# Skill transformation map

| | |
|---|---|
| **Deliverable ID:** | **D4.2.** |
| **Project acronym:** | **Engage 2** |
| **Grant:** | **101114648** |
| **Call:** | **HORIZON-SESAR-2022-DES-ER-01** |
| **Topic:** | **HORIZON-SESAR-2022-DES-ER-01-WA3-1** |
| **Consortium coordinator:** | **Deep Blue** |
| **Edition date:** | **29 May 2025** |
| **Edition:** | **00.08** |
| **Status:** | **Final** |
| **Classification:** | **PU** |


## Abstract

This deliverable reports on the activities conducted and the results achieved within Engage 2 Task 4.2, “Study pathways to skills and career development”. Based on the findings related to future technical and operational trends in T4.1, a three-step empirical data collection process has been applied to understand the ATM sectors’ likely evolution related to human roles, professions, skills and education within the future of 2035-2040.



Co-funded by

## Authoring & approval

### Author(s) of the document

| Organisation name | Date |
|---|---|
| Veronika Takacs, Deep Blue srl | 05.02.2025 |

### Reviewed by

| Organisation name | Date |
|---|---|
| Andrew Cook, University of Westminster | 03.12.2024 |
| Thomas Feuerle, TU Braunschweig | 27.11.2024 |
| Graham Tanner, University of Westminster | 03.12.2024 |
| Georg Trausmuth, Frequentis AG | 27.11.2024 |

### Approved for submission to the SESAR 3 JU by[1]

| Organisation name | Date |
|---|---|
| Peter Hecker, TU Braunschweig | 11.12.2024 |
| Micol Biscotto, Deep Blue srl | 12.12.2024 |
| Micol Biscotto, Deep Blue srl | 12.02.2025 |
| Micol Biscotto, Deep Blue srl | 19.02.2025 |

### Rejected by[2]

| Organisation name | Date |
|---|---|
| S3JU | 11/02/2025 |
| S3JU | 18/02/2025 |

### Document history

| Edition | Date | Status | Company Author | Justification |
|---|---|---|---|---|
| 00.01 | 07/11/2024 | Draft | Veronika Takacs | Initial version |
| 00.02 | 27/11/2024 | Draft | Veronika Takacs | Draft for first internal review |

[1] Representatives of all the beneficiaries involved in the project

[2] Representatives of the beneficiaries involved in the project

| | | | | |
|---|---|---|---|---|
| 00.03 | 03/12/2024 | Draft | Andrew Cook<br>Thomas Feuerle<br>Graham Tanner<br>Georg Trausmuth | First internal review completed |
| 00.04 | 05/12/2024 | Draft | Veronika Takacs | Draft for second internal review |
| 00.05 | 11/12/2024 | Draft | Peter Hecker | Second internal review completed |
| 00.06 | 05/02/2025 | Draft | Veronika Takacs | Update methodology and results |
| 00.07 | 19/02/2025 | Final | Micol Biscotto | Integration of final comments from S3JU |
| 00.08 | 29/05/2025 | Final | Micol Biscotto | Integration of comments from S3JU |

# Engage 2

THE SESAR 3 KNOWLEDGE TRANSFER NETWORK

Engage 2

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114648 under European Union's Horizon Europe research and innovation programme.

# Table of contents

# 1 Introduction

This deliverable is intended to introduce the main activities conducted within T4.2. “Study pathways for skills and career development”. Leveraging on the trends -identified in D4.1. [3]- in which the air traffic management (ATM) sector will likely be moving in the future, potentially important new skills have been identified along with some key topics to include in future education in the aviation industry. Based on the answers collected, the Skills Transformation Map for Air Traffic Controllers has been developed as an example. Finally, important needs and challenges related to future education within the field have been identified and collected. The results and recommendations introduced within this deliverable shall serve as the basis of recommendations for the pathway for skills and career development within the same task of Engage 2.

As a result of technological advancements, the role of humans in complex socio-technical systems such as the air transport industry is foreseen to evolve. Therefore, the skills and knowledge that is required by future workforce to accomplish everyday tasks will also change, mostly due to an increase in digitisation, automation, and artificial intelligence. As a consequence, anticipating these future skills and knowledge is necessary in order to strategically design adequate training and educational paths to ensure the smooth transition of professionals in the field [2]. T4.2 therefore aims to identify the most important skills and knowledge related to a variety of future scenarios, as well as it aims to provide recommendations on potential topics within future curricula. In addition, the characteristics of future education are also discussed, including the most relevant expectations and challenges related to the successful recruitment of future generations in the air transport industry.

With the specific aim of attracting more individuals to a career in ATM and at the same time having academia provide education to future professionals that is in line with these trends, T4.2. specifically focuses on how the identified future skills may require the re-definition of future curricula, in order to ensure strong and effective links between academia and industry. In order to provide a diverse range of perspectives, university researchers and university students were asked to provide their insights and thoughts related to the future skills and education in the air transport industry, by organising two consecutive workshops for the two samples respectively, as well as collecting answers via an online survey. Finally, with the aim of creating an example of the “skills transformation map” for the role of air traffic controllers (ATCOs), an online interview with a training instructor for air traffic controllers has been conducted.

**The deliverable consists of four major parts:**

The “Future changes in aviation” chapter introduces the latest results of research related to future skills, based on sister EU projects.

The “Methodology” chapter consists of the detailed introduction to the three-step methodological approach taken to explore future roles, skills and future training.

The “Results” chapter includes all the results of the three-step research process, emphasising the key words to take into further consideration.

The “Discussion” chapter included a reflection on the results captured in the previous sections.

# 2 Future changes in aviation

To ensure a smooth, safe and secure operation within aviation, proactively anticipating future trends and related challenges is a vital process inspiring many research and development projects within Europe.

By looking ahead to the future of 2035-2040, the most important general trends are related to global challenges (such as climate change/extreme weather events), technological progress, cybersecurity and environmental protection [7] [9], all of which require prompt actions to investigate future skills needed and to re-shape education. When focusing specifically on the evolution of the human role in the ATM sector with significantly increasing traffic, a higher level of automation and collaboration with assistants based on e.g. artificial intelligence (AI) or higher levels of automation is envisaged, focusing actively on the challenge of how to ensure a smooth and trustworthy collaboration process where humans are kept in the loop [5]. With a particular focus on future changes within the ATM sector, one key action from the human perspective will be the development and implementation of mitigation strategies to prevent skill degradation due to an increased level of automation and the gradual introduction of new AI systems. Related to that, the definition of role-based responsibilities between humans and AI systems will be a crucial prerequisite for successful human performance in a highly automated and complex socio-technical working environment [6]. In addition to the introduction of AI-based systems, other types of technological advancements related to virtualisation, digitalisation and augmented reality are also foreseen to shape the human role within the field. Virtual control centres and remote virtual towers are expected to result in a more efficient and flexible use of resources [11], requiring, on the other hand, a new set of skills and the adjustment to a generally different physical working environment and new scenarios. Moreover, another important trend foreseen is the integration of remotely piloted aircraft systems (RPAS) traffic into a non-segregated controlled airspace, resulting in important implications regarding new procedures, techniques, and tools for controllers, and in general for the aviation industry [12].

Translating these future trends into the competences required, Table 1. summarises the most important knowledge, hard and soft skills as well as cognitive abilities of future professionals in the ATM sector, collected within the SKILL-UP and HAIKU projects [6] [12].

| Technical competences | Soft competences |
|---|---|
| Knowledge related to geography and different meteorological conditions | Strategic planning |
| IT knowledge | Decision making |
| Management of complex robot systems | Situational awareness |
| Knowledge of augmented reality | Coordinating among different actors |
| Knowledge of traditional methodologies | Communication with both humans and technology |
| Knowledge of rules, regulations, and ethics | Teamwork |




Co-funded by the European Union

| | |
|---|---|
| Legal and compliance | Safety mindset |
| System and safety knowledge | Flexibility |
| Emergency and risk management | Adaptability, openness to change |
| Technology/hardware skills | Stress management |
| Data and digital literacy | Multitasking and multi-environment approach |
| Language skills | Attention and vigilance |
| Process management | Logical reasoning |
| Route planning and re-planning | Emotional stability |
| Separation techniques | Attention to details |
| | Scanning |
| | Speed perception |
| | Prioritisation |

**Table 1: General future competences within the aviation sector [6] [12]**

As far as future technical competences are concerned, the majority of new expertise is linked with new technical systems (e.g. augmented reality or complex robot systems), new regulations (e.g. legal and compliance, procedures, ethics), and safety aspects (e.g. safety approach, language skills, emergency and risk management or keeping up with the traditional methodologies in order to prevent skills loss). When considering future soft competences, the list indicates a shift towards the importance of more managerial, coordination skills along with the skills to team up and communicate with humans and AI-based systems, as well as highlighting the necessity to be flexible and open to change and adapt to new technologies.

# 3 Methodology

Human factors assessment methodologies at large focus on the impact of certain changes on humans' activities and importantly, humans' performance in complex socio-technical systems, including certain cognitive activities (e.g. workload, situation awareness, etc.). When looking to the future, the estimation of the impact of certain changes is challenging, as the analysis is not based on facts, but on plausible future changes that have not *yet* happened, making the reasoning on future impacts a challenging task for experts involved in the process.

To overcome this difficulty, the methodology of introducing future scenarios is widely used in the framework of international research and development activities [13]. These future scenarios aim to sketch plausible futures, including the implications of a variety of external drivers.

Within the Engage 2 project, the scenario building technique was specifically used to collect insights related to the following questions:

- How will the **human role** likely emerge in the future as a consequence of the envisaged future changes in the ATM sector?
- What specific **human skills and knowledge** will be needed to perform successfully in the envisaged future?
- What kind of **professions** will likely become obsolete, and what new professions will likely emerge?
- How should the **content and the format of the current education** change in order to make sure that these changes are well reflected in the curricula?
- How should university education be modified in order to **successfully attract and recruit young talents** for the future of aviation?

## 3.1 Backcasting methodology

In order to support the reasoning on future skills and education within ATM sectors, the backcasting methodology was applied for gathering empirical data related to the aforementioned questions. Backcasting was originally developed by Robinson [10] as a "method for exploring the implications of alternative development paths and the values that underline them". By using this methodology, challenges of the future can be approached from the opposite direction, in which the future desired conditions should be firstly envisioned to then map out the different pathways to achieve them [8]. While forecasting identifies what *might happen* in the future, starting from today, the backcasting technique analyses the actions that should be taken to attain a certain, desired goal [11].




