots' cognitive resources to prevent fatigue and to deal with unforeseen situations. • The issue of interaction modalities and timing are particularly relevant in this use case because too much information at the wrong time, regardless of the sensory channel, might lead to an excessive workload both for controllers and pilots. Therefore, the assistants must be designed with the workload management aspects in mind.
Use Case #3: Urban Air Mobility	
Human supervision & engagement	• Given the expected traffic management complexity, the intelligent assistant should be in charge of doing most of the legwork while humans' roles should be more for supervision and emergency management. How to keep the human engaged and maintain a good level of situation awareness is a potential issue that needs to be addressed.
AI system management	• Given the high complexity of managing the entire airspace of a city, a whole new level

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	of system management should be envisioned.
Team interaction design	• A clear definition of the roles of operators and AI is crucial, followed by an accurate design of the team interaction.
Use Case #4: Digital Tower	
Personalisation	• The intelligent assistant could personalise its support according to each ATCO's way of working.
ATCO supervision	• The intelligent assistant may take over some of all human tasks, meaning that the ATCO's role might need to be completely revised. It is expected that the intelligent assistant will deal with repetitive tasks, with ATCOs always present to supervise what the AI is doing.
ATCO management of exceptions	• Other than supervising the IA, the ATCOs should manage the exceptions that deviate from the normal conditions for which the AI had been trained (i.e: the progressive shift towards low visibility conditions). In all ambiguous situations, a clear definition of rules and tasks should be defined, considering liability aspects.
Interaction modalities	• Interaction modalities (vision, audition, touch, ...) should be designed to ensure a smooth and effective teaming, taking the human factors into consideration since the early design stages.
Use Case #5: Airport Safety Watch	
Learning to learn	• Given that this use case revolves around a massive amount of data provided by airports, the main task for humans would be to understand how to extract meaningful information from the data.
Human training AI	• Once humans learn how to interpret data provided by the IA, they can instruct and train the assistant, aligning it to their (safety) models, or restructuring them.

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	• Visibility and assessment of the AI implicit models are also required at this stage.
Interaction modalities	• Interface design and visualisations should be designed to ensure a smooth and effective teaming, taking the human factors into consideration since the early design stages.
Use Case #6: Monitoring and prevention of COVID-19 spreading in airports	
Route planning across the airport	• DAs should be able to collect data about the flow of passengers in airports and therefore recommend a "minimum risk" route to passengers and/or suggest how to rearrange the flow to avoid congested areas.
Recommendation of prevention strategies	• By leveraging sensors that measure parameters such as air quality, the AI should also be able to recommend preventive measures - i.e. rearranging the airport layout - to ensure that the risk of infection is minimised.

Human-Centred A

Table 3: Human-Centred AI: application in all Use Cases.

For HAIKU, Human-Centred AI is achieved when **human-machine interactions** are designed starting from **stakeholders' needs**, human **abilities** and **limitations**, ensuring a compatible fit with technological possibilities. Stakeholders may be primary users (e.g. pilots and controllers) but also other people directly interacting with AI (e.g. system designers, trainers, supervisors and line managers).	
Ad-hoc explainability strategies need to be designed for each AI application, supporting **workload managemen**t and ensuring **adaptability to users' mental** states and models and overall **transparency**.	
Use Case #1: Flight deck startle response	
Explainability fitting users' mental states	• The concept of explainability, in human-centred AI terms, refers to the idea that the intelligent assistant should flexibly understand users' needs and provide an adequate level of explanations about what is happening, while also keeping the pilots' mental state into account. For example,

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<table>
<tr><td></td><td>during a startle response, simply suggesting actions would not be appropriate, and a certain degree of explainability is expected.</td></tr>
<tr><td>Interaction Modalities</td><td>As highlighted in the Human-AI Teaming principle, the interaction modalities should be designed from users' needs, abilities and limitations, taking the human factors into consideration since early design stages. Ensuring transparency should be a must in the interactions design process.</td></tr>
<tr><td colspan="2">Use Case #2: Flightdeck route planning and re-planning</td></tr>
<tr><td>Explanations available in the most adequate format</td><td>Explanations must be available for users at the depth level they need to reach a good understanding of the situation and/or the reasoning the AI presents. The user also must be able to understand if the AI performance is degraded and is thus impairing decision-making instead of supporting it.
The need for explanations to ensure transparency to other stakeholders during the assistant lifecycle shall also be mapped and taken into account during the development.
The intelligent assistant should be also designed to optimise workload. This means that the system should only intervene when appropriate, and should never be perceived as an annoyance by either pilots and ATCOs. For example, the assistant should not constantly provide updates and suggestions, as well as it should take the whole picture into account to avoid generating side effects.</td></tr>
<tr><td>Interaction Modalities</td><td>The same logic of Interaction modalities presented for Use Case #1 should be applicable in this Use Case #2.
Interaction modalities and strategies should fit to the user explanation needs, especially in non-nominal conditions or in edge/corner cases that must be explored during the development.
Different interaction modalities may be needed in training to support understanding of time-critical situations.</td></tr>
</table>

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AI fitting human needs, abilities, and limitations	• A complete human-centred assistant should take into account at the same time the needs, abilities and limitations of the users who will interact with the system. If the system is explicitly designed with only one or two of these (as is the case of many technologically advanced assistants already available) they would not be 100% human-centred.
Use Case #3: Urban Air Mobility	
Interaction design	• A brand new HMI is expected. The human-machine interaction should be designed on the basis of the defined roles, responsibilities and related team interactions, also taking into account human needs, abilities and limitations since the early stages of design.
Explainability fitting users' mental states	• The intelligent assistant should flexibly understand users' needs and provide an adequate level of explanations about what is happening, while also keeping the operators' mental state into account.
Workload management	• The intelligent assistant should be designed to optimise the workload while ensuring that the human is constantly engaged and kept in the loop.
Transparency of criteria to prioritise users	• In crowded airspace, the criteria chosen to prioritise certain users and operations over others should always be transparent.
Use Case #4: Digital Towers	
Customisation	• The intelligent assistant should be customisable in order to be applicable to different airports, thus fitting different situations.
Interaction modalities	• The same logic of Interaction modalities presented for Use Cases #1 and #2 should be applicable in this Use Case #3.
Use Case #5: Airport Safety Watch	
Interaction design	• As highlighted in the Human-AI Teaming principle, the interaction modalities should be designed. The best modality to share aggregate data,

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	information, and suggestions need to be identified in order to ensure smooth interactions, transparency, simple and fast interpretation and understanding, and thus effectiveness.
Use Case #6: Monitoring and prevention of COVID-19 spreading in airports	
Tailor-made experience	● The intelligent assistant should offer a tailor-made experience to passengers. It is expected to start from data collected and predicted at a system level (e.g. the number of people currently at the airport, flight schedules, etc.) which should be crossed with individual needs, characteristics and preferences in order to suggest tailor-made solutions. ● The passengers should be able to understand how their individual needs, characteristics and preferences connect to the intelligent assistant suggestions.
Fitting with airlines' operational demands	● While offering tailor-made solutions to passengers, the intelligent assistant must also take into account the operational demand in order to ensure on-time passenger boarding and avoid side effects (e.g. delays, missed flights, ...). Therefore, airlines' needs and priorities should be taken into account in the intelligent assistant design.
Applicability	● The intelligent assistant should be applicable to all airport contexts .
Usability	● The intelligent assistant should be easily usable by passengers.

Trustworthiness

Table 4: Trustworthiness principle: application in all Use Cases.

For HAIKU, trustworthiness is achieved when **safety**, **security**, **robustness** and **transparency** are ensured, **clear indications of system limitations** and information on potential side effects are provided, and **responsibilities** are well defined.
Training to provide the right level of knowledge on how the intelligent assistant works is also key to achieving trustworthiness and **addressing any users' acceptance resistance**. Furthermore, intelligent assistants have to work

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collaboratively with the user, being **aligned with users' goals** and priorities and values.	
Confidence level	• The intelligent assistant should provide information on confidence levels associated with the actions suggested to the pilots to ensure trustworthiness.
Robustness	• Robustness should be ensured, for instance including an indicator of how the system is capable of dealing with different scenarios.
AI System Knowledge	• There should be an optimal level of knowledge pilots need to build in advance about how AI works. The threshold of required knowledge may vary according to the task.
Accountability	• Roles and responsibilities should be clearly delineated in order to clearly define accountability.
Anthropomorphism	• Research shows that, in unpredictable situations, anthropomorphic features may generate more trust. During a startling event, an assistant with certain human-like characteristics may raise trustworthiness.
Use Case #2: Flightdeck route planning and re-planning	
Information about side effects	• If the intelligent assistant suggests an action, it should also provide information on possible side effects. This might increase trustworthiness, especially in cases in which alternatives are present.
Intention alignment	• The intelligent assistant should be aligned with user goals and expectations. Correcting mechanisms that allow convergence of the assistant suggestions towards pilot goals should be designed.
Accountability	• Roles and responsibilities should be clearly delineated in order to clearly define accountability.
Robustness	• The intelligent assistant should be able to adapt to different operational conditions, including

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	off-nominal scenarios due to e.g. weather, aircraft problems, strikes, and so on.
Use Case #3: Urban Air Mobility	
Accountability	• Roles and responsibilities should be clearly delineated in order to clearly define accountability.
Transparency	• As described in the Human-Centred AI principle, the prioritisation criteria should always be transparent. In a reliable system, the higher the transparency, the higher the trustworthiness.
Use Case #4: Digital Towers	
Ability to manage exceptions with the support of the system	• The intelligent assistant should be designed to handle regular operations, but it is also expected to support and suggest solutions in case of exceptional events. This will increase trustworthiness.
Confidence level	• The idea of confidence level is linked to the idea of managing exceptions. The system should always mention the confidence levels in which certain solutions might be applicable.
Robustness	• The handover of control from Tower ATCOs to the intelligent assistant and vice versa should be adequately designed. How frequently this happens, and how this interaction is set up, is a matter of robustness. The higher the robustness, the higher the trustworthiness.
Availability	• The amount of time in which the assistant is up and running can influence its trustworthiness. The assistant should always be available when needed, and conversely, it should not jump into processes where the human operator does not require its assistance.
Accountability	• Roles and responsibilities should be clearly delineated in order to clearly define accountability.
Use Case #5: Airport Safety Watch	

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Robustness	• The intelligent assistant needs to be robust, ensuring the safety relevance of all findings and thus trustworthiness.
Correlation is not causation	• The intelligent assistant needs to "embed" the safety reasoning that is typical of experts, to avoid flagging purely statistical correlations that are not significant for safety.
Bias prevention	• Safety data captures only specific events, not the normal behaviour and operations of the system. For this reason, training an intelligent assistant on a safety data set may introduce undesired biases. These effects must be understood and mitigated. Identified limitations of the assistant derived from biases must be clearly stated to stakeholders. Corrective mechanisms and a clear governance should be in place.
Use Case #6: Monitoring and prevention of COVID-19 spreading in airports	
Robustness	• The intelligent assistant should be able to adapt to different airport-specific layouts and environmental aspects. The more the assistant is capable of adapting, the higher the trustworthiness would be.

