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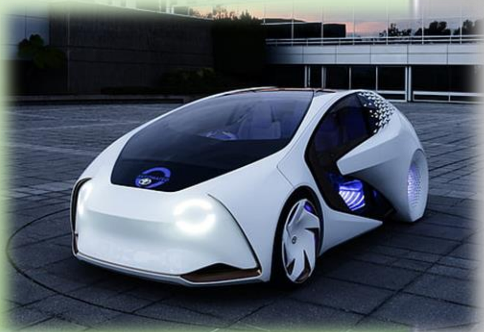

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Introducing artificial intelligence in air traffic control

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Abstract: The usage of artificial intelligence (AI) is spreading nowadays and by now it has reached the safety critical industries as well, but it is not clear when and how it is going to be used in related primary systems. Air transport is a good example for such an industry. Although the introduction of new technologies in this sector should be maintained with an obvious care, scientific projects have already started to explore the possible benefits AI can bring for air traffic controllers. One of those projects is the AISA (AI Situational Awareness Foundation for Advancing Automation) which found that for safe implementation of advanced automation concepts in air traffic control, the human and the machine should share the same situational awareness. Therefore, within the AISA project experiments are made to analyse whether the AI system and the air traffic controller can cooperate effectively and if automation can significantly improve the work of the controllers. The system is to be used to support simple monitoring type of tasks at the beginning but has more significant potentials. The results can also be useful for other sectors where artificial intelligence is to be implemented.

Keywords: automation, artificial intelligence, machine learning, air traffic control, situational awareness, safety critical industries

Introduction

Automation is probably the most important technological tendency nowadays. It means that machines or computers are used for an activity without direct human control [1]. The evolution of automation techniques accelerated with the computer industry and for decades it was a synonym for “traditional” or in other words, “hard coded” automation, meaning that the system has definite answers to the certain inputs and learning and improvement is not possible [2]. The use of artificial intelligence (AI) is a relatively new method in automation. Although AI was used as a phenomenon since the 50s (Turing test and the Dartmouth meeting), its emergence as a new science started really towards the late eighties when a systematic, gradual development process started [3]. Unlike traditional automation methods, AI can act as human beings and is able to learn and adapt to circumstances [2]. The definition on AI from EASA (European Aviation Safety Agency) is: „any technology that appears to emulate the performance of a human” [4]. Having a closer look on the main characteristics, one can recognise that it many aspects AI is closer to human beings than to traditional automation (Table 1).

Table 7. Comparison of the main characteristics of systems using traditional automation, human beings and systems using artificial intelligence, own work in the frame of the AISA project [2]

	Uncertainty	**Creativity**
Traditional automation	NO	NO
Human being	YES	YES
Artificial intelligence	YES, but decreasing	YES, and increasing

As artificial intelligence is a relatively new science and its components are developing rapidly, there is not yet a widely accepted categorisation of its components. The table below (Table 2) is prepared on the basis of the classification of JRC (Joint Research Centre) [5].

Table 2. The domains of AI – own creation on the basis of AI Watch [5]

Core AI domains	**Short description**
Reasoning	The domain deals with the data transformation into knowledge, deducing facts from data.
Planning	The process of designing organised set of actions by intelligent agents, autonomous robots, etc.
Learning	Machine learning (ML) is the capability of the systems to automatically learn, decide, predict, adapt, and react to changes, being able to improve from experience, without being programmed.
Communication	Natural Language Processing means the ability of the system to identify, process, understand and/or generate information.
Perception	Perception domain is related to computer vision and audio processing, and it means ability of the system to become aware of their environment through the senses.
Transversal AI domains	
Integration and Interaction	This transversal subdomain combines the core domains with different characteristics like autonomy, cooperation, integration, etc.
Services	The AI related services usually mean cloud platforms provided as off the shelf products being available on demand.
Ethics and Philosophy	As AI has a significant impact on human and society, related solutions should be compliant with ethical principles and applicable regulations.