Co-funded by the European Union

## 3.2 Scenario development

In order to successfully apply the aforementioned methodological approach, the development of hypothetical future scenarios was necessary. To generate the scenarios, the following steps were taken:

1. **Identification of future trends:** a process conducted in T4.1. [3] to identify trends by analysing recent developments in the field and by projecting these into the near and mid-term future.
2. **Selection of trends:** based on the results of Step 1., the most relevant trends were collected.
3. **Scenario generation:** by clustering the most relevant trends, four hypothetical scenarios were generated to apply during the data collection activity.

### 3.2.1 Identification of future trends

The task of identifying the future trends in the field of air traffic management has been undertaken by T4.1 within the Engage 2 project. Among a variety of other sources (e.g. AI based literature review and different networking activities), two surveys have been developed and sent out to universities and, parallel to that, to industry, asking participants to outline their views on future developments [3]. More specifically, participants were asked about the technical and operational trends they consider as relevant in the next ten years, along with the challenges they expect regarding the current and future workforce. Table 2. summarises the answers of both participants groups.

| | Industry | Academia |
|---|---|---|
| **Technical trends** | • Opportunities related to **virtual/augmented reality**,<br>• Integration of **drones** into the airspace ATM/UTM,<br>• **Data communication** (air-air; air-ground),<br>• General **automation** as well as the management of **AI and ML**,<br>• **Sustainability** and green propulsion systems,<br>• **Information security** and cybersecurity, and,<br>• Flying above **stratospheric altitudes**. | • Human Factors and **HMI**.<br>• **New design methods for aircraft components and structures** (e.g. eco-driven and sustainability-driven approaches).<br>• **Digital Twin** for all Life Cycle aspects.<br>• Development of **new functional materials.**<br>• **New computing techniques**, e.g. quantum.<br>• **Eco- and Sustainable Design**.<br>• **Open Science/Open Source software** and knowledge transfer - especially from institutions funded by governments.<br>• **Digital communication navigation and surveillance**, New Space and Satellite-based CNS.<br>• **Green aviation and transition**. |

| | | |
|---|---|---|
| **Operational trends** | • **Climate change** and better predictions for **weather forecasts**,<br>• More **data based steered operations** and flight execution,<br>• **Passenger experience** (reliable information provided to passengers),<br>• Administrative and **bureaucratic burden** to manage future air traffic,<br>• ATM concepts in **highly automated environments** (e.g. automation of tasks and controls),<br>• **Competition with other industries** to talents,<br>• **Social attitudes** towards aviation. | • **Increased automation**, increased **machine to machine communication**, increased dependency on GNSS and **satellite-based services**. Increased use of internet-based protocols, increased resource virtualization, increased dependency on services-based architectures (ground and airborne).<br>• **Flexibility** to adapt to requirements.<br>• **Free routes and TBO**.<br>• Ground and airborne high level of **automation**.<br>• **Civil-military coordination**.<br>• Human role in an environment with **an increasing level of complexity and automation**.<br>• User and **social acceptance**.<br>• Infrastructure development.<br>• **Multimodal regulation**.<br>• Evolution of the **Societal point of view**: needs and constraints.<br>• **Policy & regulatory**. |
| **Challenges** | • The challenge of **hiring and retaining technical staff** (need for attracting young engineering talents),<br>• The importance of **reaching out to the new generation**,<br>• The importance of training and reskilling existing staff in a **more interactive and reinforced way**,<br>• The **financial burden** being the result of the increasing number of personnel. | • High level of exchanges and interactions between industry and academics. **Ensuring seamless transition between academic programmes and the advanced technical and scientific expertise required by industry**. Making the workforce **highly adaptive and proactive to contribute to innovation acceleration**.<br>• **Environmental protection**.<br>• **Proper dialogue with specific industries and sectors** (e.g. ANSPs) to understand their needs and to reflect those in a balanced way in the curricula.<br>• Digitalization should not lead to **reduced chances of being employed**.<br>• **Adaptability to change**.<br>• **Less human resources** in ATM due to automation and AI. |

**Table 2: future trends identified by the industry and academia in ENGAGE2 T4.1. [3]**

In order to align with and reflect the most important future trends introduced in Chapter 2., three different hypothetical scenarios were developed focussing specifically on technical and global trends, and one additional scenario has been developed to reflect the envisioned changes in future education, as identified in T4.1. In the following section the scenarios are introduced in detail.

### 3.2.2 Scenario #1: Multimodal transportation business model

After the slowdown due to the COVID pandemic, a significant increase in air traffic complexity and movements is expected with no trend reversal foreseen. Moreover, thanks to advanced technologies, new types of aerial vehicles are being developed and are entering the skies. The integration of unmanned aircraft into the airspace is expected to play a significant role in the future, resulting in even more complex traffic management. Along with the continuous rise in air traffic, there is a need to cope with the increasing number of passengers, by giving their needs and experience a high priority [12]. Moreover, airports are foreseen to start a transformation process in order to become part of an end-to-end transport network that operates and integrates other transport modes and infrastructures [4]. Based on these foreseen future trends, the following hypothetical scenario was developed to serve as the basis for data collection.

**Imagine you are in the future of 2035-2040!**

**Alongside with the ever-growing increase in air traffic of manned aircraft, new aerial vehicles (e.g. drones) are entering the airspace as key parts of new transportation business models. In addition, the integration of the airspace is an exciting new trend, just like the potential new direction of flying above stratospheric altitudes. In this future, passengers' experience is of high priority, and trajectory based free route operations are ensuring a seamless traffic in the crowded airspace. Connected to this vision, a more general multimodal transportation system is foreseen, requiring stronger and structured coordination between aviation and the other transport modes.**

### 3.2.3 Scenario #2: Digitalisation, automation and AI

Due to the quickly evolving advancements in automation, robotics and artificial intelligence (AI), the working environment and the nature of work are under transformation with virtual and augmented multimodal sensorial solutions foreseen to be the key in modernising the ATM service as well as to reduce costs [12]. Along with the technological solutions, skills required from employees to do their job are also expected to change. The future workforce is foreseen to spend more time on activities of monitoring and supervising systems and spend less time on physical activities where machines exceed human performance [9]. Parallel to these trends within the air transport industry, there is a growing awareness of the threads related to cybersecurity, requiring industry to develop a shared approach to tackle cybercrimes, prevention and detection strategies [7]. Based on these foreseen future trends, the following hypothetical scenario was developed to serve as the basis for the data collection.

**Imagine you are in the future of 2035-2040!**

**As a result of digital transformation, communication, navigation and surveillance are fully digital, control towers are digitalised, and digital twins are available in operation. There is an increased machine-to-machine communication with an increased dependency on satellite-based services. Thanks to the advances in technologies, the envisaged highly increasing level of air traffic can be safely managed, with new technologies and AI autonomously performing a variety of traffic management tasks and with the supervision and coordination of human operators. Consequently, more robust security and cybersecurity systems and measures are in place to ensure safe and secure operations.**

### 3.2.4 Scenario #3: Environmental protection, and extreme weather events

In recent decades, the aviation industry has been considered as one of the most significant contributors to global carbon emissions, emphasising the need for prompt actions towards the use of renewable, eco-friendly resources within the sector. As an important future challenge closely related to climate change, the frequency and severity of extreme weather events is expected to increase, indicating the potential future need for advanced knowledge and skills in crisis management and response [12]. Based on these foreseen future trends, the following hypothetical scenario was developed to serve as the basis for data collection.

**Imagine you are in the future of 2035-2040!**

**As a result of a special focus on environmental protection, sustainability, seen by many in the past as an aspiration, has become a 'given', an essential attribute of future air traffic that is non-negotiable. As a result, for instance, applying new, eco-driven design methods and producing new functional materials for aircraft components is within the focus of aircraft manufacturers, and more generally, the aviation community as a whole, requiring high investments and efforts. In addition, extreme weather events, stronger than today, require better predictions, more flexibility and quicker reactions, thus creating more disruption in the general air traffic management.**

### 3.2.5 Scenario #4: Future education in the air transport industry

In order to pay particular attention to the future trends and challenges foreseen for education within the field, a fourth hypothetical scenario was developed, specifically including the insights gained in T4.1. related to future training. The major trends included in this scenario were linked to the importance of training a highly adaptive and innovative future workforce, a close collaboration

between academia and industry, the modification of the format of education and the prevention of potential skill degradation as a result of automation. Based on these foreseen future trends, the following hypothetical scenario was developed to serve as the basis for data collection.

**Imagine you are in the future of 2035-2040!**

**In the future, one key focus of university education is to train a future workforce that is highly adaptive and proactive to contribute to innovation acceleration. This requires universities to continuously interact and understand the needs of the industry and reflect it in a balanced way in their curricula. By having new technologies and a more interactive way of teaching, the key challenge of education is associated to the potential skill decay of human operators who are having a more passive role (monitoring, supervising...). Moreover, universities are continuously challenged to address the social attitudes towards aviation and therefore, effectively attract young talents.**

The selected timeframe of 2035–2040 was strategically chosen to capture a pivotal transition period in the evolution of the European Air Traffic Management (ATM) system as outlined in the European ATM Master Plan 2025. This period marks the full deployment of Phase C (targeted operational improvements) and the early implementation of Phase D, which is focused on the digitalisation of the European sky.

Focusing on the 2035–2040 period allowed to examine not only the culmination and operational maturity of Phase C developments but also the initial implementation and early impacts of Phase D technologies. This overlapping phase is particularly critical because it represents a time of transition—where legacy systems, emerging innovations, and evolving operational paradigms must coexist.

Furthermore, when assessing future skill needs and workforce readiness, it is essential to anticipate changes that will not only define the end of Phase C but also shape the trajectory toward 2045. By studying this in-between window, we position ourselves to better understand emerging trends, identify transitional challenges, and proactively prepare for the competencies and roles required in a more digitally integrated and automated ATM environment.