Societal Benefits

Table 5: Societal Benefit principle: application in all Use Cases.

The success of HAIKU's Intelligent Assistants is strongly connected with a **clear understanding and consideration** of possible **societal concerns** and **acceptance issues** - since the early design stages - as well as with the definition of **desired societal benefits**. Apart from self-evident aspects like **safety** and **security**, HAIKU is addressing **cultural aspects** (e.g. the preservation and enhancement of safety culture across all stakeholders), the **human role** in future AI systems, and **sustainability**.	
Use Case #1: Flight deck startle response	
Tackling loss of control risk	• At the moment, the only means of handling a startling event is to train pilots to respond to it. As tackling the loss of control is one of EASA's top priorities, the introduction of AI systems may ultimately lead to more effective strategies to

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	avoid the risk of losing control of an aircraft. This would generate a relevant benefit for society.
Suggested improvements	• The intelligent assistant may be able to collect data about pilots' reactions to startling events, providing an overview of the strategies currently put in place to face those situations. Then, it would generate relevant suggestions on possible mitigation and improvement actions aimed at improving safety.
Use Case #2: Flightdeck route planning and re-planning	
Sustainability	• The intelligent assistant should support more optimised flights, reducing the environmental impact and improving operations efficiency.
Better services	• By proposing the best routes, the intelligent assistant should be able to reduce delays and improve the quality of the air transport service.
Use Case #3: Urban Air Mobility	
Safety enhancement	• The introduction of the IA should be seen as an introduction of an additional safety layer. Given a safety level that must be ensured, the assistant will enable the feasibility of complex operations that will address the growing demands of society.
Service equality	• The intelligent assistant should enable effective management of intense UAM traffic, ensuring equal service to all airspace users and, in case of emergencies, adequate prioritisation.
Societal Acceptance	• The whole UAM development may encounter societal resistance. Addressing societal concerns from the early stages of design is key to ensuring acceptance.
Use Case #4: Digital Towers	
Sustainability	• The intelligent assistant should provide suggestions also considering the environmental impact, ensuring a lower carbon footprint.
Acceptance	• The introduction of the intelligent assistant is expected to impact the human role. On a societal level, the way ATCOs (and their unions) accept (or not) its introduction and the changes in their

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	roles need to be carefully considered and possibly addressed with specific design solutions.
Use Case #5: Airport Safety Watch	
Proactive safety	• The IA, with its capability of making sense of data, identifying patterns, and predicting potential risks and events, should enable a shift towards a more proactive approach to safety.
Enhanced Safety culture	• The intelligent assistant should allow the involvement of all airport stakeholders in safety management, even the ones that have fewer resources and maturity for safety. This is expected to increase the safety culture level in the whole airport ecosystem.
Use Case #6: Monitoring and prevention of COVID-19 spreading in airports	
Virus spreading risk reduction	• The IA should be able to ensure safer flows of passengers and thus it would strongly reduce the risk of spreading viruses in airports.
Public perception	• By ensuring a safer and smoother journey, this intelligent assistant may positively impact the public perception of air transport

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Annex D

2030 Landscapes - Interview grid

Table 6: Interview Grid for aviation Subject-matter Experts

N.	Question
Q1	Focusing on the *whole aviation domain* and looking ahead to 2030: what will be **different compared to today**?
Q2	Imagine it's 2030, what will be your **3 main operational challenges**?
Q3	Fill the shoes of a 35-years old frequent flyer and user of air services: how will your **journey** differ from today?
-	*The technological change is having an important impact on operations.* *In 2030 we expect to have AI-based Digital Assistance in the Ops room, cockpit, airport…* *Please* focus on *your aviation segment and answer the following questions…*
Q4	What do you understand by the term **Digital Assistant**?
Q5	Where do you think it will be beneficial to have **AI-based Digital Assistants**?
Q6	What will be the **impact on operations**? Please list 3 benefits and 3 issues.
Q7	What will be the **impact on the human role**? Please list 3 benefits and 3 issues.
Q8	Are you aware of any **Digital Assistant already in place** in your domain at the moment?
-	*Considering all the aspects that have emerged so far…*
Q9	What are the **top-3 emerging safety risks**?
Q10	What are the **top-3 emerging security risks**?
Q11	Any **other risk** that comes to your mind?
Q12	Going back to the 2030 journey discussed in Q3: any **concern** and/or **potential pain points** that you can envisage?

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Annex E

2030 Landscapes workshop - Materials

Co-design workshop in Rome (Task 2.1)

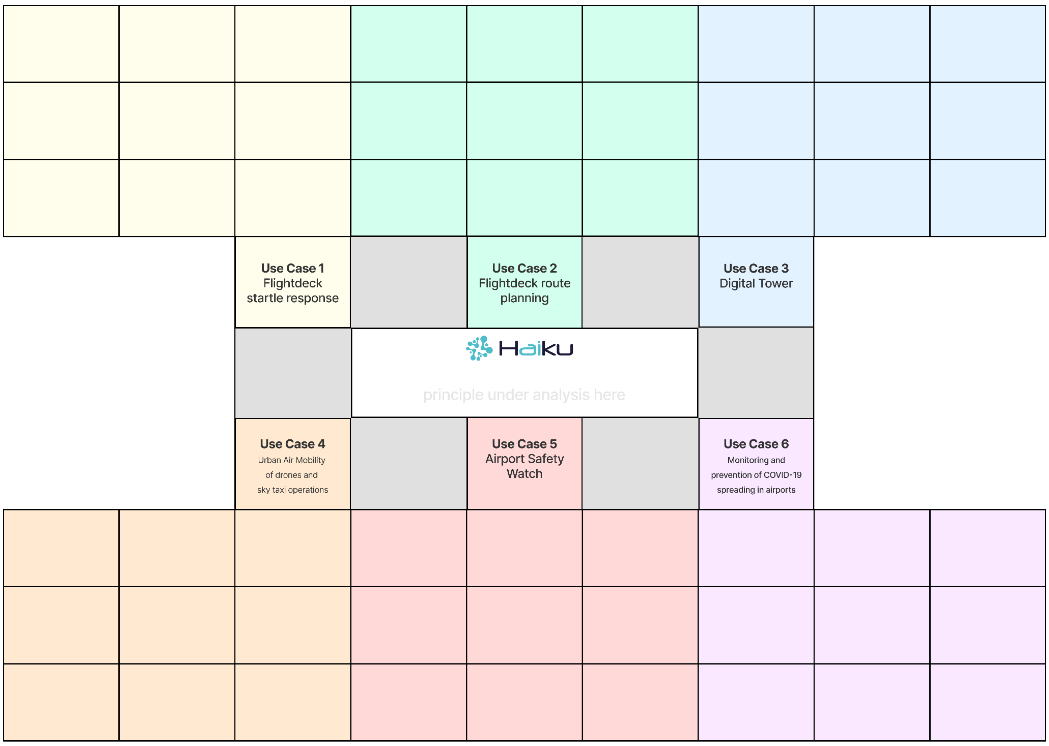

Figure 1: Lotus Blossom Board used during the HAIKU co-design workshop in Rome

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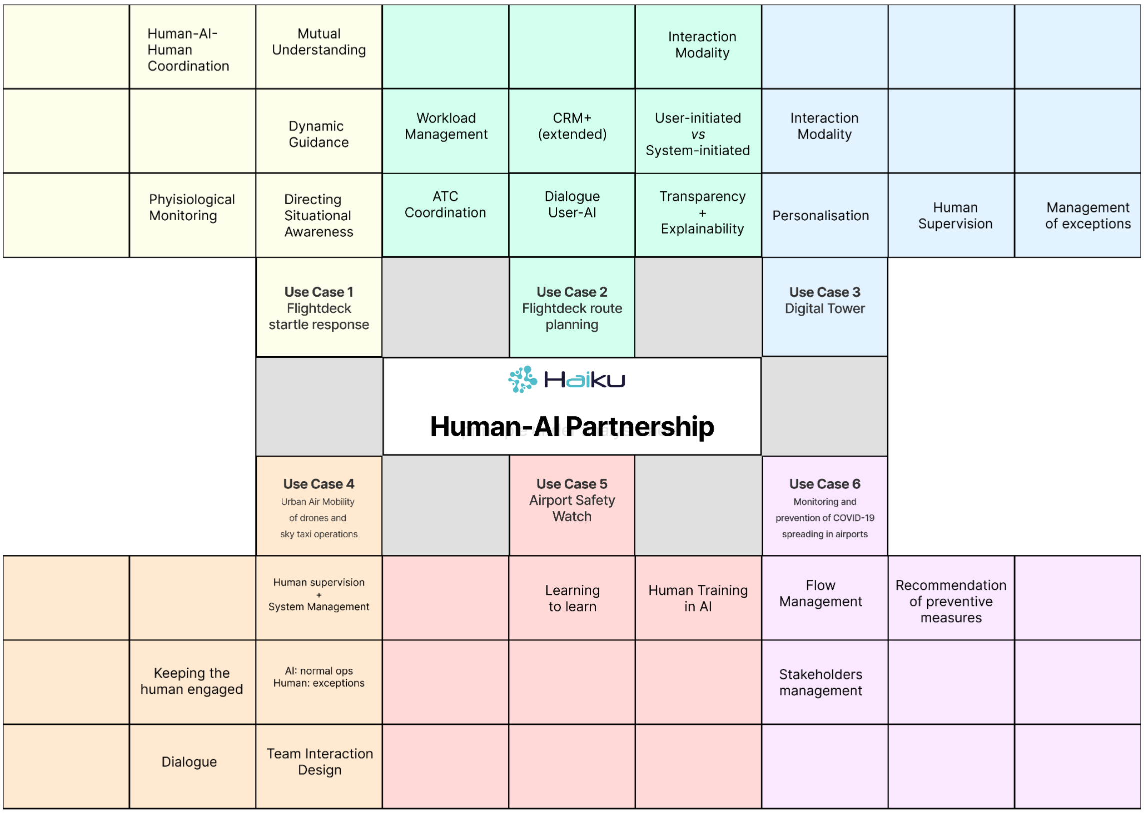