As artificial intelligence is a new scientific brand with a lot of uncertainties at the moment, its development and use should be maintained with special care. The High-Level Group on Artificial Intelligence has created a list of guidelines to achieve a trustworthy AI: human agency and oversight, technical robustness and safety, privacy and data governance, transparency, diversity, non-discrimination and fairness, societal and environmental wellbeing, accountability [6]. Because of the novel nature of artificial intelligence methods, the introduction of the technology is maintained with an obvious care, during implementation one must pay attention to the aspects mentioned above. These issues are especially crucial in safety critical industries, for example, healthcare, transportation and manufacturing where machine learning techniques can provide lot of benefits. However, there are several open questions and one of them is that the probabilistic nature of ML is conflicting with the typical safety culture in these industries [7]. Another aspect is the lack of new standards for the use of AI. For example, in the aviation industry the boundary for the using of safety-critical AI is the absence of AI-based standards and regulations as the relevant bodies are focusing mainly less safety-critical use cases [8].

Consequently, the question emerges: *will artificial intelligence be used in primary systems in safety critical industries? If yes, what are the main steps to be taken care of?*

My hypothesis for the first question, is that artificial intelligence will be used in primary systems in safety critical industries as well and the emergence of growing number of examples is not far away. However, the process should be maintained with a rigorous planning and via a gradual approach. I try to justify this hypothesis, via the example of an AI related research project from a safety critical industry (air traffic control), I participate in. In this article there are three main sources of information:

- new research work conducted when writing this article,

- the deliverable establishing the requirements in the above-mentioned project, where I performed as the lead author [2],
- other project documents cited to show the implementation possibilities of AI.

1. Why the European air traffic management needs automation?

Although, during the pandemic the volume of the air traffic heavily declined both in Europe and at a global level, the industry is on the rise again. It is forecasted that it will reach the 2019 volume by 2024 [9]. Therefore, the overall tendency is unlikely to change: the air traffic is continuously growing, putting pressure on the capacity management of the system. Air traffic flow management (ATFM) related delays were quite substantial before the pandemic in Europe and this problem will certainly arise again without significant improvements. In 2018 for example delays increased by 104%, while traffic increased by only 3.8%. The category "lack of air traffic control" (ATC) had the highest share in the en-route ATFM delays [10].

Research, development and innovation are the primary means in Europe to cope with the rising demand, otherwise the limits of supply would ultimately lead to price increases and smaller growth in traffic, causing deceleration of the European economy. Within the research topics, automation has a clear and emerging role. As air traffic management is a very complex sector, it is not an easy sphere for traditional hard-coded automation. On the other hand, artificial intelligence, especially machine learning is suitable to be used where there is a larger amount of data, for example the set of radar plots or ADS-B (Automatic Dependent Surveillance-Broadcast) data of the aircraft in a certain period of time.

The relevant SESAR [11] objectives show that automation has a lot of benefits for air traffic management but at the same time human cognitive abilities can be better than machines and this is a counter argument for full autonomy in certain aspects of ATM. Therefore, new solutions using automation should provide substantial and verifiable performance benefits and at the same time maintain the safety level [12]. Automation will create significant changes in the European air traffic control practices as the workload of air traffic controllers is a significant constrain in the industry.

AI is already used in aviation. However, in line with the statement above, it is primarily used for forecasting [13] and also, on trainings as for example the EUROCONTROL's integrated Flow Management Position (in Maastricht Upper Area Control Centre) analyses the routes that air traffic controllers (ATCO) give to aircraft to use the information for ATCO training [2].

Automation and especially the use of AI is foreseen to increase both in the air and on the ground and in between them, making machine-machine communication more frequent. Consequently, many tasks implemented by people today will be performed partly or completely by machines. This process will decrease the overload on humans and will increase the safety level of the air traffic systems [14].

One of the main issues within the automation process is how to make the human and machine working together effectively. Therefore, there are several research projects examining this cooperation from different angles, and one of them is focusing on shared situational awareness.

2. The objectives, concept and requirements of the AISA project

2.1 General information

AISA (AI Situational Awareness Foundation for Advancing Automation) is a European research project investigating how to increase automation in air traffic management. The project is funded by the SESAR 2020 programme of the European Commission (SESAR Exploratory Research, 892618). The project has started in June 2020 and runs for two and half years [15].

2.2 Objectives

The overall objective of the project is increasing the possibility of the introduction of automation in ATM by researching domain-specific application of transparent and generalizable artificial intelligence methods.