## 3.3 Workshops

Within T4.2., Engage 2 has organised two online workshop sessions to collect insights about future professions, skills, and modifications in future university curricula required to successfully address future trends and prepare the workforce accordingly. In order to gain a comprehensive understanding about the aforementioned topics, the two workshops were targeting different audiences: university researchers and students, respectively. By applying the principles of convenient sampling, participants for both workshops were recruited throughout the social network of the project consortium. The maximum participants' number per focus group was set to ten, in order to smooth the interaction and gather experts' feedback during the event. Each workshop lasted three hours, during which participants were first introduced to the objectives of the event and the most important findings of T4.1. After that, they were re-directed to a visual interactive collaboration platform (Figma board), to

facilitate their active engagement, and were introduced to the four scenarios, to discuss them together. Figure 1 shows the agenda followed during the workshops.

| Time | Description of activity | Duration |
|---|---|---|
| 9:00-9:10 | Introduction to the objectives of the meeting | 10 mins |
| 9:10-9:45 | Scenario #1 | 35 mins |
| 9:45-10:20 | Scenario #2 | 35 mins |
| ***10:20-10:35*** | ***Coffee break*** | ***15 mins*** |
| 10:35-11:10 | Scenario #3 | 35 mins |
| 11:10-11:45 | Scenario #4 | 35 mins |
| 11:45-12:00 | Wrap-up | 15 mins |

**Figure 1: Agenda of the online workshops**

### 3.3.1 Online Workshop for researchers

The online workshop organised for senior researchers took place on the 23rd of September 2024. The event hosted ten participants currently employed as senior researchers in Austria (n=2), Germany (n=2), Serbia (n=3), Spain (n=2), and Sweden (n=1). To encourage discussion among participants, during the workshop the following specific questions were asked related to:

**Each of the technical scenarios (#1, #2 and #3)**

- How do you envision the human's role in this scenario?
- What kind of new skills are likely to emerge?
- How do you think the content and format of the current curricula should change to cover these future trends?
- What kind of new professions are likely to arise?
- What kind of new professions are likely to disappear?

**The scenario related to the future of education (#4)**

- From the above-mentioned trends, which ones are already being addressed in education?
- From the above-mentioned trends, which ones are NOT being addressed in education?
- How do you think the content of current education should change in order to reflect these trends?
- How do you think the format of current education should change in order to reflect these trends?
- How do you think the collaboration between academia and industries could be strengthened in education?

- How do you think that the attraction of the future workforce could be addressed by educational institutes?

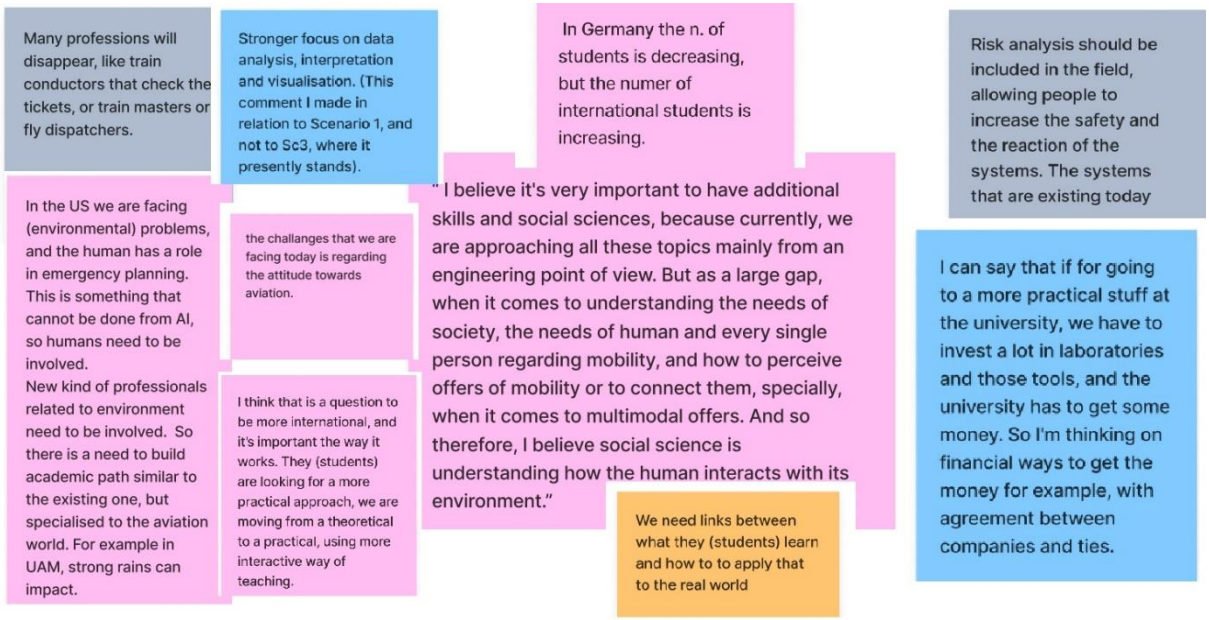


**Figure 2: Screenshots from the online workshop with senior researchers (Figma)**

### 3.3.2 Online Workshop for university students

The online workshop organised for university students took place on the 14th of October. The event hosted five participants, currently being enrolled in graduate or postgraduate levels of education in Germany (n=1), the Netherlands (n=1), Italy (n=1), and Spain (n=2). In order to gain a comprehensive understanding on the views of the two different samples (senior researchers and students), the same scenarios have been applied in both workshops, however, the questions, in the case of students, were slightly different from the ones addressing senior researchers. To encourage discussion among participants, the following questions were asked during the workshop:

**Technical scenarios (#1, #2 and #3)**

- How do you see the evolution of human role in general within these scenarios?
- Thinking about the university you are currently attending: to what extent are these topics addressed by the current curricula?
- Having these scenarios in mind, what kind of new skills do you foresee as crucial in future aviation? Are you currently trained to acquire these skills? How do you think you could most successfully acquire them?

- Having these scenarios in mind, which part(s) of your curricula do you consider as outdated? In which terms?
- Having these scenarios in mind, do you foresee the change of ATM professions (emerging or obsolete professions)?

**The scenario related to the future of education (#4)**

- Thinking about the university you are currently attending, what are the trends that are already being addressed at your university?
- Can you name/share best practices from your university related to how these trends are addressed? These are practices that you think are beneficial, and advantageous in focusing on the future of education.
- Having these scenarios in mind, what aspects of your current study programme do you consider outdated? In which terms?
- What kind of changes and innovations do you think would be crucial in your current study programme to better address the aforementioned trends? How would you change the current curricula in structure? What kind of obstacles do you see in realising them?
- Thinking about the way of teaching (style, format), what would be your most important requirements for the future? Can you share some existing aspects you are satisfied with or dissatisfied?
- What do you see as the most important challenge related to attracting the future generation and young talents?
- What ideas or tips would you suggest, recommend to universities to effectively address the challenges of future recruitment and social attitudes towards aviation?


**Figure 3: Screenshots from the online workshop with students (Figma)**

After the two workshops the most important results were identified and collected due to qualitative data analysis. These key results served the basis for the online questionnaire that has been sent out in the second stage of the data gathering process.

## 3.4 Online surveys

In order to acquire data from a more diverse sample, the intermediate step of an online survey was considered as necessary. To do so, the most important topics and key findings of the online workshops were identified and collected, and based on them, two separate surveys were prepared and sent out for a sample of senior researcher and students (different from the ones of the online workshops). The questions and answer options were all based on the information collected during the workshops. The surveys were distributed online in October 2024. By using the method of convenient sampling, respondents were directly contacted within the social network of Engage 2 consortium.

Participants in this stage of the data collection were asked to answer the following questions (for the complete survey, see Appendix 1.):

- Related to the vision described in the introduction, how do you envision the human role will evolve in future aviation?
- According to your perception, what are the current professions(s) that will become less relevant or obsolete in future aviation?
- According to your perception, what new professions (non-existent today) will likely emerge in future aviation?

- Related to this envisioned future, how important do you think the following skills will be on a scale from 1 to 5? (e.g. situation awareness, quality assurance skills, emergency preparedness, etc. For the complete survey, see Annex 1.)
- Related to this envisioned future, please rate the importance (1-5) of the following topics in future curricula!
- According to your day-to-day experience, to what extent do you agree with the presence of the following challenges in education? (e.g. low salaries/scholarships, accreditation challenge of new courses, etc. For the complete survey, see Annex 1.)

  To what extent do you think the following solutions would be important for future education in your field? (e.g. Internationalisation of students, more interactive courses, partly distance learning, etc. For the complete survey, see Annex 1.)

By using convenience sampling, a sample of N=6 for senior researchers has been collected. In the case of students, a sample of N=24 participants has been collected through convenience sampling and advertising the survey at the Engage 2 winter school (Belgrade, January 27-31, 2025). Respondents of the survey for the senior researcher represented the countries of Italy (n=4), Australia (n=1), and Türkiye (n=1), while respondents answering the student survey represented the countries of the United Kingdom (n=2), Germany (n=8), Sweden (n=1), Italy (n=6), Spain (n=2), France (n=1), Turkey (n=1), Hungary (n=1) and the Republic of Ireland (n=1). One student respondent did not disclose their nationality.

## 3.5 Online interview

As the last step of the data gathering process, the trends, along with the skills have been collected, grouped, and customised to the future profile of air traffic controllers, as an example role for the skills transformation map. This step was considered necessary as the changes of the skills collected in the previous steps were addressing the more general level of the ATM sector as a whole, while to draw the transformation of specific skills from now to the future, these insights must be further analysed focusing on specific job profiles, in this case, the one of air traffic controllers. For this purpose, an ATCO training instructor has been invited to participate in an online interview where he was introduced to the hypothetical scenarios related to future technical trends along with the skills that were considered as key in the future. After the introduction, he was asked to reason each skill, by answering the following two questions:

- “Within this scenario, ATCO needs this skill to....”
- “In what way is it different from today’s skill?”
- “Any additional skill to add?”

# 4 Results

This section summarises the results of the three related steps of the data gathering process: the workshop, the survey and the interview.