Figure 2: Example of a Lotus Board filled with participants' input

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Co-design workshop in Brussels (Task 2.2)

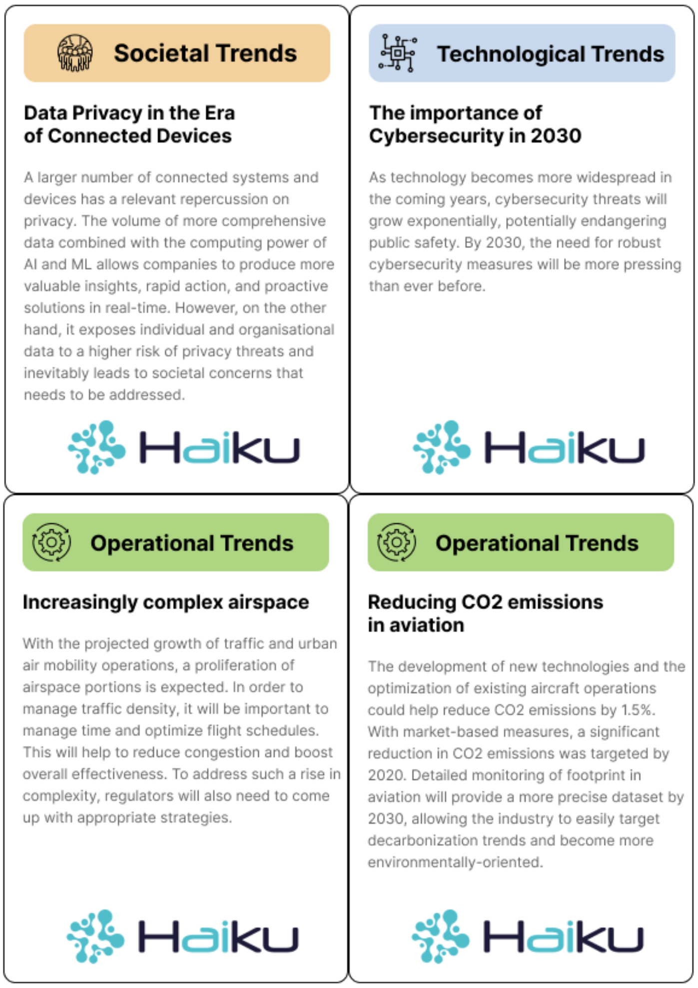

Figure 3: Example of cards used to represent operational, technological and societal trends during the workshop in Brussels

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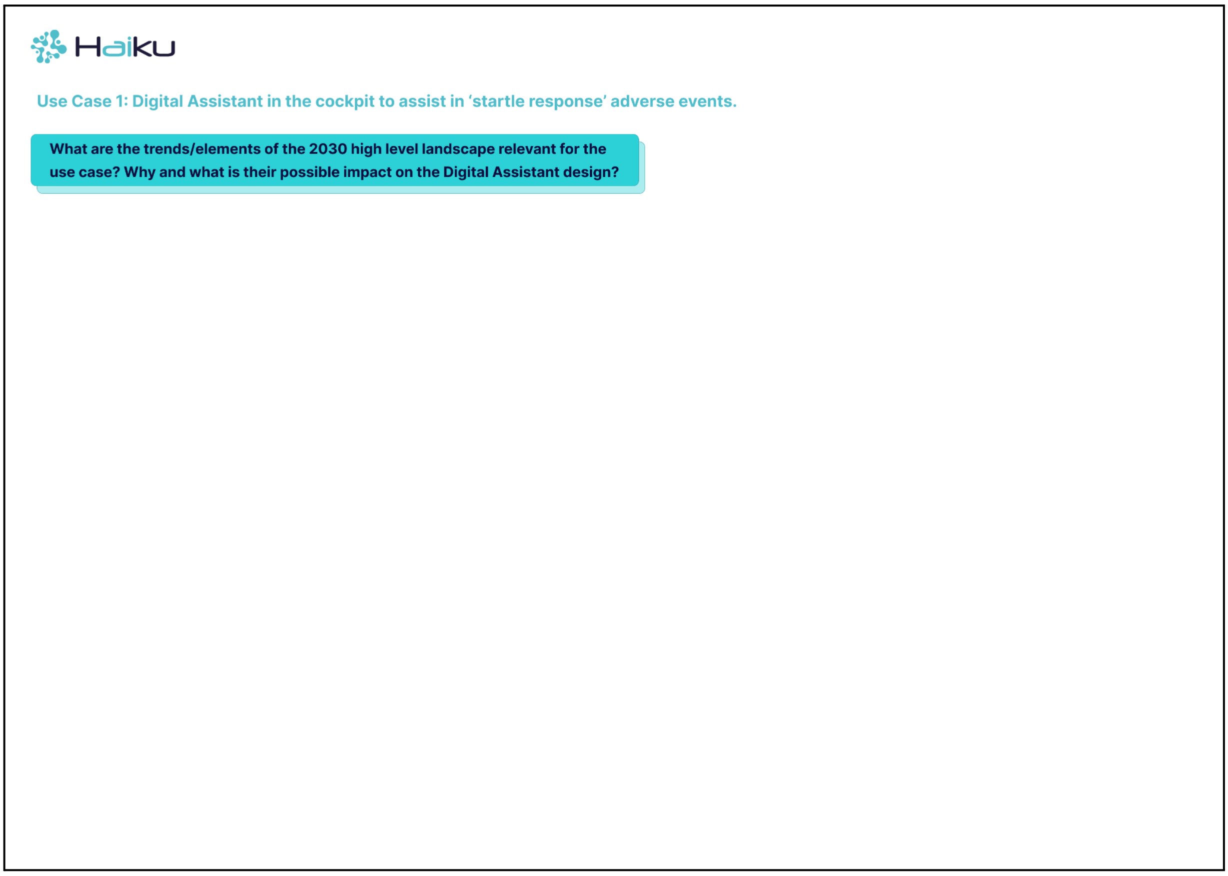

Figure 4: Example of a board used for the first activity of the workshop in Brussels

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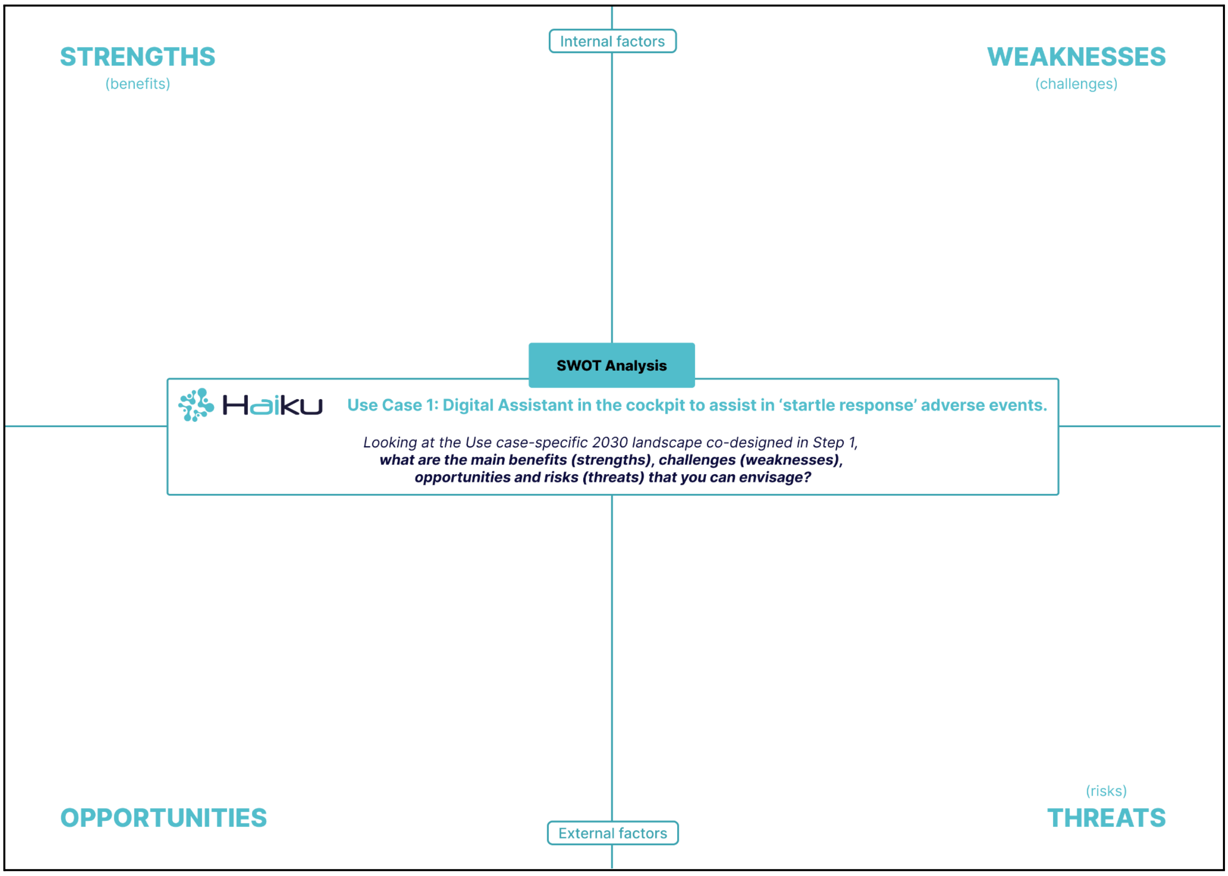

Figure 5: Example of a board used for the SWOT Analysis activity during the workshop in Brussels

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Annex F

Future trends

The future trends in this section are built according to the information collected through the desk research and the experts' interviews. The main sources of information consulted during the desk review are reported in the bibliography. The interview grid has already been presented in Annex D. The results of this work are presented in the following paragraphs.