The more detailed objectives of the project include:

- Exploration of the effects of human-machine distributed situational awareness and opportunities for automation of monitoring tasks in en-route operations.
- Identifying the data needed by air traffic controller to ensure that the proposed solution is correct.
- Finding methods for adaptation of the automated system to changes of the environment [15].

2.3 Overall concept

Maintaining the necessary separation between two aircraft is the main responsibility of an air traffic controller (ATCO). Performing the separation, the ATCO must sustain a certain level of situational awareness (SA). A drop in the level of SA results in the loss or decrease in the level of separation. Nowadays the main issue for ATCOs is that they are facing a large amount of information generated by different systems and it might also result in the "out-of-the-loop" effect and loosing SA.

As the introduction of automation is gradual and the involvement of human controller (although in a different role) is foreseen even in the long-term, the establishment of the cooperation baseline between the human and machine is paramount. In other words, artificial intelligence and human should be able to share the same situational awareness (SA).

SA is usually used for interactions between people, when two or more persons have a commonly understood mental image on what is happening or what will happen. In the project the machine is brought in the SA as part of the team. Consequently, the project introduces a human-machine distributed team SA (TSA) where the team is composed of an executive air traffic controller, a planning air traffic controller and the AI itself (Figure 1) [14].

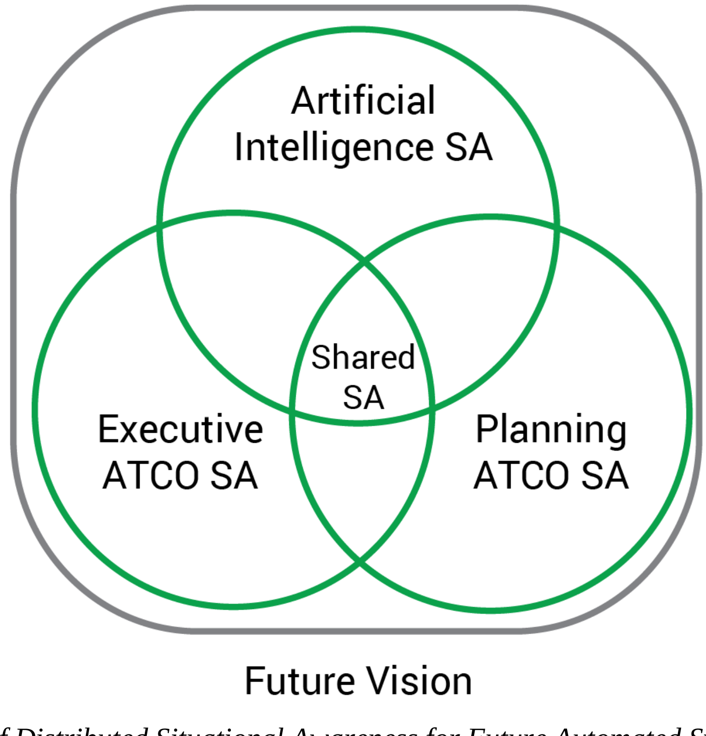

Figure 1. Concept of Distributed Situational Awareness for Future Automated Systems, own drawing on the basis of the AISA concept [14]

The novelty of the concept is that „actors will be able to continually monitor each-others' states, with AI being aware of the probable human actors' states via analysis of traffic situation" [16].

Following a gradual approach, the AISA project is focusing on introducing AI first into activities where it is easier to involve it. This means AISA plans to start primarily with those air traffic control tasks requiring only monitoring type of contribution by the controller for two reasons: the task is already automated to a significant extent (by "traditional" automation) or the task is simple and the human performs only monitoring activities in relation to it [2]. A selection of the proposed tasks to consider are: detection of incoming traffic, monitoring conformance of aircraft to the planned trajectory, identifying conflicts, monitoring adverse weather areas and restricted airspace, monitoring of the status and performance of ATC sub-systems [2].

Besides automation, the ASIA system is also forecasted to evolve to “be the central decision-support tool with the awareness of all the relevant interactions enabling it to suggest or choose the correct course of action” [14].