## 4.1 Online workshops

### 4.1.1 Technical and operational trends

When it comes to the hypothetical scenario of multimodal transportation business models, the greatest challenge is foreseen to be related to the contradiction between growing traffic, automation and manually driven traffic. Senior researchers emphasised the challenge of either making higher automation on the new vehicle entries or maintaining a manually driven mode and facing potential capacity issues. Related to this vision, it will be particularly important for human operators to **understand and predict system operation and have a clear understanding and protocol of how they can collaborate with it**. Researchers also highlighted the potential issue of approaching new trends solely from the technological point of view, while **there seems to be a gap when it comes to understanding the needs of the human and the society regarding mobility**, and how to reflect these needs in offers related to multimodal transportation systems. It would therefore be **important to understand how humans would and will interact with their environment in the future**, how to enhance their experience by understanding their needs at individual level and at the level of society at large. When it comes to reflecting these needs in the university curricula, the greatest challenge seems to be related to **the lack of customised courses in human factors**. As explained, most of the already existing courses (e.g. traffic psychology, sociology, ergonomics) are introductory ones, focusing on a rather general level of human behaviour in socio-technical systems, and they are less customised to the different operator profiles, as well as lacking a holistic approach to understand transportation from a societal point of view. As emphasised by students, **human factors related topics are perceived as insufficiently represented in the current curricula**, and they are **less customised to specific majors**, targeting other mobility sectors as well. As further highlighted, social science courses should not only be taught to pilots and air traffic controllers, but also to individuals who manage public relations, specifically in crisis (e.g. delays, flight cancellations or accidents). Related to the envisioned multimodal transportation, **some very operational professions are foreseen to become obsolete**, such as the one of train conductors or station masters, as they will **likely be replaced by automation and AI**, while the number of **professionals controlling unmanned aerial vehicles is expected to rise**. As a consequence, the **frequency of everyday human-human interaction** within the future multimodal transportation model is foreseen to significantly **decrease and gain specific relevance in handling non-nominal, emergency situations**. Students during the workshop also discussed the **skills related to remote control towers** in an increased traffic future scenario. As emphasised, being in charge of multiple airports requires a completely different type and level of knowledge than what they have today. Being in charge of one airport today requires familiarity with the characteristics and implicit rules or know-hows related to that airport, which is a more nuanced, detailed understanding. The **remote tower controller,** in contrast, **needs to have a more holistic knowledge with strong coordination, organisational and multitasking skills, however, their knowledge about different airports is less detailed.**

Focusing on the scenario of digitalisation, automation and AI, the most relevant topic to be further addressed in future training is **human-AI teaming**. Related to this topic, having a **holistic overview of the system's functioning** will be the key for successful collaboration. As explained by both the senior researchers and students, having a high level of situational awareness, where one does not only understand the system but is able **to project its functioning to the future** ("being one step ahead of the system"), as well as **oversees its vulnerabilities and potential failures** will be crucial when teaming up with AI. Related to this vision, the **topic of trust, explainability and transparency should be better addressed in future curricula**, according to the sample of senior researchers. In addition, they also mentioned the importance of **analytical thinking**, as a skill being relevant today and in the future as well. As it has been highlighted, **monitoring and coordination skills** will be crucial to be able to downgrade future systems to a controllable way, and if needed, to manage air traffic manually. To reach this goal, **system architecture understanding should be addressed with more detail in future training**. One important challenge to that has been mentioned by senior researchers during the workshop is the **potential monotony of the future tasks in the air traffic sector**, as a higher level of AI and automation may cause a potential cognitive underload among professionals who are expected to supervise and monitor new systems, instead of being actively engaged in task execution.

Closely related to automation and AI, a major topic to emphasise even more in the future curricula is **cybersecurity**, along with the ability of future professionals to detect the potential hazards and violations behind unexpected system behaviours. For this reason, a more intensive introduction of **professions such as "data manager" and "system supporter" is envisaged as crucial** in the next five years, with these professionals coming from data science, with strong quality assurance skills. As it has been underlined during the workshop, they do not only need to be recognized at the maintenance level but shall rather be considered **as active contributors to decision making processes**. In addition, a critical skill identified related to the AI and automation scenario is **communication, both between human-machine and human-human**. As highlighted, the introduction of AI and automation in the future is expected to require a working atmosphere in which psychological safety and open communication plays a vital role. During their online workshop, students also expressed a strong need for the **topic of AI-related ethics and liability to be built in the future curricula**, along with the need for studying **up-to-date programming languages** at the university, which, as reported is not always the case in some of the countries involved in the current research.

When discussing the hypothetical scenario related to environmental protection and sustainability, the importance of topics such as **sustainability, life cycle management and eco-driven design methods were** highlighted **for future curricula development**, providing knowledge from the operational domain with **skills for environmental protection and meteorology**. Moreover, senior researchers identified the topic of **emergency preparedness** and **emergency management** as crucial in the future of air transportation. Closely related to the topic, **adaptability and flexibility** were mentioned as key skills in the future, in order to be trained for a wide range of emergency situations and to be able to adapt one's strategy according to the actual problem. When discussing future training paths, the need of a potential new path has been highlighted for safety managers with a potential specialisation on aviation. As reported, this would be especially important for urban air mobility, as in case of certain frequent weather conditions (e.g. strong wind or heavy rain) they are expected to be affected the most. In this new envisaged field, coordination, communication, planning and organisational skills will be vital due to the substantial number of actors involved in a **multi-agency emergency management** procedure. For this reason, as highlighted during the workshop, the **cross-training of the future**

**professionals** in this field would be beneficial to become aware of the information needs of each actor and therefore ensure smooth coordination. Closely related to emergency preparedness, the importance of a greater focus on **post-operation analysis theory and practices in future curricula** has been discussed during the workshops, along with the need to address the **topics of just culture in greater detail**.

Table 3. summarizes the most important results of the online workshops.

| Topics for future training | Impact on professions | Needs on training | Needs on future competences (knowledge, skills, abilities) | Challenges identified |
|---|---|---|---|---|
| **Multimodal transportation** | | | | |
| • Human-AI Teaming<br>• Social science (human behaviour, needs and motivation)<br>• Traffic psychology<br>• UX and explainability | • Some very operational professions will disappear, such as “train conductors” who check the tickets or station masters, or flight dispatchers. They will be replaced by automation and AI.<br>• The number of professionals controlling unmanned aerial vehicles will increase. | • Knowledge in social sciences (e.g. environmental psychology) to understand the needs of humans and the society regarding mobility and to reflect these needs in multimodal transportation systems.<br>• It is not only pilots and ATCOs who need to be trained in social science but the ones who manage public relations, specifically in crisis (e.g. delays). | • Ability to anticipate and predict the automated system’s behaviour<br>• Knowledge on Human-AI Teaming to understand the ways of collaboration with an AI based system<br>• Knowledge in human behaviours, needs and motivation on individual and societal level (ergonomics, psychology, sociology).<br>• Knowledge related to user experience.<br>• Knowledge related to explainability and trust.<br>• Communication skills, especially in non-nominal, emergency situations<br>• Stronger coordination and organisational skills compared to today | • Either make higher automation on the new vehicle entries or keep manually driven mode maintained, facing potential capacity issues.<br>• Social science courses are not customised or tailored to the specific field. They are introductory courses. |

| Topics for future training | Impact on professions | Needs on training | Needs on future competences (knowledge, skills, abilities) | Challenges identified |
|---|---|---|---|---|
| **AI and Automation** | | | | |
| | • Need for more jobs/professions like "data manager" or "system supporters", not on the maintenance level but on the active level – supporting decision making | • A data manager in terms of skills: different studying points. They do not come from the domain. They do not need to understand how e.g. separation is being managed. They need to come from data science.<br>• Cybersecurity will need to be improved, faster than technology. This needs to be reflected a lot more in future curricula.<br>• The system architecture understanding is something that should be taught to future operators.<br>• Co-creative design of tools, with the help of end-users, to understand and include their natural behaviour and way of thinking, the way they approach processes. | • Strong quality assurance skills to understand if the system still works the way it should, to detect any kind of violations from its expected behaviour.<br>• A holistic overview and detailed understanding of system behaviour.<br>• Technical knowledge and situational awareness to anticipate potential vulnerabilities of the system.<br>• Communication skills (human-human and human-machine)<br>• Communication and empathy to create a working atmosphere with psychological safety and just culture.<br>• Analytical reasoning, rigorous reasoning and mathematical skills.<br>• Supervision skills from the human, to downgrade the system to a manually controllable level.<br>• Emergency preparedness & management skills<br>• Adaptability: being prepared for any kind of situation.<br>• Flexibility to adapt new technologies<br>• Vigilance and managing monotony | • New knowledge shall not be loaded all on the shoulders of the existing ATCOs. New professions (e.g. data manager) should be introduced in operation, collaborating with ATCOs. |

| Topics for future training | Impact on professions | Needs on training | Needs on future competences (knowledge, skills, abilities) | Challenges identified |
|---|---|---|---|---|
| **Environmental protection and sustainability** | | | | |
| | | • People who are familiar with hazards and safety, meteorology, natural disasters. Even a new training path could be built for safety managers – to be specialised for aviation. This will be especially important for UAM.<br>• Cross-training could be important, in order to become aware of the information needs of the other actors | • Communication skills<br>• Coordination skills<br>• Organisational skills<br>• Planning skills<br>• Adaptability<br>• Environmental protection and meteorology.<br>• Decision making skills<br>• Collaboration skills for multiagency teamwork | |

**Table 3: Skills and training needs identified during the online workshop**

### Connection to 'Destination 2050' Decarbonisation Drivers

The four hypothetical scenarios used in this study were designed to reflect major trends expected to shape aviation by 2035–2040. These scenarios are also aligned with the four main decarbonisation levers identified in the Destination 2050 roadmap: technology, sustainable aviation fuels (SAF), economic regulation, and air traffic management (ATM). Table 4. below illustrates this alignment.

| Scenario | Linked Destination 2050 Driver(s) | Corresponding Future Skills / Themes |
|---|---|---|
| Scenario #1: Multimodal Transportation Business Models | ATM improvements | • Coordination across transport modes<br>• Human-AI teaming<br>• System supervision<br>• Multimodal traffic integration |
| Scenario #2: Digitalisation, Automation and AI | Technology, ATM improvements | • Data science and AI<br>• Explainability and trust in systems<br>• Cybersecurity<br>• Monitoring and supervising automated systems |
| Scenario #3: Environmental Protection and Weather | Sustainable aviation fuels (SAF), Technology | • Eco-driven design methods<br>• Environmental and meteorological awareness<br>• Emergency preparedness<br>• Lifecycle management |
| Scenario #4: Future Education | Economic regulation, Policy & workforce | • Curriculum reform<br>• Skills for innovation and adaptability<br>• Stakeholder alignment<br>• Integration of social, ethical, and regulatory topics |

**Table 4: Skills' connection to Destination 2050 Decarbonisation Drivers**

This mapping ensures that the future skills explored and recommended in the deliverable contribute meaningfully to achieving Europe's aviation climate goals while also addressing the evolving needs of the sector.