1.1. Technological trends

The review of the technological trends is performed at a general level and does not only focus on the aviation industry. It has shown the existence of specific pathways in which such trends will further thrive, namely digitalisation, data, personalisation, and decarbonisation. As such, they have been discussed separately in the following subsections.

1.1.1 Digitalisation

By 2030 there will be 1.6 billion fibre broadband subscribers, and 23% of homes will have access to 10-gigabit fibre broadband. Also, 40% of companies will have access to 10 gigabit Wi-Fi networks (Gilder et al., 2021, p18).

The prioritisation of investments and digitalisation of technologies related to performance dramatically changed across all industries due to the COVID-19 pandemic. Future investments are mainly converging towards Cloud as one of the main performance support systems used for banking and financial markets, aerospace and defence, consumer products, healthcare, life sciences, media and entertainment, and petroleum. Artificial Intelligence (AI) has also seen its role enhanced in several industries. Meanwhile, technologies such as the Internet of Things (IoT) and Robotics used to process automation are associated with higher performance in manufacturing industries (Payradeau et al., 2020).

Artificial Intelligence

Machine Learning (ML) and Artificial Intelligence (AI) are making access to information easier, allowing for data-driven decision-making and better connected and synchronised physical components. AI technologies curate and enrich data that "thinks" and "acts" to meet specific sets of business needs, as well as manage IT resiliency and risk management and improve support services. Further, they supply chain planning, resource use and forecasting. When writing about AI, PwC (Brown et al., 2018) makes useful distinctions to think it through three different levels, namely:

1. Assisted Intelligence, which is currently widely available and prevalent in the automotive sector (e.g., GPS navigation programmes offering "best routes" to

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drivers), manufacturing sector more in general (e.g., knowledge management and forecasting platforms), and domotics (e.g. in-house intelligent assistants);

2. Augmented Intelligence, which is emerging today, is fundamentally changing the nature of work as humans and machines collaborate to make decisions;
3. Autonomous Intelligence, which is expected to be fully developed in the future, sees machines as being autonomous (e.g., self-driving vehicles, self-operating production lines) and able to navigate in an ecosystem mainly populated by other autonomous entities.

Therefore, when thinking about future tech trends related to AI, one should consider mainly autonomous systems as a future target, where AI will need to continuously adapt and take over decision-making.

Autonomous intelligence will be developing across fields. Thanks to such advances, medical diagnosis and treatments will move from intuition-based to precision-based. With the help of AI technology, for example, adaptive radiation therapy (ART) systems will automatically identify changes in lesion positioning and more accurately outline the target areas for treatment, reducing the contouring workload from hours to minutes, while the radiation damage can be reduced by 30%. Furthermore, genome segmentation will permit more precise disease identification (Gilder et al., 2021, p. 27).

Autonomous driving technologies will further spread across the various transportation domains. Broadband coverage will be extended beyond the ground into the air and will be available to drones, aerial vehicles and low-orbit spacecraft, even at hundreds of kilometres above the ground (Li et al., 2018). The number of skyscrapers will continue to grow over the next decade as global urbanisation continues, which, moving forward, stresses the need to focus on air emergency rescue (e.g., firefighters, medical services) and air taxis. In particular for air taxis, NASA estimates they will support 740 million passengers by 2030 (NASA, 2018, p. 20).

Air- or water-based drones and vehicles will be operating autonomously in the future through a preselected and defined flight plan, yet allowing authorised remote pilots to take control. Urban Air Mobility (UAM) will progressively enter our everyday life. Three areas are predicted to be the ones with the biggest AI potential in the automotive sector: autonomous fleets for ride-sharing, semi-autonomous features (e.g., driver assistant), and vehicle-integrated health monitoring with predictive, autonomous maintenance, as well as the development of automated driver assistance systems (e.g. parking assist, lane centring, adaptive cruise control etc.). Instead, in the transport and logistics sector, future trends of AI tech development are moving towards autonomous trucking and delivery, traffic control and reduced congestion, and enhanced security (Knoedler et al., 2020).

Specifically in the aviation sector, by 2030 it is likely that AI-based systems will appear in the cockpit and in remote control towers to support pilots and ATCOs.

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Robots

Robots will be further introduced in the manufacturing sector, for which an estimated number of 390 robots for every 10.000 workers is expected. Households with robots will have a growth of 18% (Gilder et al., 2021, p. 19).

Robotics is a dynamic field that has recently developed across fields (entertainment, education, medicine and rehabilitation, military, space, and underwater) and has several applications (robot control, intelligence and learning, human–robot interaction, multi-robot systems, and humanoid robots). The robotics market is going to reach USD 214.68 billion, growing at a compound annual growth rate of 22.8%, by 2030 (Globe Newswire, 2022). While it is not unusual to currently see robotic arms collaborating with humans in assembling tasks, or humanoid robots operating in educational contexts, the future of robotics seems to be directed and influenced also by the parallel technological advances in AI and IoT, particularly in the manufacturing and medical fields.

Collaborative robots will be located along the production lines, working together with the human operators. While they have been mainly used in the manufacturing of computers, electronics products, and automobiles, in the future they will be introduced to new manufacturing sectors, such as the medical industry for analysis and testing (Gilder et al., 2021, p. 105).

Manufacturing will also see the deployment of Autonomous Mobile Robots (AMR). These robots are mainly powered by simultaneous localization and mapping (SLAM) technology to enable autonomous navigation. Such navigation skills can reshape the production and logistics processes, making them more efficient. In production lines and warehouses, AMRs will perform unmanned execution of several tasks, such as material handling, intelligent picking, and stock-in or stock-out procedures (Gilder et al., 2021, p. 106).

Robots will be increasingly present also in the medical field. The surgical robots market today is currently growing at over 19.3% annually and is expected to reach $18.2 billion in 2030 (DLL, 2022). In the next few years, there will be growing adoption of automated minimally invasive surgical procedures, providing a much less invasive approach, as well as a quicker recovery time. Remote robotic surgery will further develop, allowing for critical procedures to be adopted regardless of the doctors' location, thus providing access to medical treatments to a larger population (Poverly, 2022).

Cloud

By 2030 we will manage our possessions in a digital catalogue powered by a 10GB network. Cloud services will account for 87% of the enterprises' application expenditures (Gilder et al., 2021).

Cloud computing mitigates outages and threats to businesses improving resiliency, as it enables businesses to run applications on multiple levels. Cloud facilitates the scaling in response to spikes in demand as well as improving customer and user experiences through the use of their shared data. Modernising core business processes, cloud systems are enabled to share data across industries or Software-as-a-Service (SaaS) applications, and to create and/or participate in different ecosystems and platforms,

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often simplifying collaboration and support for remote work and, ultimately, workflows (Knoedler et al., 2020).

It is foreseen that in the future there will be an established Energy Cloud that will store a great number of data assets based on the distribution of energy sources and end-to-end information (e.g., energy generation, grids, load, storage, and consumption). Together with AI, the ability to store in a Cloud a large set of data concerning energy enables forecasting opportunities, to better manage energy demands based on historical data and energy market prices, to provide a smoother and cheaper flow of energy from producers to customers (Gilder et al., 2021, p. 112).

IoT

The IoT virtually connects physical objects. IoT devices collect and analyse information, and share it with other devices, in order to perform specific tasks. The IoT is already part of our everyday life: intelligent devices can be found in households, factories, vehicles, and cities, making our homes more efficient and tailored around our needs and use, improving production processes by saving time and reducing costs, and saving electricity and energy through greater efficiency (Infineon, 2022).

In the near future, IoT will transform the supply chain. While the traditional supply chain sees every link of the chain depending on the previous link, a supply network will provide materials from several alternative sources through multiple routes. In the future, IoT will allow for the creation of a supply ecosystem based on a collaborative network where enterprises could connect and exchange sources and information relevant to their production. Importantly, this will reduce the impact of a single link on chain paralysis (Gilder et al., 2021, p. 112).

For Infineon, "almost all vehicles will be part of the Internet of Things by 2030" (Infineon, 2017). Cars are now equipped with sensors to detect the distance to objects or people, emergency call systems, wifi or mobile connections. Such connectivity and interaction will be subject to a further push forward. Connected vehicles will make road traffic safer by using cloud-based functions: cars driving ahead will send advanced warnings of slowing traffic, and vehicles behind will ease off the gas before a dangerous situation can arise (Infineon, 2017).

The IoT will also transform cities. Data collected through surveillance systems, bikes, scooters, bus or taxi stations, for example, will be used to create a much more efficient and safe transportation system. Traffic lights could adapt their duration to the actual traffic conditions thanks to specific sensors to detect pedestrians. Cities will not only be safer and more efficient, but public services, in general, will also be easier to access, with information and tailored solutions delivered to the citizens' smartphones (Infineon, 2022).

Extended Reality technologies

Huawei predicts that the number of Virtual Reality (VR) and Augmented Reality (AR) users is expected to reach 1 billion and that eXtended Reality (XR) will be fully immersive by 2030 (Gilder et al., 2021, p. 163).