Describing the system architecture, the knowledge graph is in the centre position, it includes factual knowledge on the basis of aeronautical data. On top of the factual knowledge, rule-based knowledge is defined and executed. In the project rule-based reasoning follows a flexible approach, being open to new requirements. At a lower-level machine learning is adopted, and its main role is to predict individual probabilistic events. The main role of the reasoning engine is on a higher level, drawing conclusions from the system state. “By combining reasoning engine with ML, we believe that it will be possible for AI to be ‘aware’ of the situation in a manner similar to a human, that is, AI will be able to assess complex interactions between objects, draw conclusions, explain the reasoning behind those conclusions, and predict future system states” [14]. A real-time monitoring function is enabled as for each task of the system, queries are prepared and run continuously (Figure 2).

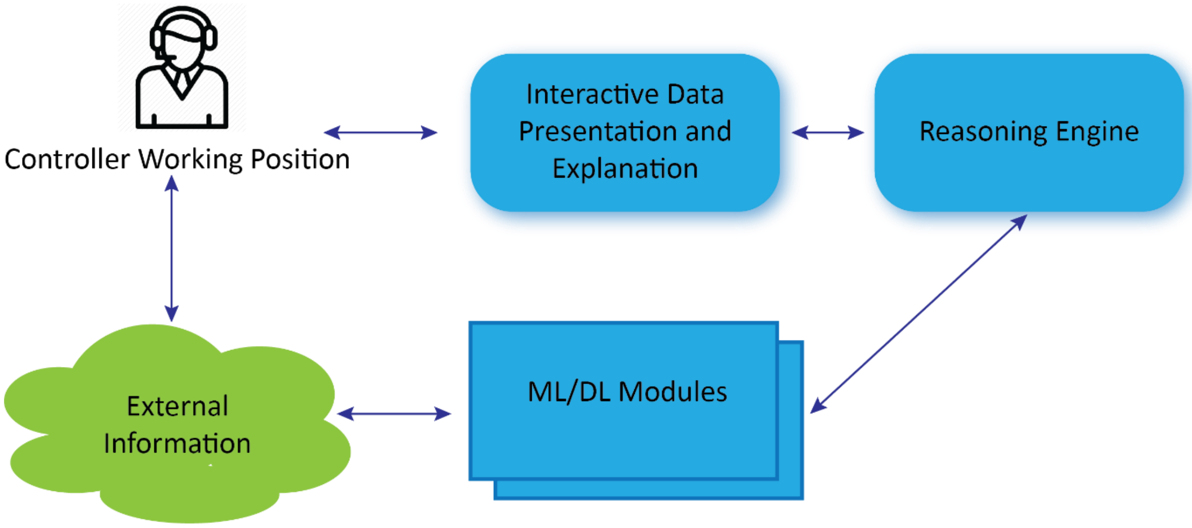

Figure 17. A simplified conceptual diagram of an AISA-like system, own drawing on the basis of the AISA concept [14]

2.4 The evolving role of AI

One of the main conceptual pillars of the AISA project was that the introduction of a new technology to air traffic control should be maintained with a gradual approach. Within AISA there are two implementation milestones, one is in the middle-term, around 2035, the time of the full implementation of the SESAR Master Plan [17] and the other is a longer-term, around 2050. In terms of the different roles, the following classification is followed in my work in the frame of AISA D.2.2 [2].:

ATC system:

Apply: the ATC System analyses the situation, decides, and implements the most suitable solution on its own according to available information,

Propose: the ATC System proposes to the ATCO a set of actions to implement,

Support: when needed, ATC system supports the ATCO decisions by providing him/her necessary information.

ATCO:

Apply: the ATCO analyses the situation, decides, and implements the most suitable solution from those proposed by the ATC system according to the information from the ATC tools,

Approve: once the ATC system has proposed a solution for the conflict; the ATCO must approve it in order to be implemented,

Monitor: when the ATC system is assuming the major tactical actions; the ATCO has to monitor its behaviour to prevent system deviations [2]. It should be noted that this monitoring differs from the “monitoring tasks” identified for the first use of AISA, as the first one indicates tasks and duties where the ATCO has to perform only monitoring as the system is capable of doing the rest of the work, whereas the second category means that there are tasks today with the current (traditional) systems in place, where the ATCO's main job is mainly to monitor the situation and this is where AISA can provide contribution at the first place.

It is assumed that by 2035 the AI enabled systems will mainly perform supporting service in ATM (Table 3).