### 4.1.2 Future requirements in education

When discussing the fourth hypothetical scenario related to future education, some senior researchers (e.g. Sweden and Germany) have mentioned the challenges of the **dropping number of students** at their university. As explained by these participants, aviation in some countries is facing the issue of **becoming a less prestigious field to work in**, therefore a successful branding of this field is a key task to address the next generation's attitudes towards aviation. As a result, **marketing activities for high school and university students (e.g. career centres, career days) and for the younger generation**, starting from the age of twelve are conducted, by inviting school children to visit the university, and be part of the conversations around future challenges in aviation. Related to this strategy, the importance of **adjusting communication channels** (e.g. using a variety of social media channels) **and the language of communication** to the next generation has been emphasised. As explained by the students, **there is a great interest in** expanding one's knowledge in the topic of sustainability. The growing interest in sustainability, as highlighted during the workshop discussions, appears to originate primarily from a broader societal awareness being implicitly linked to environmental concerns, rather than being exclusively driven by scientific or technical innovation. As this is one of the "hot topics" among the next generation, courses focusing on this particular aspect tend to be very attractive, therefore are **recommended to be part of the general marketing strategy of universities**. As mentioned by many senior researchers, the **internationalisation of the study paths** in aviation could be one important factor in attracting more students to the field, by offering scholarships to students to study in other countries. Related to this idea, however, the accreditation of international courses at home universities is foreseen as a challenge. In addition, as highlighted by senior researchers, **Ph.D. salaries in some European countries are considered as low** which poses a challenge on ensuring the future of research in the field. As suggested, the role of industry in this case would be specifically important by undertaking some extra compensation and by offering a clear career path to follow and a workplace in return. Nonetheless, this solution would further strengthen the collaboration between academia and industry. As explained during the workshop with senior researchers, there are efforts to include industries in shaping future curricula, however, **industry partners are sometimes perceived as less aware of anticipating their own needs in terms of knowledge, skills and abilities required by future professionals**.

Related to the format of future training, the need for increasing the number of **practical courses** ("learning-by-doing") and a more **interactive way of teaching** has been discussed both by the senior researchers and students. To address this, lecturers outside the university are often invited to deliver courses or lectures on new topics, in order to ensure that the curricula stay up-to-date. Related to this trend, the **potential advantage of short courses from external stakeholders** (e.g. IATA) in the university curricula was discussed to acquire specific skills in specific topics. In order to ensure a high number of students attending each course, the **possibility of hybrid learning** was discussed, with offering **online courses** video recorded by professors. As the students during the workshop explained, online video courses would not only support them to focus on more practical, specific questions when meeting their professors in person, but this approach would also give the opportunity for "**lecture exchange with other universities"**, thus contributing to knowledge exchange. Nonetheless, having a video lecture uploaded would **enhance the visibility of the lecturer and the university ("networking")**. This approach would, however, require an **initial extra workload** and the acquisition of new skills from university lecturers, who would need to learn how to record their lectures and share them online. One particular challenge mentioned by the senior researchers related to digitalised education is the

tendency of universities to **stick to the status quo**, as new content and format of courses would certainly require significant additional effort from the accreditation, financial, logistic and human resources point of view. Table 5 summarizes the most important results of future education scenario.

| Best practices | Needs | Challenges |
|---|---|---|
| Actively addressing 12-year-old students and above inviting them to be part of the daily research and to discuss the challenges of the future with them (Germany).<br><br>Career days, career centres to support students in finding their career path. | A greater emphasis on topics such as sustainability and environmental protection to attract more students. | Numbers are dropping in some countries. |
| | Internationalisation could be the key. To go for scholarships and learn from other universities. | The major challenge here can be regulations, the accreditation of international courses at home universities. |
| Lecturers from outside the university are invited to address new topics for which there is no internal knowledge (e.g. sustainability). | Today's students look for more practical courses, instead of long theoretical ones. There is a need to invest in laboratories.<br><br>Needs of students related to education: shorter track, quick, easy to use knowledge, highlighting more the practical advantage of the knowledge they need to acquire. They are asking for sustainability in their lecture.<br><br>It would be beneficial to include short courses from external stakeholders (e.g. IATA) in the university curricula to acquire specific skills in specific topics. | |
| | The industry could undertake some extra compensation for Ph.D. students and also for degree students. They would have a clear path to follow and a workplace in return. | Ph.D. students in some European countries have very low salaries |
| | Communication channels and people: we need diverse channels and the younger generation to communicate with | |

| | | |
|---|---|---|
| | the future workforce. Job fairs, open days are important but for the younger generation the language should be changed. | |
| University staff is being trained on how to use video tools (media, camera use, green screen) | Students have difficulties focusing for hours. Shorter, more interactive sessions would be needed.<br><br>There is a need for hybrid learning modes, incorporating online classes with materials video recorded in advance. | This is financial, logistics, accreditation and workload issues for universities. Recording videos in the flip classroom requires a lot of new knowledge and work from the teachers. Sticking to the status quo. |
| During their education, there are various occasions for university students (e.g. info days) to communicate with industry stakeholders about future career paths. | Some students tend to lack a clear career path after their degree. | There are efforts to include industries in shaping future curricula, but they are perceived as less proactive, and less aware of their own needs, or by the time they are, it is too late for the university to accommodate their needs. |

**Table 5: Challenges, needs and best practices related to future education**

## 4.2 Online surveys

### 4.2.1 The evolution of human role in future air traffic

When asked about the general evolution of the human role within the future hypothetical scenarios, senior researchers highlighted the somewhat contradictory role of **humans being the supervisors of the system but also keeping their decisional power**. As emphasised by them, the human role will remain fundamental in making decisions, therefore the greatest challenge related to these visions will be about how to keep humans in the loop enough to possess all relevant information for effective decision making.

As one of the respondents from the students' survey underlined, humans might become less involved in the main management of an aviation system such as an aircraft, but **AI** will increasingly come alongside it, becoming an additional **"staff-member" to reason with**. On the other hand, it still remains necessary to have someone able to monitor the situation on board and able to make decisions fast in critical situations based on experience. The human role is foreseen to be focused on introducing correct data to the information system, conducting extensive safety analysis to increase redundancy in the systems, and anticipating causes of incidents/accidents to prevent them.

Related to the change of landscape in future professions, senior researchers envision the job profiles of **"admin personnel in ANSPs", "professions with a high degree of repetitive activities", "most passenger services", "loading of catering products", and "jobs related to security processes" as becoming obsolete**. On the other hand, respondents expect "remote ATCOs, "cybersecurity managers", "experts of AI for aviation systems" to become more important in the future, while also emphasising the importance of more hybrid roles (technical background and passenger assistance functions) and a **more horizontal, holistic knowledge instead of being experts in one narrow segment of the sector**:

> *"The reduction of human workforce in the frontline area due to new technology could probably require a professional able to overview the whole ecosystem of aviation, overcoming the current categorization and getting a horizontal knowledge instead of a vertical one*."
> (Student respondent of the online survey)

### 4.2.2 Future skills

When asked about which skills they find important for the future operation in the ATM sector (see Figure 4), both the senior researchers and students highlighted the importance of **situational awareness** to understand and predict the behaviour of automated systems. Researchers also found equally relevant the **monitoring skills** one needs to have to supervise automated systems, while students rated **organisation and coordination skills** for multiagency collaboration as equally important. On the other hand, both senior researchers and students rated the need for **mathematical skills** and **communication skills** (human-human) as less important ones from the list. When asked about whether there are any additional skills they would mention as important for the future, students added the skills and knowledge related to using low altitude airspace, fast decision-making skills in critical situations, technical skills for HMI, and skills related to individualised customer support.




Co-funded by the European Union

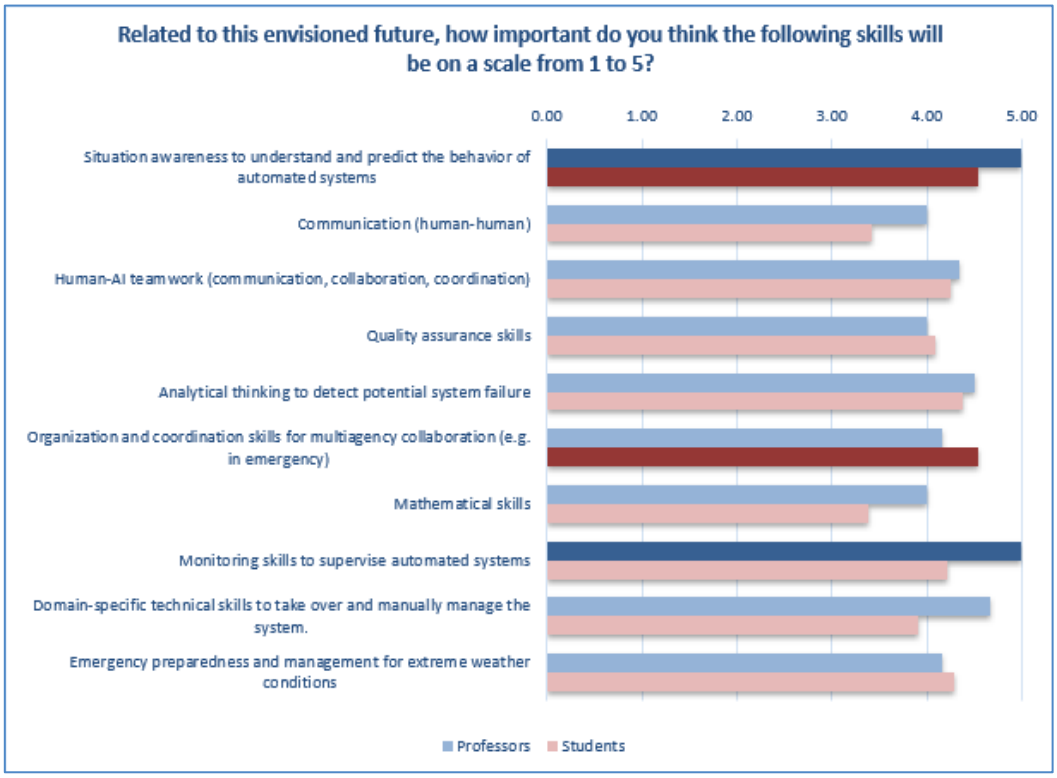


**Figure 4: Comparison of senior researchers and students regarding the perceived importance of future skills**

### 4.2.3 Future curricula

When asked about the importance of potential topics in future curricula (see Figure 5), senior researchers rated the options of **"Explainable AI & Trust in the system"** and **"Data science"** as the most relevant, while students rated **"Safety and emergency management"** as well as **"Sustainability and environmental protection**" as the most important topics to focus on in future education. Contrary to what has been highlighted during the workshops, respondents of the online survey from both the students' and the senior researchers' perspective rated the importance of social sciences as less important. When asked about whether there are any additional topics they would mention as important for the future, senior researchers underlined the relevance of keeping the traditional aeronautical engineering background, while students emphasised the importance of traditional, formal method-based validation and verification (V&V).