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Communication networks are evolving to support more and more human-machine interaction experiences to be able to apply XR and involve human senses through naked-eye 3D display, digital touch, and digital smell. XR is a term comprising VR, AR and Mixed Reality (MX). While VR is used to render packaged digital visual and audio content, AR is used to overlay information or artificially generated content onto existing environments, and MX is an advanced form of AR that integrates virtual elements in physical scenarios. (Gilder et al., 2021, p. 162).

XR is considered the next platform trend to establish human-machine interactions, generated by computer technologies and wearables where humans can interact intuitively through three-dimensional environments, spatial computing, and other features. By 2030 XR will reach the stage of full immersion as it will be supported by 8K monocular resolution, 200° FOV, and a gigabit-level bitrate.

Gilder et al (2021, p.163) identified three main tech trends with their related challenges concerning XR:

Naked-eye 3D Displays

Naked-eye 3D displays will be developed if, by the year 2030, the required components for digitising 3D objects, optimising network transmission, and implementing optical or computational reconstruction and display become available. Such technology would allow the recreation of life-like reproductions. Naked-eye 3D Displays' main challenge is that they mainly require support from highly operable networks (i.e., networks capable of delivering 1–10 Gbit/s bandwidth per user, a latency of 1–5 ms, and 99.999% availability). Moreover, their adoption requires real-time capturing of user location and dynamic adjustments.

Digital Touch

When considering digital touch, one needs to take into account two main interaction modes: machine control and hyperfine interaction. Machine control mode, which is mainly used in industrial settings, includes remote driving and remote control interactions. Instead, the hyperfine interaction is primarily used through electronic skin in remote surgery. It is argued that electronic skin powered by flexible electronics in hyperfine interactions has the most development potential for the future. Thus, as electronic skin integrates a high number of sensors able to produce very precise data sets (e.g., pressure, temperature), for it to be applicable and working each square inch of electronic skin will require a bandwidth of 20 to 50 Mbit/s (i.e., an average hand would require bandwidth of 1 Gbit/s). This is considered to be the main tech challenge to overcome in order to be able to develop the tech trend of digital touch, as networks are expected to deliver "1–10 Gbit/s bandwidth per user, availability greater than 99.999%, and latency below 10 ms, or as low as 1 ms in certain use cases" (Ibid., p.166).

Digital Smell

Digital smell includes three technical phases: odour perception, network transmission, and smell reproduction. Electronic noses can be used for odour perception and its further reproduction. These two steps are required to deliver an olfactory experience through the internet. Digital odour perception has been applied to composite materials to form a barcode that changes colour according to the related chemical reaction. For

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odour reproduction, smelling generators for VR games are already available in the market and they release odours from a selected cartridge among the ones available. The future of smell in VR is however going to change. Brain-computer interfaces will soon enable people to directly have an olfactory experience. Use cases for the adoption of digital smell could potentially be scenarios where it is needed to promptly detect dangerous goods and food freshness (Gider et al., 2021).

Looking into a diverse number of non-aviation domains (e.g., automotive, domotics, robotics), few examples of technology were collected (see Table 7) in order to give an overview on the main benefits that are currently targeted by digitalisation. These may provide insights for potential cross-fertilisation opportunities.

Table 7: Examples of technologies for the DIGITALISATION trend

Technology	Status	Features	Field	Expected Benefits
Naked-Eye Display	In experimental phase	Allows the recreation of life-like reproductions.	AR/VR/MR	Safer and more immersive HMI
Machine Learning algorithms (i.e., disease detection)	Already in use	Allows to detect and to recognise a pathology if this is present.	Artificial Intelligence	Supporting doctors in the identification of a specific pathology
Adaptive Radiation Therapy (ART) Systems	Already in use (but not all medical institutions have access to it)	Allows to improve the accuracy of radiation therapy treatments and make the process more efficient.	Artificial Intelligence	Automates the process of identifying changes in lesion positioning and more accurately outline target areas for treatment. The use of AI in ART is expected to reduce the contouring workload and radiation damage.
Socially Assistive Robotic	In experimental phase	Allows to support and help elderly people in daily life activities	Robotics	Home automation and robotics systems can help the elderly in daily home living tasks, sustaining their autonomy and delaying their need for social / health service interventions
Cloud as a service	Already in use	Allows to reduce time/infrastructure costs for IT services and	Cloud	Cloud computing allows businesses to store and to share data securely. It also helps organisations develop, deploy and scale applications

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		easily scale applications		quickly while accessing work across teams in real-time, improving the availability of data and computing resources.
Smart City - traffic alert	Already in use	Allows to know the traffic in the city	IoT	Helping citizens to improve their quality of life and to optimise their movement in their daily activities as well as improving mobility planning and/or possible travelling experience.

1.1.2 Data

By 2030, there will be 200 billion connections worldwide and 1YB of data will be generated annually worldwide. Privacy-enhanced computing technologies will be used in more than 50% of computing scenarios. 85% of enterprises will adopt blockchain technology (Gilder et al., 2021).

As a consequence of the increasing investments in AI and ML, and the increasing pervasiveness of the IoT, by 2030 we will have to deal with massive data sets. As an example, taking the automotive industry under consideration, cars by 2030 will be "connected" which means they will be able to connect and exchange data with networks, and services inside and outside of the vehicle. From the report written by Halmos & Golding (2019), we learn how cars will be able to communicate with at least five different domains in the environment:

1. V2V – Vehicle to vehicle
2. V2N – Vehicle to network
3. V2I – Vehicle to infrastructure
4. V2P – Vehicle to pedestrian
5. V2E – Vehicle to everything

While to a certain extent, some of these connections are already feasible, such a complex and multi-layered connectivity will not solely be applicable to the automotive industry, but rather will be generalised to most industries wherever physical objects (or groups of objects) with sensors, software and other technologies are able to connect and share data with other devices and systems over the internet or through communication networks (i.e., IoT technologies and products).

From a medical perspective, for example, portable devices powered by advanced software and hardware, cloud-edge device computing, and stable networks will be available in grassroots-level hospitals, communities, and households. These devices will collect medical data in real-time and upload the data to the cloud for processing, allowing users to access coordinated telemedicine services and keep track of their

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health from the comfort of their homes (Gilder et al., 2021). Moreover, it is expected that by 2030 biosensors will be in widespread use, and with health data stored on the cloud health will become "computable" (Gilder et al., 2021).

A larger number of connected systems and devices has a substantial impact on the way we need to think about data and privacy. Data "can sometimes directly or indirectly identify people" using certain networks and devices or products. Therefore, data should not only be considered as "technical, performance, service, or usage data, but as Personally Identifiable Information (PII)" (Halmos & Golding, 2019, p.2). The volume of more comprehensive data combined with the computing power of AI and ML radically reduces the latency of information and while on the one side it allows agencies to produce more valuable insights, rapid action, and proactive solutions in real-time, on the other hand, individual and organisational data will also be more and more susceptible to threats. Trust models based on responsible authorities are being replaced by algorithmic trust models to ensure the privacy and security of data, source of assets and identity of individuals and things (Roe, 2022). Algorithmic trust helps to ensure that organisations will not be exposed to the risk and costs of losing the trust of their customers, employees and partners. Emerging technologies need to be tied to algorithmic trust including Secure Access Service Edge (SASE), differential privacy, authenticated provenance, bring your own identity, responsible AI and explainable AI (Roe, 20220). Gilder et al. (2021) write that "as data analytics and data warehouse environments become increasingly complex, traditional data desensitisation technologies seem no longer sufficient". Therefore, privacy-enhancing computation (PEC) technologies are being explored as an alternative.

Challenges and Future Tech Trends concerning *Data Management*

The aviation industry can leverage its results and new solutions from the advancements achieved in data management in other sectors. Through the desk review, two main challenges were identified concerning data:

Privacy and Compliance

Personally Identifiable Information (PII) is always owned by the user of the data, thus, in 2030 more than ever there will be the need to verify who is given access to our data, and for which purposes our data are processed: customer expectations on privacy management currently do not always align with manufacturers' regulations and the needs of whomever ultimately processes and acquires the data. For this reason, as we are going to be generating more and more data worldwide, it becomes fundamental to include "privacy by design" (Halmos & Golding, 2019, p.2) as a holistic concept to be applied during the design of any organisation's ecosystem (i.e., IT, Business practices, Processes, Networked infrastructure etc.).

Cybersecurity

Sensible data can be accessed by unauthorised people if a system where data is collected is harmed and exploited through its vulnerabilities (Abomhara & Køien, 2015; Bendovschi, 2015), disrupting normal operations. Compromising the confidentiality, integrity and availability of organisational data is a current challenge to be taken into consideration moving forward towards the 2030 landscape. Cybersecurity is then

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expected to protect organisational resources both in transition and storage (Abomhara & Køien, 2015,) addressing the protection and mitigation of threats to information assets (Zafar & Clark, 2009). By 2030, the importance of the safety of operations will have become more salient with the widespread use of technologies (Gilder et al.,2021).

Emerging challenges concerning data management in the near future include:

- End-to-end privacy: privacy protection as an integrated and prioritised feature in the entire data lifecycle from personal data collection and use to its retention, transmission, disclosure, and disposal;
- Transparency and trust: designing systems that empower people to be in control of their data (e.g. which data is acquired, with whom it is shared, where it is stored and for how long etc.) will improve customer trust. Turning the datasets used in AI and ML and stored in black boxes into glass boxes will make the entire process of data acquisition and management transparent, well-structured, strictly controlled, and traceable.
- Privacy Policies: designing and embedding privacy policies as a foundational setting in the design process of any IT, digitalised and connected system. Early on in the process, it will be fundamental to design policies and robust procedures to mitigate loss, should security breaches occur.

Moreover, considering current technologies, it must be underlined that currently Privacy-Enhancing Computation (PEC) technologies are being explored as an alternative to traditional data desensitisation technologies.

“PEC technologies are data security technologies used to protect and enhance privacy and cybersecurity during the collection, storage, search, and analysis of private information. PEC supports efficient, high-quality services by protecting personal data from abuse, while allowing effective use of the data, and realising its business, scientific, and social value. In the future, PEC will be supported by more algorithms and widely used in more applications, helping us to find the right balance between privacy and data value” (Gilder et. al, 2021, p.145).