Table 3. The forecasted roles of human and AI at particular tasks by 2035, own work in the frame of the AISA project [2]

AI	ATCO	Probability
Support	Apply	High
Propose	Approve	Low
Apply	Monitor	Unlikely

However, by 2050 the situation is expected to change and probably AI will be increasingly used in proposing actions (Table 4). Nevertheless, AI implementation related forecasts, especially the long-term ones should be treated with care, as the pace of AI related development is not visible in that time-frame.

Table 4: Roles of human and AI at particular tasks in the future – 2050, own work in the frame of the AISA project [2]

AI	ATCO	Probability
Support	Apply	High
Propose	Approve	Medium
Apply	Monitor	Low

3. Examples of results

The machine learning related research in AISA is probably the closest to a future implementation, therefore I show it as an example for analysing it as a representative AI related method for the short-middle term. This is partly because machine learning is already the most used AI technique but also as it seems to be able to support current working methods relatively easily. Conflict detection is an area with air traffic control where a data-driven approach is adequate [18].

The analysis focused on the Situation of Interest (SI) in the airspace between aircraft pairs. "One SI can be defined as an aircraft pair that will intersect, infringing horizontal and vertical pre-defined separations" [19]. The system detects the possible conflict on the ground of what happened in previous situations as the assumption is that aircraft have followed a similar trajectory earlier. The main characteristics of the system (ATC tool with embedded ML support):

- The tool updates the prediction in a certain period of time.
- The tool realises both the aircraft currently in the sector and the ones approaching it.
- Utilising historical 4DT (4D trajectory [20]) data and the current ADS-B data (position, velocity, heading), the tool makes prediction for each aircraft.
- The tool supports the tactical ATCO in his/her airspace monitoring work [18].

Figure 3 presents the AISA conflict detection tool graphically.

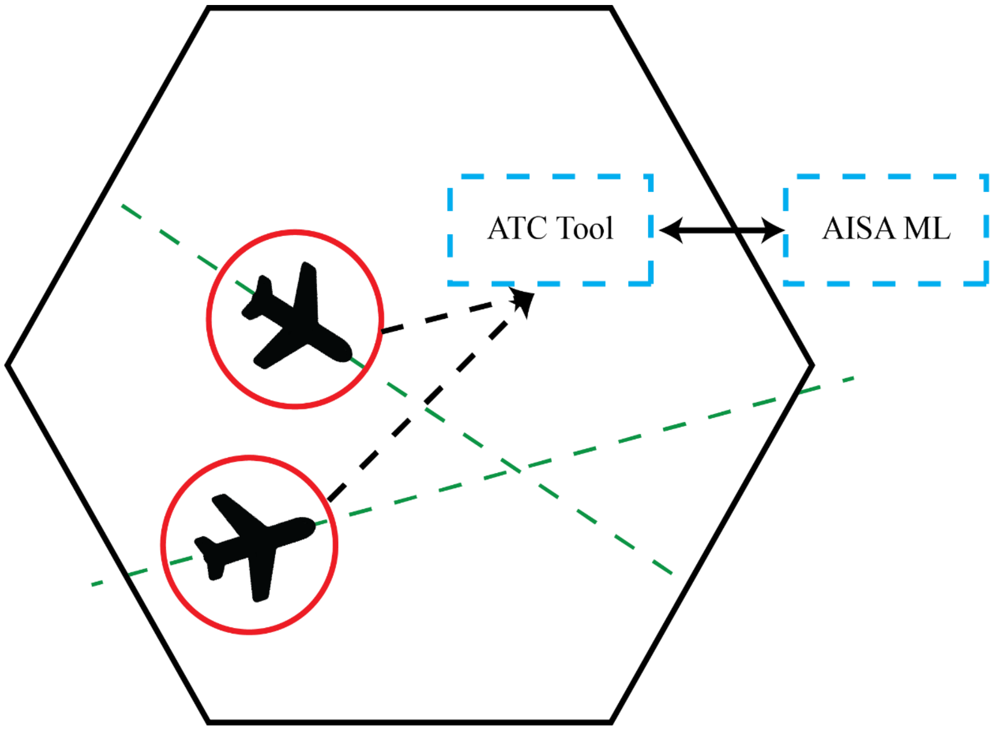

Figure 3: Conflict detection of the ATC tool, own drawing on the basis of an AISA related article [18]

The testing of the ML module was conducted with the use of classification techniques to identify SI (binary prediction SI or not SI) and regression techniques for the prediction of the minimum distance among the pairs. Different models were used, and the metrics were high (around 99%) in all the cases. The root main square error for example was only 1.5 nautical miles (NM) in case of the hybrid model (in this case a filtering process was applied on the dataset).