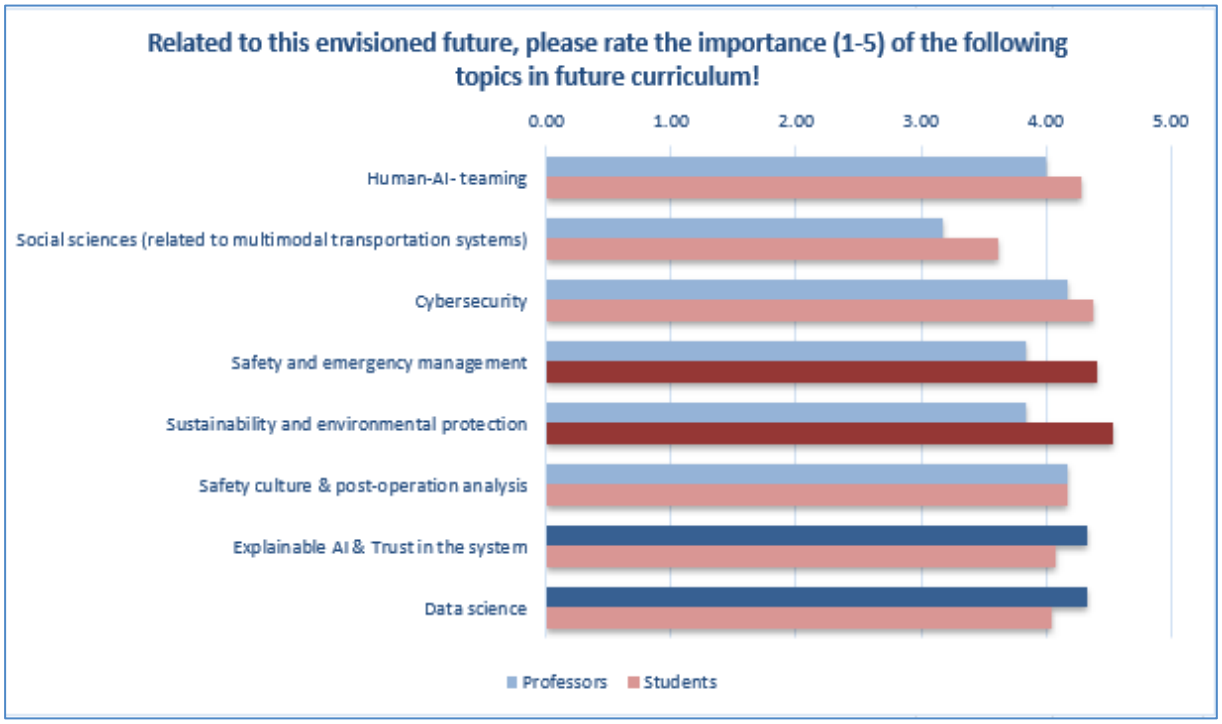


**Figure 5: Comparison of senior researchers and students regarding the perceived importance of topics in future curricula**

### 4.2.4 Challenges and mitigations in future education

When asked about their perceptions about the presence of certain challenges (see Figure 6), both senior researchers and students highlighted the problem of **low salaries/scholarships** in education within the sector, while students additionally rated the problem of **financial burden to innovate** as the most important challenges they perceive in education. This perception reflects a **lack of adequate investment** in modernising education—such as access to updated labs, software, or digital platforms—which students view as a barrier to innovative learning experiences. By providing the choice of adding free-text answer options, too, one researcher underlined that new opportunities and fast growing (e.g. web economy) market have impacted the **younger population who do prefer to not be involved in a long (and uncertain) pathway that aviation still requires**. On the other hand, students in their free text answer options highlighted the perception that the **industry does not involve students (e.g. internships) in innovation and culture of innovation not nurtured** enough, along with the **access of women in STEM (science, technology, engineering, and mathematics) not encouraged enough.** Moreover, **legislation and regulators have been mentioned as an important challenge to innovation in the sector as a whole**, and indirectly in education as well.

Finally, when asked about potential solutions and mitigation strategies (see Figure 7.), senior researchers rated the option of i**nternationalisation of students (exchange programmes, international scholarships) to enhance knowledge exchange and attractiveness** as the highest, while students perceived the **need for future knowledge and skills to be communicated by industry**

**partners timely and proactively** as the most important aspect. Moreover, students in their free text answer options highlighted the importance of **enhancing the conditions and opportunities for researchers/Ph.D. students** through national and international competitions with significant fundings as a prize. In addition, the increase of **institution-institution and institution-stakeholders collaboration at European level** has also been underlined to understand cultural differences and to exchange and harmonise relevant knowledge.

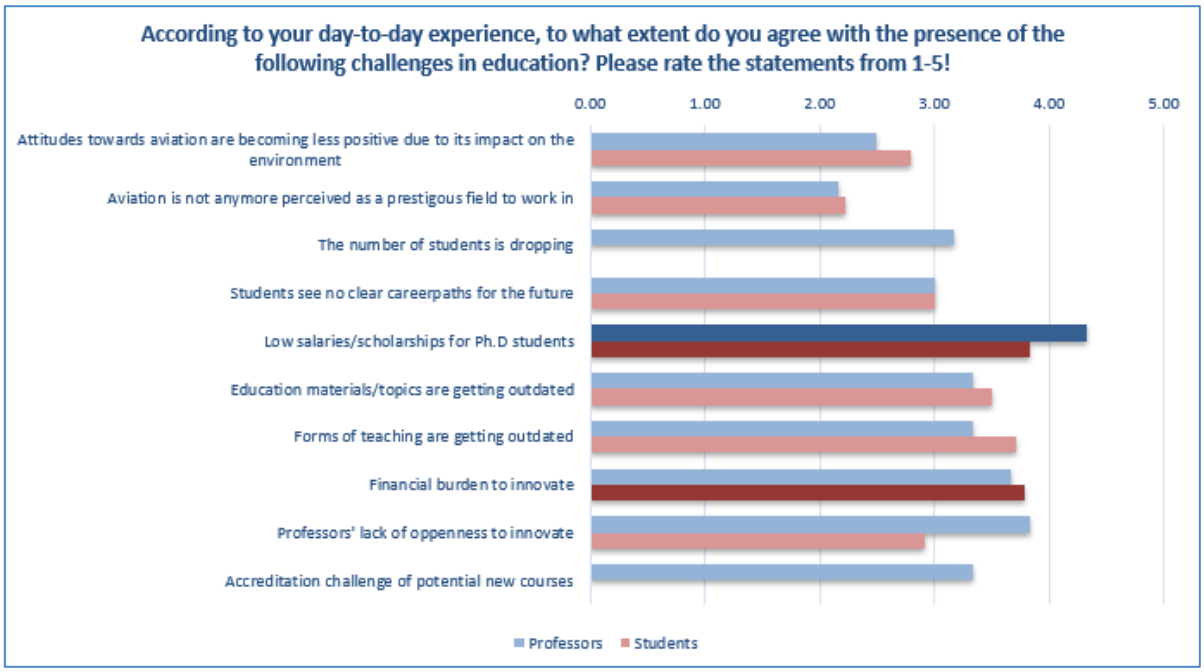


**Figure 6: Current challenges in education**

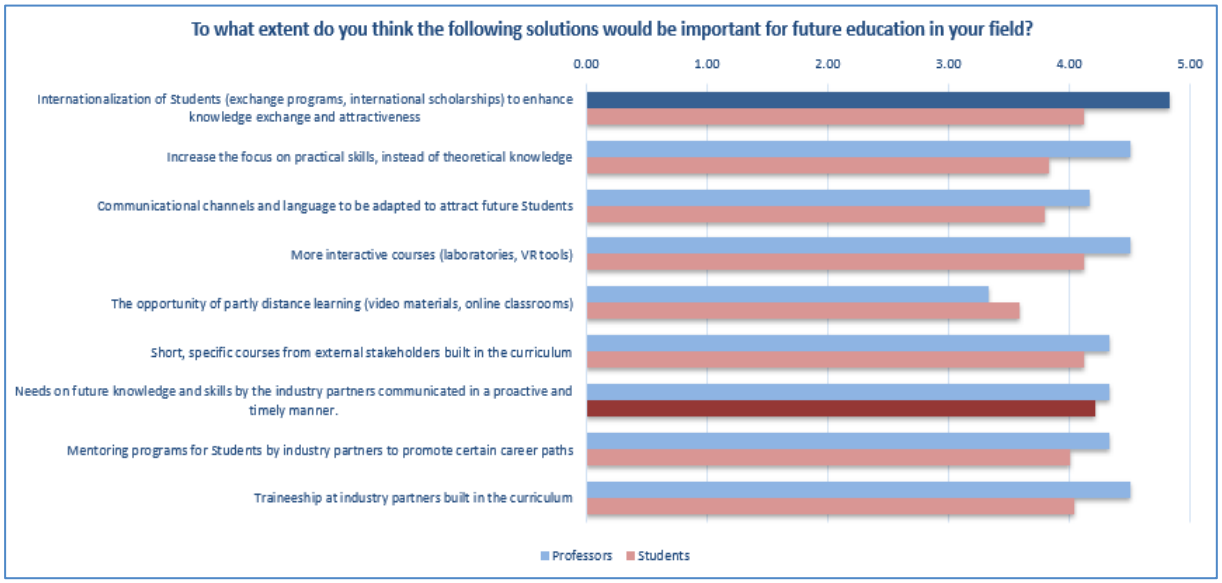


**Figure 7: Priorities for future education**

## 4.3 Skills transformation map: a case-study of ATCOs

As the last step of the data gathering process, an ATCO training instructor has been asked to participate in an online interview where he was introduced to the hypothetical scenarios related to future technical trends along with the skills that were considered as key in the future.