Looking into a diverse number of non-aviation domains (e.g., automotive, domotics, robotics), few examples of technology were collected (see Table 14) in order to give an overview on the main benefits that are currently targeted by this technological trend. These may provide insights for potential cross-fertilisation opportunities.

Table 8: Examples of technologies for the DATA trend

Technology	Status	Features	Field	Expected Benefits
Electronic Health Record (HER)	Already in use	Allows data collection from patients and data sharing across health care settings	Healthcare	Creation of a patient-tailored medical profile, quicker intervention and communication between health departments

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Open data for the Smart City (i.e., EU projects)	In experimental phase	Allows to share data among the citizen to improve the quality of life	IoT	Aims to improve the quality of life by enabling the creation of innovative services for mobility, safety and tourism. In addition to this, this technology will enhance the ability of people to react to unforeseen adverse events
Open data for emergency situations (i.e., https://dati-covid.italia.it/)	In experimental phase	Allows researchers or expert of the sector to find a solution using common data (i.e., https://github.com/pcm-dpc/COVID-19/blob/master/README_EN.md)	Healthcare	Leveraging open data can foster synergies that facilitate the sharing of information, ultimately leading to faster and more effective solutions for all
CityScapes	Already in use	Large collection of urban video data	ML/DL - Urban scene understanding	Performance assessment of models, large volumes of weakly annotated data for DNNs.
LabelMe 12-50K	Already in use	50k images for training and testing	ML/DL - Object classification and classes	Provides a huge amount of data for object detection and classification. As AR/VR and AI are moving forward, such datasets are essential for generalisation and classification
Perception 1.0 by Unity technologies	Experimental - in use	Provides the tools necessary for generating synthetic visual data	ML/DL - Synthetic data creation	Generating near to real-life quality datasets for training and testing, faster and cheaper than real-life capture

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1.1.3 Personalisation

The future is personalised - users are at the core centre of technological innovation. User and customer data can be used to deliver integrated services with better user experience, higher customer value and greater lifetime (Payraudeau et al., 2020).

AI technology will follow such interest, moving into a much more personalised and customised user experience in all sectors. Personalised medical treatment solutions will become a reality soon while deep learning systems will be widely used in areas such as precision medicine, adaptive radiation therapy, and rehabilitation robots so as to create ad hoc interventions, tailored around the patients' characteristics (Gilder et al., 2021).

"Smart" will be another keyword in the world of personalised technology. For example, smart doors, smart smoke detectors, and delivery notifications are already widespread smart services. In the future, Huawei foresees the emergence of new communities capable of delivering a wide range of services to residents, such as virtual community events and smart pet management. Also, the way we interact with home appliances will change. Touch panels, apps, voice commands, and gestures will enable a smoother and more personalised interaction. Appliances and apps will cooperate to anticipate users' needs in different situations. For example, depending on the sleeping patterns, bedroom lighting, temperature, and humidity could be consequently adapted to offer the most adequate facilitating conditions (Gilder et al., 2021).

Transportation will also move towards more personalised options. Mobility-as-a-Service (MaaS), the integration of different forms of transportation, will improve the customisation of the user experience. These systems will identify passenger travel modes, deliver tailored information (e.g. dining, accommodation, tourist attraction, etc.) and build an intelligent transport schedule. With online payment functions integrated, MaaS systems will also offer booking, one-tap itinerary planning, seamless connections between different transport modes, and one-tap payments (Gilder et al., 2021).

The manufacturing sector will exploit AI technology to personalise the customer experience. In the future, consumers will be directly involved in design processes, expressing their opinions and delivering opinions on the design of products. Flexible and new human-centric production models will be adopted. 3D printing will become more widely adopted in several settings, allowing for brand-new personalised production models (Shah et al., 2022).

Looking into a diverse number of non-aviation domains (e.g., automotive, domotics, robotics), few examples of technology were collected (see Table 9) in order to give an overview on the main benefits that are currently targeted by the personalization trend. These may provide insights for potential cross-fertilisation opportunities.

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Table 9: Examples of technologies for the PERSONALISATION trend

Technology	Status	Features	Field	Expected Benefits
Mobility-as-a-Service	Already in use	Integrates different forms of transportation and related information into one application	Transportation	Smoother and much more reliable journey planning and user experience
3D printer	Already in use	Making cheap prototypes to better express an idea and to build at home any needs in few steps, for example, using drafts (Computer-Aided Design, CADs) already available in the market: downloadable from the web (i.e., https://www.thingiverse.com/)	IoT	Encourage people to be more creative and to make prototypes at lower prices
Speech recognition Open API (i.e., Google, etc.)	Already in use	Integrate with existing systems given additional features to them	Artificial Intelligence	Gives the possibility to the end-users to interact with a system in a different way than making a physical operation (i.e., pushing a button), for example, through speech
Smart buildings	Already in use	Create a scenario with the objects connected at home (i.e.,	IoT	Avoid manual operations, like switching the light on when you get home

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		Google home, Apple homekit, etc.)		
ChatGPT	Experimental - Demo in use	Human-like dialogue format communication with AI	ML/DL-Speech	Provide insights and results in dialogue format; improve communication, adapting to the style of different users
DALL.E 2	Experimental- in use	Art and realistic images from natural language	ML/DL - Art (many branches can benefit)	Art and creativity is sometimes the least focused field of research. Human interaction with an artistic AI can provide benefits to learning and creativity, as well as helping evaluate the importance and value of self-interpretabl e pictures to improve text -message comprehension.

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1.1.4 Decarbonisation

Renewables will account for 50% of all electricity generation globally, reducing greenhouse emissions by 55% by 2030 (vs 1990) and achieving carbon neutrality by 2050 (Gilder et al., 2021). Electricity share in final energy consumption is expected to increase from 20% to 30% by 2030 (Ibid.). By 2050, the number of electric vehicles (cars, vans, buses, and trucks) is expected to reach 145 million by 2030, with the potential to reach 230 million vehicles by 2050 with governments' cooperation (GWEC, 2020). By 2030, 50% of new vehicles sold will be electric vehicles and"whole-vehicle computing power will exceed 5,000 TOPS (Tera Operations Per Second) (Gilder et al., 2021).

Renewable energy will drive the energy revolution. Although fossil fuels are still dominating the market, the drop in the cost of renewable energy against the recent increasing prices of fossil fuels is becoming a turning point for the shift towards a greener environment. In addition to such economic benefits, renewable sources are demonstrated to be much more flexible in terms of implementation, thus having a considerable positive impact on other sectors like agriculture and manufacturing.

As an example, in the future Floating PV (FPV) will soon be utilised for photovoltaic capacity and installed in near-shore marine areas, small/medium-sized lakes, and reservoirs, saving lands for agricultural purposes. Such FPV will soon outperform land-based PV (LBPV)(Golroodbari and van Sark, 2020). This has important implications for the agricultural sector, as FPV will reduce land use.

Offshore wind capacity is exponentially growing as one of the main sources of renewable energy. By 2030, an offshore wind turbine is expected to have an average rotor diameter of 230-250 metres and a capacity of 15-20 MW. Such capacity will increase the power produced by 40-50% than of inland wind systems, having the potential to become a baseload technology as Europe's largest single source of electricity by 2040, leading to a consistent increase of clean energy production (GWEC, 2020; Gilder et al., 2021). Innovations have led to a significant cost reduction for offshore wind installations (cost in 2040 is expected to be 60% lower than in 2019) and while current offshore wind turbines are mainly deployed in shallow water areas, future advances in technology will allow for turbines to be installed at a greater distance from the coast and in deeper water.

Cities cause important pressure on the environment (air pollution, carbon dioxide emissions, solid waste, and water pollution). Cities currently consume about 75% of global primary energy and emit between 50% and 60% of the world's total greenhouse gases (UN Habitat). Annual plastic pollution could reach 53 million tonnes every year by 2030 (Barrett, 2020). Therefore, making the most efficient use of resources is a primary concern for cities. The vision of a "Zero Waste City" is spreading around the globe, for which government bodies are proposing a number of deals to reduce waste and pollution by 2030. AI could offer a useful solution for some of the environmental issues within the growth and expansion of cities. AI could support the waste management process, from collection and transportation to sorting and processing. Furthermore, the near future could see the rise of intelligent waste recycling bins, driverless garbage trucks, automated waste sorting robots, and automated garbage recycling devices (Gilder et al., 2021). Nanosensors will track the pulse of cities. In the following years, these sensors will be further introduced into communities and big cities. These will be

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able to accurately identify hazardous, toxic, or explosive gases in the air, thereby greatly improving safety. Net-zero-carbon buildings will be made possible by eco-friendly designs and clean energy sources. Energy management systems will also contribute by effectively managing energy sources and accurately controlling indoor environments to minimise energy consumption (Gilder et al., 2021).

When considering MaaS, its key objective will be to convert public service transportation into on-demand transport where local (e.g. cars, rail, shared cars) and intercity transport (e.g. places, high-speed rail) are integrated providing an intelligent system model able to identify passenger modes and needs and to tailor it based on groups of people with similar schedules. Such service would improve transport satisfaction while providing green transport as it would better manage the resources, allowing for a user-centric experience with lower-carbon emissions (Gilder et al., 2021).

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1.2. Operational trends

The review of the operational trends is focused on the aviation domain only. It is built on the basis of the outcomes of the 11 SME interviews conducted and also integrated with some relevant aspects that emerged during the desk review. Each trend is discussed separately in the following sections.

1.2.1 Increase in airspace complexity

By 2030, a significant increase in operations is expected, reaching around 50.000 flights in a peak day in Europe (approximately +50% over 2019) (EUROCONTROL, 2022). Furthermore, UATM operations will be started, which will rapidly increase during the 30s. Controlling time and optimising flight schedules will be key in handling traffic density, as it would help reduce congestion while increasing overall efficiency. Dedicated actions to maintain, and perhaps even raise, the current level of safety will be required.