The current separation minima is 5 NM horizontally and 1000 feet vertically. The results of the ML related assessment in AISA are promising. The model was 100% right when the predicted minimal distance between pairs was within 5 NM and 97% when it was 5 to 10 NM. In other words, with this AI technique if a system is trained with a dataset large enough to build rules from that, it can predict all the possible serious conflicts (within the horizontal separation minima range) and most of the conflicts which are in a 10 NM SI [18].

4. Possible future impact

The most important benefit that the future AISA system might bring in the middle term is the improved situational awareness both for the ATCO and the system. In the improved situation the ATC system (with an AISA element included) "is able to gather all necessary data regarding the current traffic situation, turn it into knowledge, and then draw conclusions based on the knowledge gained" [14]. The main benefits that an AISA kind of system might bring for ATC is the following: automation of monitoring tasks, central coordination of other tools and modules, gathering missing information and automated reporting (Figure 4).

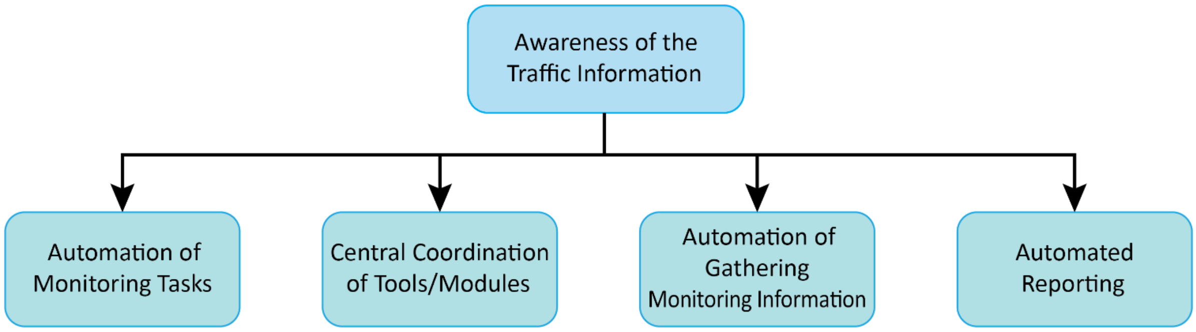

Figure 4: Predicted benefits of the system being aware of the traffic situation, own drawing on the basis of the AISA concept [14]

5. Outlook - beyond AISA

As AISA is only one of the many projects dealing with the introduction of artificial intelligence in aviation, there are many options to utilise AI. As the FLY AI report indicates: „AI has huge potential for use in areas where it can reduce human workload or increase human capabilities in complex scenarios, e.g., to support air traffic controllers (ATCOs), pilots, airport operators, flow controllers or cybersecurity officers" [21].

On a wider scale, AI can be utilised in more and more systems in the sectors affecting public health, safety and welfare. Although there are some technological obstacles and some negative feelings in the public, these systems can improve the quality of life of many. In order to use it more in critical infrastructure, new design methodologies and flexible standards are needed [22].

Answering the initial question, in my opinion, AI will certainly be used more in safety critical industries as well, also for primary, control type of activities. The promising results in the AISA project have proved that even in the primary system (e.g., ATC systems) of safety critical industry (e.g., air traffic control) there are promising opportunities for artificial intelligence. However, project and other findings also underline that the road to that point is long, not necessary in time, but many steps are needed to take to ensure safety, security and transparency of the systems in use.

Conclusions

The application cases for artificial intelligence are increasing day-by-day. Although it is a relatively new scientific technology, it is entering safety critical industries, such as aviation, as well. In air traffic control in order to cope with the growing demand, automation is needed to support human controllers. One example for the AI related research in the domain, is the AISA project, which investigates how human and machine can share situation awareness in a team. The possibility for a team shared awareness is first analysed with those tasks of the air traffic controller, which are simpler, monitoring type of activities. As an example of the outcomes, the machine learning module of the project has indicated some promising results, but what is more important is that the project shows a possible pathway to follow for a successful use of AI not only in aviation but in other safety critical industries as well.

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