After the introduction, he was asked to reason on each skill, by explaining in what way that particular skill will be important for the future ATCOs and how this skill will be different from what it is today. Finally, the interviewee was asked whether any additional skills would be necessary to complement the list with, to draw future ATCOs' profile.

Related to the scenario of **multimodal transportation business models (#1)**, the interviewee emphasised that the role of air traffic controllers in this situation will become crucial in a potential emergency. Within this perspective, **coordination and organisation skills** will be crucial to handle these emergency events rather than normal situations. Closely related to this vision, there may indeed be less need for ATCOs to perform **human-human voice communication** in routine automated situations, but this skill will **become crucial in emergency situations** to understand what is happening and to provide support effectively. For this purpose, the skill of **"Holistic view and understanding"** has been added to the list of skills. Instead of having a thorough understanding of each and every aircraft (this task will be automated), the importance of ATCOs' role will lie within their ability to supervise the system, and become less operative, being less involved in direct task execution. As the likelihood of an ATCO being able to track everything will be very low, the main challenge related to this vision will be to keep them in the loop to act effectively. If air traffic controllers within this scenario are expected to jump in and catch up with the situation quickly, there has to be an **effective human-AI communication** in place, and a bond between the human and the system that is strong enough to be able to understand the situation and intervene accordingly. For this reason, ATCOs must have advanced skills in **human-**

**AI teaming and an understanding of the system's reactions**. This understanding will require **trust from the human's side and explainability from the system's side**, mostly to fully rely on the information that is gathered through the system.

When asked whether any knowledge on **basic human behaviour and needs** would be important for ATCOs, the interviewee pinpointed that since the role of ATCOs' in emergency multimodal transport situations is foreseen as crucial, an extended knowledge on human behaviour will be crucial, as the emergency situations are mostly related to the people that are in the vehicle (e.g. pilots, passengers). The main difference in the future will be the person that the ATCO will be in contact with: this will not necessarily be the pilot anymore but a central coordinator, with different background, different communication channels, and partly different phraseology to use. Closely linked to the role of ATCOs in emergency scenarios, the importance of **stress tolerance and stress management** skills have been underlined and added to the list of skills. As explained, the frequency of emergency situations may drop in the future, causing air traffic controllers to become less used to them. As a result, when they happen, they may have more serious consequences, including possible startle effects of the ATCOs. For this reason, the ability to stay composed, and quickly regain focus will be essential in the future to handle rare but serious emergency events.

Related to the scenario of **AI and automation (#2)**, the interviewee emphasised that although **empathy** will be indeed the key to a pleasant and psychologically safe working atmosphere, the role of air navigation service providers will remain inevitable to provide and foster an organisational culture that supports just culture, collegiality and safety. Assuming a more supervisory role of air traffic controllers with less involvement in direct task execution, **maintaining vigilance and staying tolerant to monotony** will likely be crucial skills of future air traffic controllers. As explained, while monotony today is rather related to periods with lower peaks of workload (e.g. night shifts) in a future of highly automated systems, this challenge will be continuously present, as ATCOs will be less involved in direct task execution. Related to the skill of **holistic overview on system functioning**, the interviewee underlined that the key difference between today and future operation will be **the time it will take someone** during a potential intervention **to "jump back in"** and build an accurate mental model of the situation. By relying more and more on automated systems, operators tend to lose their ability to follow the operation on a step-by-step basis, thus requiring more time to catch up when needed. As a result, the skill of **quickly building a holistic overview** on system functioning will be essential in the future. In addition, **verbal communication skills** are foreseen to be highly impacted as they will be based on the inputs and outputs of an automated system, causing a radical decrease in the amount of verbal communication required by air traffic controllers. While on the one hand systems may ensure a continuous and timely information flow, relying heavily on communication with and through them may result in misunderstandings due to the **lack of read-backs and the loss of using standard phraseology** on a daily basis. The skill of **adaptability**, on the other hand, is foreseen to become even more crucial. As explained: the higher the variety of traffic and the higher the variety of automated systems an air traffic controller has to handle, the higher the variety and the likelihood of possible future events that require immediate intervention from the human's side.

Finally, related to the scenario of **sustainability and environmental protection (#3),** no major changes are foreseen from the air traffic controllers' point of view. As explained, although weather events may become more frequent and more extreme, the way ATCOs would need to handle them in the future will not be radically different from how they manage them today. On the other hand, as they are

foreseen to be more frequent in the future, the importance of **coordination, communication, planning and organisation** skills will be even more important to manage the traffic safely during these events.

| SKILL | FUTURE IMPORTANCE | SKILL REQUIRED FOR... | NOTE |
|---|---|---|---|
| Anticipate and predict automated system behaviour | ↑ | ...building an accurate situational awareness and planning effectively. | |
| Human-AI teaming | ↑ | ...understanding the situation, the potential or real failures and intervene accordingly. | |
| Collaboration skills | = | ...multiagency teamwork in emergency situations | The actors with whom ATCOs must collaborate with may change and become more diverse. |
| Human behaviour & needs | ↑ | ... understanding the needs of different actors in emergency situations | The actors with whom ATCOs must collaborate with may change and become more diverse. |

| | | | |
|---|---|---|---|
| Explainability & trust |  | ... relying on the data provided by the system in critical decision making and for interpreting the data correctly. | |
| Verbal communication |  | ... effectively intervening in and managing multi-actor emergency situations. | Although less required in routine task execution, this skill will be crucial in emergency events!<br>Digitalised communication may lead to the lack of human-human verification (no closed-loop communication) |
| Coordination & organisation |  | ... effectively intervening in and managing multi-actor emergency situations. | Related more to emergency events along with the understanding of the needs of diverse actors. |
| Holistic understanding |  | ... forming an effective team with the automated system, building trust and intervening effectively. | The main difference will be the time it will take for someone to understand the whole situation at hand. |

| | | | |
|---|---|---|---|
| Stress tolerance |  | ... for staying composed and quickly regain control in emergency events. | The frequency of emergency situations may drop in the future, but they may have a more serious impact on humans. |
| Situational awareness |  | ... for "jumping back in" whenever more manual operation is needed.<br>... for planning effectively according to the situational requirements. | |
| Adaptability |  | ... for being prepared for any potential emergency event and acting promptly. | The higher the variety of traffic, the higher the variety of automated systems an ATCO must handle, the higher the variety and the likelihood of possible future emergencies. |
| Vigilance, tolerance to monotony |  | ... for staying active and alert despite automation taking over some tasks. | While monotony today is related to lower peaks of workload (e.g. night shifts) in the future this challenge will be continuously present, as ATCOs will be less involved in direct task execution. |

| | | | |
|---|---|---|---|
| Planning |  | ... for preparing for extreme weather events and other emergencies. | |

**Table 6: Skills transformation map for the ATCO role: changes in skills in the future of 2035-2040**

# 5 Discussion

By looking ahead to the future of 2035-2040, technological advancements, technical and operational trends will require a novel approach in how humans operate successfully within this industry. The document's aim was to report on the research conducted within T4.2. with the objectives to answer the following questions:

- How will the human role evolve in the future of ATM as impacted by the trends?
- What professions will emerge or become obsolete as a result of the changing nature of work within the sector?
- What skills may become crucial from the human's side to successfully operate within the sector in 2035-2040?
- How should education and training evolve in terms of content and format to align with the changing requirements on the human role?

In order to answer these questions, future scenarios related to multimodal transportation business models, AI and automation, environmental protection and sustainability and university education have been investigated within a three-step research process.

One major change is envisaged to be related to the type of knowledge required from the future workforce. As it has been identified, horizontal knowledge across several fields within the sector will be essential in the future, as compared to today's approach to acquire very detailed knowledge in a rather narrow segment within the industry. As a potential solution, the importance of cross-training among different job profiles has been emphasised.

Related to the role of humans in the future, the main message to underline here is the importance that humans will play in future potential emergency scenarios. Although automation may take over simple, repetitive tasks and therefore may cause a decreased need for workforce in such areas, humans will remain crucial as supervisors, managers and decision makers, especially when a potential emergency situation requires immediate human intervention. Closely related to this vision, it is important to emphasise that future emergency management will probably require a collaboration with more diverse actors (including human but also AI-based team members). Therefore, the skills of adaptability, flexibility, emergency preparedness, as well as voice communication will become crucial in such events. These emergency events, although envisaged to occur very rarely, may have a greater impact on humans in operation, as a result of a potential overreliance on automated tools. Therefore, the skills and knowledge related to stress management will inevitably become important in the future of ATM. Further related to the topic of automation and AI, the greatest challenge foreseen will be linked with keeping the human in the loop, with fully-fledged team members of human-AI teams as well as the supervisors of the overall operation. As a consequence, professions with a data science background (e.g. data managers) will become essential in the future of ATM, not only as supporters of the system but as equal partners and contributors to decision making. Closely related to the changing role of humans within the future of aviation, there is a need for educating social sciences in a more detailed and more customized way to understand how basic human needs of different actors (e.g. crew, passengers) can be taken into consideration in future decision making a safe operation.

To support this vision, the importance of “Data science”, “Explainable AI and trust”, “Safety and emergency management” and “Sustainability & environmental protection” has been emphasised as topics in future education that require a more detailed and focused approach. Accommodating the needs of students, a hybrid learning environment with a greater focus on practical knowledge may be advisable for future education, along with a greater emphasis on international exchange programmes, to attract future generations and to facilitate knowledge exchange between educational institutions.

There are a few limitations of the recent study that are important to underline. First of all, the methodology of applying convenient sampling in data gathering along with the fairly low number of responses for the online survey may lead to the inaccurate representation and the difficulty replicating and generalising the results. It is also important to emphasise that the skills and trends on human role described above are addressing a more general level within the ATM sector and are not customised to the specific needs of the different future job profiles. To mitigate this limitation, the role of an air traffic controller has been selected as an example to create a “skill transformation map” introducing it as a methodological approach to identify future skills required by a profession. On the other hand, creating the skills transformation map to all the current and future job profiles within air traffic management is beyond the scope of the current deliverable, as it would require specific use cases, customized to each and every job profiles under analysis, along with a variety of specific target groups to involve in the data gathering process.

While some skills may become less important or even obsolete and some skills may become crucial in the future, one shall not forget about revising the exact definition of these skills as some of them - although keeping the same level of relevance in the future- may describe a remarkably different behavioural characteristics and requirements from future professionals. To overcome this challenge, the potential future use of the skills has been discussed by using the example of air traffic controllers.