As of today, the airspace is divided into approximately 1000 units (eg. TMA, CTR, CTA, etc.) per country. Due to this envisaged increase in airspace complexity, a proliferation of airspace units is expected. One solution could be the creation of separated airspace categories for UATM and traditional operation, which would allow for more efficient management and coordination of the increased traffic levels, especially foreseeing a rapid increase in UATM flight operations. The integration of UATM into the airspace is foreseen as a slow and very gradual process.

The transition from crewed to autonomous aircraft is another big challenge raising airspace complexity. By 2030, it is expected to have autonomous aircraft initially operating in segregated areas, shifting to integration in the next decade. To make this integration possible, strong collaborations between regulatory bodies, industrial players, and other relevant stakeholders will be required to ensure a safe and efficient integration. Overall, regulators will need to develop new strategies and technologies to effectively manage such an increase in complexity.

1.2.2 Towards a more digitised aviation

To face the increased complexity trend and maintain the current level of safety, it is likely that the aviation industry will significantly increase the investments in digitalisation and automation, such as digitising current CNS (Communications, Navigation and Surveillance) systems and ATM infrastructure, using cloud-based services, and speeding up the digitisation process for Tower and Remote Tower systems.

With the use of AI, the industry will create digital twins of the infrastructure and optimise the use of data to improve the efficiency and safety of operations. SkyGuide and MUAC (Maastricht Upper Area Control Centre) are already working in this direction. The trend of digitalised infrastructure will become concrete, but the applications of

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digitalised data will not run at the same speed. Within seven years we will see many projects in which infrastructures are digitised, but not many projects in which the needed data is available. Furthermore, the industry will invest in tools for digital certification, blockchain and other technologies to improve the overall efficiency and safety of operations.

Digital Remote towers are expected to become more prevalent, with the use of more intelligent cameras, digitalised systems and AI-enhanced HMI to improve the interaction between sensors and operators.

EVTOLs (electric vertical take-off and landing aircraft) will become more common and will be operated by a single person with the help of AI automation as a "co-pilot" in the cockpit. The inclusion of advanced technologies such as AI, automation and digitalisation will support the management of UATM. AI will be used to manage the complexity of urban airspace, integrating information from weather, traffic and other sources to detect, process, and resolve issues quickly.

AI will also help operators. For instance, it could be capable of alleviating pilot workload in high-stress situations. It will also help to streamline and present only important information, supporting their situation awareness and reducing the risk of missing relevant aspects. In this case, AI will probably change the human role, which will become a supervisory one.

Smart maintenance

The capability to monitor damage and failures in the aircraft system in real-time will improve fleet operations while reducing maintenance costs and, ultimately, enhancing safety. Real-time data will be collected and provided to ground operations while, at the same time, ground staff will be able to process this data and derive decisions based on it (Mobility4EU, 2019).

As the use of robots and autonomous vehicles is increasing in several domains, aviation will also follow such a trend. Robots and drones will be used for the inspection and maintenance of the infrastructure, improving inspection efficiency and aircraft safety, and reducing maintenance costs (SKILL-UP, 2021).

Smart traffic management

By 2030, innovative technological and operational ATM solutions empowered by AI will be implemented in the ATM domain. With the implementation of AI and its forecasting abilities, a large set of data deriving from multiple sources (e.g., infrastructure, aircraft radars and sensors, ...) will be processed and analysed in real-time, crossed with forecasting and safety records, allowing to safely manage the forecasted level of traffic. ATC/ATM virtualisation will also be possible, providing new ways of managing the exchange of data protocols (Mobility4EU, 2019).

The number of digital remote towers will significantly increase (with thermal-infrared camera technologies, video-based monitoring and tracking functionality technologies). Some multiple remote towers will also start operating to optimise the traffic management of small airports.

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To face the UATM demand, segregated airspace will be used at the beginning with a view to quickly shift towards an integrated traffic management system leveraging new advanced digital technologies and AI systems for highly heterogeneous traffic management.

Smart monitoring

The wide use of smart technologies will ease passenger and environmental monitoring in highly crowded hub areas such as airports.

For example, the risk of spreading viruses will be monitored and managed, thanks to biometric technology which is already partially in place and will be further developed and deployed, especially as a physiological consequence of the COVID-19 pandemic. Smart technologies for theft prevention will also be possible. New cameras and facial recognition detection systems, as well as biometrical methods, will support faster identification of possible threats increasing security. As a consequence of these hyper-monitored areas, issues concerning data privacy and civil rights will be growing by 2030 (Mobility4EU, 2019).

1.2.3 Push towards more sustainable aviation

In 2019, the aviation sector accounted for 2% of global CO2 emissions. This percentage is estimated to increase to 25% by 2050 if no remedial action is taken (Gilder et al., 2021). Experts interviewed pointed out that carbon offsetting is an environmental issue with a large impact on the aviation industry and that must be carefully considered as a global ethical problem to design the 2030 landscape.

In the next few years, the aviation industry's efforts to reduce the environmental impact of air travel will continue. The development of new technologies and the optimisation of existing aircraft operations could help reduce CO2 emissions by around 1.5% (Fielden-Page et al., 2020). With the support of market-based measures, a significant reduction of CO2 emissions “up to a zero-CO2-emission operation” (Ibid, p.18) is targeted from 2020 at present. Thanks to detailed monitoring of footprint in aviation, by 2030 we will be able to have a more precise dataset considering environmental performance. Collecting realistic information on CO2 emissions of flights will support the aviation industry in targeting the decarbonisation trend and thus becoming more environmentally oriented.

Another way to tackle the sustainability challenge could be the introduction of carbon taxes and alternative modes of transportation like trains or electric cars. Experts predict that by 2030, new travel budgets may be measured by an early expenditure of CO2 rather than monetary budgets. Everyone, from corporate companies to individual passengers, might be subjected to these “sustainability” taxes. The new taxation scheme might lead to a new way of thinking, where each actor will have a CO2 budget, and will have to buy a carnet of yearly budget, rather than spending money on tickets themselves. The CO2 budget would have limits, meaning that each will need to manage their budget accordingly to avoid sanctions and fall into a specific yearly/monthly CO2 expenditure budget regulated by international or national laws/rules.

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Furthermore, aviation players are already investing in R&D projects to develop new technologies for aircraft:

- Alternative fuels and propulsion systems

The response to tackle climate change and reduce emissions in aviation is currently focused on the development of three types of clean energy aircraft: hybrid-electric, pure electric, and hydrogen-powered. Full electric/hydrogen-air vehicles will be commercially viable for passenger-carrying regional flights by 2030 (UKRI, 2021). By 2035, we can expect the introduction of a medium-sized, hydrogen-powered aircraft. However, these are long-term solutions that will take several decades to be fully implemented.
By 2030, Boundary Layer Ingestion (BLI) will be available for short/medium-range and narrow-body aircraft. With BLI one of the engines will be placed at the rear of the fuselage with its centreline aligned with that of the fuselage itself, making it easier for the engine to accelerate and produce thrust, reducing engine fuel consumption. Overall, the BLI concept is expected to deliver up to an 8.5 % reduction in fuel consumption. However, current aircraft engines are designed to operate with a 'clean' inlet airflow, such that a significant development will be required to adapt the engines (Neiva et al., 2022).

Research has also focused on the design and development of a small, fully electric propeller-driven ('turboprop') aircraft (Schäfer, et al., 2018). The improved efficiency of the electric powertrain may deliver energy consumption up to 50% less than a conventionally-engine equivalent aircraft.

As for sustainability, there will be a big push for alternative fuels like hydrogen, more efficient operations and optimization of trajectories. Hydrogen-fuelled gas turbine engines could also be available by 2030. Given the low energy density of hydrogen, such engines could be restricted to very small aircraft flying short distances. Furthermore, the combustion of hydrogen produces water vapour which, depending on the altitude and weather conditions, can produce contrails that can contribute to global warming (through the creation of cirrus clouds); a hydrogen-fuelled aircraft would produce between 3.0 and 3.522 times the mass of water vapour (Neiva et al., 2022). Thus, it must be considered that hybrid aeroplanes will have a payload specifically on the reduced capacity of an aircraft to accommodate passengers, as well as on the fuel infrastructure currently available in the airport.

One way to reduce Greenhouse Gas (GHG) emissions from aviation is with the use of alternative fuels, as well as hydrogen and battery electric (Neiva, Horton, Pons, Lokesh, Casullo, et al., 2022). The alternative fuels currently tested are generally known as 'drop-in' fuels and they can be used in current aircraft with little or no modification as they are chemically similar to the fuels currently in use. Advanced biofuels, whose main source and input is made of organic matter (e.g. fatty acids, alcohol, biomass) will be available by 2030 and will potentially reduce emission reduction by 45-90% (Neiva et al., 2022).

- Advanced low-noise technologies

Low-noise aircraft technology will be able to improve the environmental footprint considering noise emissions. This will significantly improve the quality of life for residents living in the vicinity of airports. Also, such advancements would allow for inner

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city transport operations, complying with their transportation's noise emissions standards and regulations (Mobility4EU, 2019).

- Application of AI technologies

The use of AI technologies in the aviation industry could also help to improve the sustainability of air travel by reducing fuel consumption and emissions. However, it is important to note that the development and implementation of sustainable technologies and practices in the aviation industry will depend on a variety of factors that are not solely tied to technological advancements (e.g., political decisions, and economic considerations).

1.2.4 The passenger experience in the era of multimodal transportation

The passenger experience will also be a major focus area in future aviation.

In the future, the aviation industry will focus on reshaping the infrastructure to better meet the needs of current and future passengers. This will include providing more real-time information from ATM to frequent flyers and all passengers, such as targeted take-off times. The booking will be more integrated and multimodal, suggesting the most efficient, eco-friendly and cost-effective options for travel. Going from home to the airport will become much more flexible as more options to reach the destination will be in place. Hence, in the near future, we can expect transport to be more integrated within different modalities through the implementation of transport interchanges, integrated booking systems and apps for multimodal transportation and easy access to real-time information thanks to a mobility-as-a-service approach.

At the airports, passengers will be provided with a complete self-service bag drop and self-service kiosk (SKILL-UP, 2021). Thanks to new technologies, access controls and security checks will also be improved in order to ensure a smoother journey to passengers.

The main concern that experts raised appears to be that right now the systems are often designed with a technology-first mindset. This means that often users are not concretely involved in the development process, and thus there is not an iterative, feedback loop that the developers can leverage to design user-centred technologies. Hence, UX design in the next few years should be the priority to design systems starting from users' needs that are easy to use and understand despite the complexity of AI algorithms.

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1.3. Societal trends

Returning to operations after the COVID-19 pandemic has been a significant challenge for the aviation industry. The sudden decrease in travel demand has resulted in a pilot surplus with the consequent reallocation of personnel in other sectors. As the population grows and airlines seek to increase capacity, it will be a challenge for the industry to find ways to maintain safety objectives while also accommodating such growth. It is expected that the request for cheaper tickets will lead to overcrowded airports and negative impacts on the environment. Additionally, the pressure for efficiency and lower costs will lead to a high turnover of airlines going bankrupt and new ones being created.

The use of autonomous technology in the aviation industry, such as the development of drones and pilotless aircraft, presents both opportunities and challenges. One opportunity is the potential to address the pilot shortage by replacing human pilots with autonomous technologies. At the same time, interviewed experts foresee the need of promoting the profession of the pilot, making it more attractive, especially as automation and AI technology advance.

It is fundamental to stress how central the role of the human will be, even in a highly automated system. Implementing new technologies and procedures to improve safety and efficiency, as well as addressing the cultural clash between older and newer generations of workers in the industry, will be central to the future development of the industry. To make the pilots' profession more compelling, it will be useful to provide more affordable training options making the profession more accessible, as well as stable and secure despite the advancement of automation systems. Furthermore, in terms of pilots' skills, it's important to design new, forward-looking training considering the overall impact of the implementation of autonomous technologies, to find a precise set of competencies that will be required in the future operational tasks of a pilot.

Moreover, the risk that society may not trust intelligent assistants is high, especially if the first assistant coming to market fails, as it will set the precedent for how society views the advent of AI technology. As there are big concerns about societal acceptance and trust in autonomous technology, as well as regulatory and insurance challenges, there may be resistance from current pilots and the aviation industry to adopt AI compared to more innovative sectors such as UATM.

Transparency regarding prioritisation rules is a crucial aspect in the integration of AI in the aviation industry. The prioritisation of different types of transportation, such as drones with medical deliveries versus commercial airliners with low fuel, will have to be carefully considered. The economic and ethical implications of these decisions need to be taken into account, as it involves balancing the needs of different stakeholders, such as passengers, cargo customers, emergency services users and a variety of companies.

The level of acceptance of automation and UATM also depends on the citizens' accessibility and understanding of the technology, and how it can benefit society as a whole and not just a few stakeholders. Hence, it was pointed out the need to

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collectively educate and involve society in the development and integration of AI and UATM to ensure higher levels of trust and acceptance.

Finally, the insurance of AI systems can be a further complex and challenging issue. There are several factors to consider, including who is responsible for the algorithm, who should be held liable in the event of an accident, and how to evaluate the potential risks and benefits of using AI technology.

1.4. Other relevant aspects

The following section delves into the broader implications of the technological, operational and societal trends in aviation. It explores how these trends may affect the role of human operators in the industry. A specific focus is dedicated to the role of ATCO, which is likely to be significantly impacted by the adoption of new technologies and changes in operational procedures within the industry. Thus, ATCOs are a great example that shows how the human role might be transformed in the coming years. Finally, environmental and cybersecurity considerations are also addressed as the two must be taken into account when reflecting on the possible implications of the introduction of new technologies in aviation.

1.4.1 Impact on Human Role

The integration of automation in the field of air traffic control and unmanned aerial vehicles raises important questions on societal acceptance, trust in AI, and potential job loss. While automation increases efficiency, it also raises concerns about human overreliance on the system becoming a high safety risk during potential system failures.

The displacement of jobs due to automation is a general concern, at the same time the lack of workforce for specific professions is incentivising the development of AI and automation solutions in certain domains. The shift in the typical profile of the pilot and the push for single pilot operations also raises challenges and the safety issues of automation must be constantly evaluated.

A balance between automation and human decision-making will be fundamental in order to maintain safety and efficiency. The introduction of new technology should gradually be moving humans into decision-making and managerial roles and away from repetitive tasks. However, as humans are moved further away from the action, they need to work harder to maintain their situational awareness and the required skills to be able to take control over critical situations (e.g., system failures). Furthermore, as the systems become more complex, it can be more and more difficult for operators to fully understand and monitor them, leading to potential safety risks. Hence, a lack of understanding of the limitations and potential failures of the automated systems could be one of the higher and more recurrent safety risks to take into account. It is crucial to have appropriate training and to keep the human-in-the-loop to address any issues that may arise, as well as to ensure that critical tasks such as flow management and responding to changes in the system are still being monitored by human operators. Moreover, as automated systems may not be trained to deal with every possible unforeseen circumstance, maintaining a human-in-the-loop would be crucial in handling

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totally unpredictable events (i.e: erratic behaviour of passengers causing disruptions during a flight).

If totally uncrewed aircraft are envisaged in the future, the challenge will be to understand how to maintain safety even when there is no crew on board. In the coming years, the challenge will be that of keeping the human-in-the-loop even when automated systems completely take over what today are typically considered as human roles. Overall, humans are and will still be a critical component of safe and efficient operations in the airspace as automation becomes more prevalent. However, all the actors involved in aviation - from the pilots to the individual traveller - must be educated to deal with IA and automation, and ultimately co-exist with these emerging technologies.

Finally, while automation has the potential to improve safety and efficiency, it also raises important questions about responsibility, liability costs, and the role of humans in the decision-making process as managers and monitors or as active participants.

The role of ATCOs

The future vision is that controllers, to alleviate their workload, could delegate a large portion of their tasks to machines able to provide support safely and efficiently. Additionally, the increasing use of drones in the aviation industry will also contribute to changes in the role of air traffic controllers. As the number of drones on the screen increases, it will become essential for controllers to extract the context of operations in order to effectively coordinate them. For example, instead of monitoring all 100 drones flying below a certain threshold, controllers will be more interested in identifying any drones that deviate from their expected flight path, as it could indicate a security concern.

These changes will bring new challenges to the table. For example, the introduction of AI-based technologies in ATM might lead to a loss of motivation and to a deskilling process in which the human will tend to assign tasks to the machine. Hence, it is foreseen that by 2030 training and licensing of ATCOs and engineers in high automation levels will be set up in order to move towards human-AI teaming interactions enabling cross-border and remote ATS operations. As a consequence, training will need to be redefined as different competencies will be required compared to the ones delivered in previous training versions.

1.4.2 Environmental aspects

Advances in technology, specifically in the fields of high-performance computing, have the potential to greatly improve weather and climate forecasting in the coming years (World Meteorological Organisation, 2021). However, as we work to predict and understand extreme weather events, it's important to consider how these advancements will impact the aviation industry. With a growing focus on sustainable air travel, it's worth considering how improvements in forecasting may shape the future of the industry. With more accurate predictions of extreme weather events, airlines can make better-informed decisions on flight routes and cancellations, potentially reducing

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costs associated with diversions and delays. Accurate forecasting can also help to improve safety by providing pilots with more information about potential hazards. Furthermore, flight schedule planning can be optimised and that would lead to cost savings and greater efficiency for airlines.

1.4.3 Cyber Security and related Safety Threats

As a consequence of smarter airports relying on large datasets, both from the desk research and the interviews with experts it emerged that cyber security and safety threats are a challenge to be carefully considered. Security requirements that we have today will need to be expanded to manage increased operational capacity and, therefore, an increased volume of data. The more computers and automation that are involved in aircraft systems, the more potential vulnerabilities there are for cyber attacks. This includes concerns about data flow into and outside of the cockpit, as well as communication with air traffic control and ground stations. Aviation/ATM actors will need to understand how new vulnerabilities, mainly introduced by AI/ML algorithms, should be faced to respond to more sophisticated cybersecurity attacks. To do so and increase aviation/ATM cyber-resilience, specific courses on cyber security and safety threats are foreseen to take a predominant place in training. Moreover, to allow security, the infrastructure would need to be reshaped. To address these concerns, it will be important to design systems that are robust and immune to potential cyber-attacks by implementing security checks and monitoring systems, as well as developing efficient and effective contingency procedures in case of cyber attacks. New security checks will be put in place to ensure the safety of autonomous aircraft. This includes not only the screening of passengers but also environmental checks and monitoring of aircraft systems.

To avoid consolidation of vulnerable systems it appears fundamental to include the cyber-dimension in the trustworthiness demonstration of AI-based applications for non-safety and safety-critical operations already at the early stages of the development and design. Moreover, it will be effective to customise and develop cyber intelligence services specific for aviation/ATM, exploring and developing the usage of novel techniques and frameworks to establish smoother human-AI teaming interactions (EUROCONTROL, 2020). Therefore, cyber-security is to be considered and implemented holistically on a systemic level including hardware, software, communication (channels), interfaces, and infrastructure. Additionally, it will be important to continuously identify and address cybersecurity issues through regular testing and updating of systems to be able to actuate a prevention plan.

Safety must be a primary concern as autonomy and AI become more prevalent in the aviation industry. To ensure the safe integration of autonomous aircraft into the airspace, it will be important to establish safe spots, approved routes, and defined contingency procedures to apply in order to maintain high levels of safety. Additionally, well-trained pilots and better weather prediction will also be critical for ensuring the safety of these aircraft.

Another point that was stressed more than once is that it is very important to make sure that the AI system is using quality, reliable data. If the algorithm makes predictions or applies decision-making operations relying on invalid data, safety will be endangered. As ML actions are not transparent, it is very difficult to understand if the

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data used is not corrupted. Hence, making the implementation of AI more complex to understand and deal with, will not help operations. Instead, it will risk an increased cognitive workload. It is important to keep in mind that AI and automation are tools in a toolbox and not the only solution. It is therefore important to find the right balance between the use of AI and human oversight to ensure the safety and security of autonomous aircraft.

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