Looking ahead to the future of 2035-2040 the aviation landscape seems to be as challenging as it is full of opportunities. Proactively anticipating these changes, and skilling and re-skilling workforce accordingly will be one of the most essential tasks, to make sure aviation is a safe, successful, and appealing industry for future generations as well.

# 6 References

[1] Armstrong, J. S. (Ed.). 2001. Principles of Forecasting: A Handbook for Researchers and Practitioners. Springer.

[2] Cavagnetto, N., Golfetti, A., Napoletano, L., Tomasello, P., Drogoul, F. (2022). To innovate is clever, to anticipate is smart: towards new skills in Air Transport. *34th Conference of the European Association for Aviation Psychology.* Transportation research Procedia, 66, 156-166.

[3] Destination 2050. (2025). *A route to net-zero European aviation: Destination 2050 roadmap* (2nd ed.). Destination 2050.

[4] Engage 2(2024). D4.1: ATM Sector Changes.

[5] Future Flight Vision and Roadmap (2021). Future Flight Challenge at UK Research and Innovation. August 2021. UKRI. Retrieved from https://ktn-uk.org/wp-content/uploads/2021/08/UKRI-130821-FutureFlightVisionRoadmap-1.pdf

[6] HAIKU (2023). D2.1: Vision and Scenarios.

[7] HAIKU (2023). D8.1: The Human Role in Future Aviation.

[8] IATA (2018). The future of aviation industry 2035. Available at: https://www.iata.org/contentassets/690df4ddf39b47b5a075bb5dff30e1d8/iata-future-airline-industry-pdf.pdf

[9] Kanter, D. R., Schwoob, M.-H., Baethgen, W. E., Bervejillo, J. E., Carriquiry, M., Dobermann, A., Ferraro, B., Lanfranco, B., Mondelli, M., Penengo, C., Saldias, R., Silva, M. E., & Soares de Lima, J. M., 2016. Translating the Sustainable Development Goals into action: A participatory backcasting approach for developing national agricultural transformation pathways. Global Food Security, 10, 71-79. https://doi.org/10.1016/j.gfs.2016.08.002

[10] Manyika, J., Lund, S., Chui, M., Bughin, J., Woetzel, J., Batra, & Sanghvi, S. (2017). Jobs lost, jobs gained: Workforce transitions in a time of automation. McKinsey Global Institute. Available at: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/future%20of%20organizations/what%20the%20future%20of%20work%20will%20mean%20for%20jobs%20skills%20and%20wages/mgi-jobs-lost-jobs-gained-report-december-6-2017.ashx

[11] Robinson, J. B., 1990. Futures Under Glass: A Recipe for People Who Hate to Predict. Futures, 22(8), 820-842. 10.1016/0016-3287(90)90018-D

[12] SESAR Joint Undertaking (2025). *European ATM Master Plan: Edition 2025*. Luxembourg: Publications Office of the European Union. https://sesarju.eu/masterplan

[13] SKILL-UP (2021). D1.1: Skills, needs and future work scenarios: Air Sector Skills Transformation Map.

[14] SKILL-UP (2021). D2.2: Study pathways: Skilling, Upskilling and Reskilling

# 7 List of acronyms

| Acronym | Description |
|---|---|
| AI | Artificial intelligence |
| ANSP | Air navigation service provider |
| ATCO | Air traffic controller |
| ATM | Air traffic management |
| GNSS | Global navigation satellite system |
| RPAS | Remotely piloted aircraft system |
| STEM | Science, technology, engineering, and mathematics |
| TBO | Trajectory-based operations |
| UX | User experience |
| V&V | Validation and verification |

# 8 Appendix

## 8.1 Online survey

Online survey developed and distributed among senior researchers and students. Note: in question nr.7. “the number of students is dropping” and “accreditation challenge of potential new courses” options have only been introduced to researchers.

**ENGAGE 2**
**Future skills and training**

Imagine you are in the future of 2035-2040.
Alongside the ever growing increase in air traffic of manned aircraft, **new aerial vehicles (e.g. drones)** are entering the airspace as key parts of **new transportation business models**. In addition, the **integration of the airspace** is an exciting new trend, just like the potential new direction of **flying above stratospheric altitudes**. In this future, **passengers' experience** is of high priority, and **trajectory based free route operations** are ensuring a seamless traffic in the crowded airspace. Connected to this vision, a more general **multimodal transportation system** is foreseen, requiring stronger and more structured coordination between aviation and the other transport modes.
As a result of digital transformation, **communication, navigation and surveillance are fully digital**, control towers are digitalised and digital twins are available in operation. There is an increased **machine-to-machine communication** with an increased dependency on **satellite-based services**. Thanks to the advances in technologies, the envisaged highly increasing level of air traffic can be safely managed, with **new technologies and AI autonomously performing a variety of traffic management tasks with the supervision and coordination of human operators**. Consequently, more robust **security and cybersecurity systems** and measures are in place to ensure safe and secure operations.
As a result of a special focus on **environmental protection, sustainability,** seen by many today as an aspiration, has become an essential requirement of future air traffic that is non-negotiable. As a result, for instance, applying **new, eco-driven design methods** and producing **new functional materials** for aircraft components is within the focus of aircraft manufacturers, and more generally, the aviation community as a whole. In addition, **extreme weather events**, stronger than today, require **better predictions, more flexibility and quicker reactions**, thus creating **more disruption in the general air traffic management.**
In the future, one key focus of university education is to train a **future workforce** that is **highly adaptive and proactive to contribute to innovation** acceleration. This requires universities to continuously interact and understand the **needs of the industry** and reflect it in a balanced way in their curriculum. By having **new technologies and a more interactive way of teaching**, the key challenge of education is associated to the potential **skill decay of human operators** who are having a more passive role (monitoring, supervising…). Moreover, universities are continuously challenged to address the **social attitudes towards aviation** and therefore, effectively attract young talents.

1. **At which University do you work?**

* 2. **Related to the vision described in the introduction, how do you envision the human role will evolve in future aviation?**

* 3. **According to your perception, what are the current profession(s) that will become less relevant or obsolete in future aviation?**

* 4. **According to your perception, what new professions (non-existent today) will likely emerge in future aviation?**

* 5. **Related to this envisioned future, how important do you think the following skills will be on a scale from 1 to 5?**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Situation awareness to understand and predict the behavior of automated systems | ○ | ○ | ○ | ○ | ○ |
| Communication (human-human) | ○ | ○ | ○ | ○ | ○ |
| Human-AI teamwork (communication, collaboration, coordination) | ○ | ○ | ○ | ○ | ○ |
| Quality assurance skills | ○ | ○ | ○ | ○ | ○ |
| Analytical thinking to detect potential system failure | ○ | ○ | ○ | ○ | ○ |
| Organization and coordination skills for multiagency collaboration (e.g. in emergency) | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Mathematical skills | ○ | ○ | ○ | ○ | ○ |
| Monitoring skills to supervise automated systems | ○ | ○ | ○ | ○ | ○ |
| Domain-specific technical skills to take over and manually manage the system. | ○ | ○ | ○ | ○ | ○ |
| Emergency preparedness and management for extreme weather conditions | ○ | ○ | ○ | ○ | ○ |

Is there any other skill you would include in this list?

* 6. **Related to this envisioned future, please rate the importance (1-5) of the following topics in future curriculum!**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Human-AI-teaming | ○ | ○ | ○ | ○ | ○ |
| Social sciences (understanding and reflecting human needs related to multimodal transportation systems) | ○ | ○ | ○ | ○ | ○ |
| Cybersecurity | ○ | ○ | ○ | ○ | ○ |
| Safety and emergency management | ○ | ○ | ○ | ○ | ○ |
| Sustainability and environmental protection | ○ | ○ | ○ | ○ | ○ |
| Safety culture & post-operation analysis | ○ | ○ | ○ | ○ | ○ |
| Explainable AI & Trust in the system | ○ | ○ | ○ | ○ | ○ |
| Data science | ○ | ○ | ○ | ○ | ○ |

Is there any other skill you would include in this list?

* 7. **According to your day-to-day experience, to what extent do you agree with the presence of the following challenges in education? Please rate the statements from 1-5!**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Attitudes towards aviation are becoming less positive due to its impact on the environment | ○ | ○ | ○ | ○ | ○ |
| Aviation is not anymore perceived as a prestigous field to work in | ○ | ○ | ○ | ○ | ○ |
| The number of students is dropping | ○ | ○ | ○ | ○ | ○ |
| Students see no clear careerpaths for the future | ○ | ○ | ○ | ○ | ○ |
| Low salaries/scholarships for Ph.D students | ○ | ○ | ○ | ○ | ○ |
| Education materials/topics are getting outdated | ○ | ○ | ○ | ○ | ○ |
| Forms of teaching are getting outdated | ○ | ○ | ○ | ○ | ○ |
| Financial burden to innovate | ○ | ○ | ○ | ○ | ○ |
| Professors' lack of oppenness to innovate | ○ | ○ | ○ | ○ | ○ |
| Accreditation challenge of potential new courses | ○ | ○ | ○ | ○ | ○ |

Is there any other challenge you would include in this list?

8. **To what extent do you think the following solutions would be important for future education in your field?**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Internationalization | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| of Students (exchange programs, international scholarships) to enhance knowledge exchange and attractiveness | ○ | ○ | ○ | ○ | ○ |
| Increase the focus on practical skills, instead of theoretical knowledge | ○ | ○ | ○ | ○ | ○ |
| Communicational channels and language to be adapted to attract future Students | ○ | ○ | ○ | ○ | ○ |
| More interactive courses (laboratories, VR tools) | ○ | ○ | ○ | ○ | ○ |
| The opportunity of partly distance learning (video materials, online classrooms) | ○ | ○ | ○ | ○ | ○ |
| Short, specific courses from external stakeholders built in the curriculum | ○ | ○ | ○ | ○ | ○ |
| Needs on future knowledge and skills by the industry partners communicated in a proactive and timely manner. | ○ | ○ | ○ | ○ | ○ |
| Mentoring programs for Students by industry partners to promote certain career paths | ○ | ○ | ○ | ○ | ○ |
| Traineeship at industry partners built in the curriculum | ○ | ○ | ○ | ○ | ○ |

Is there any other solution you would include in this list?