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ORIGINAL PAPER

Virtual flight deck crew assistance utilizing artificial intelligence methods to interpret NOTAMs: a user acceptance study

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Abstract
Over the past few years, artificial intelligence (AI) and machine learning (ML) methods have become deeply embedded in everyday applications. Great progress has been made, which is why these methods are now being introduced to other areas including aviation. The use of such methods in safety-critical areas like aviation, medicine or jurisdiction, entails not only benefits but also challenges, such as regulatory and ethical aspects and the necessary acceptance of users and other stakeholders. This research paper presents the findings of a qualitative user study conducted to investigate the potential benefits of integrating AI on the flight deck to improve the usability of Notices to Airmen (NOTAMs). Currently, pilots receive a large amount of NOTAMs for each flight. This overload of information can lead to important information being overlooked. Semi-structured interviews with ten pilots were conducted to gather their perspectives on current challenges in their daily work with NOTAMs, acceptance of AI-based methods in aviation with focus on the flight deck and possible fields of applications. Recommendations are derived for future developments. The findings suggest that methods based on AI have the potential to improve the usability of NOTAMs, making them more efficient and user-friendly for pilots. Additionally, the study highlights the importance of addressing pilots' concerns and taking into account human factors, safety considerations, and the need for effective human–machine collaboration.

Keywords Crew assistance · Artificial intelligence · Future flight deck operations

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1 Introduction

Machine learning (ML) and artificial intelligence (AI) methods and algorithms have undergone rapid development in the past decades. The use of such methods can be beneficial in many applications, such as recognizing patterns in large amounts of data while learning new concepts and receiving new insights. However, the use of AI also raises a number of challenges, especially in safety-critical environments such as medicine, jurisdiction, or aviation. Certification in these areas can be challenging, because, as for instance defined in the concept paper for guidance on applications using Level 1 machine learning by the European Union Aviation Safety Agency (EASA) [1], a certain level of transparency, comprehensibility, traceability and accountability is required, which is not always easy to obtain for AI methods. Another challenge of using AI in aviation is acceptance, both by users such as pilots, but also by society, politics and the passengers themselves.

As part of the German Civil Aviation Research Programme (LuFo VI-1), the joint project ViCKI - Virtual Crew

Assistant - Context-Specific Support for Reduced Crew Operations Using Artificial Intelligence - is investigating the use of artificial intelligence methods to develop a supporting virtual assistant for flight personnel and evaluating initial developments on the foundation of selected use cases. The use case considered here is the structuring, interpreting and processing of NOTAMs - Notices to Air Men or Notices to Air Missions in US wording in order to facilitate the work with them for pilots. The ViCKI consortium consists of five German industry and academic partners supported by advisory activities on the part of a regulatory authority and commercial pilots. The developed AI based assistant is referred to as the Virtual Crew Assistant (VCA) in the project. The VCA is conceptualized, developed and evaluated for today's dual pilot cockpits, as well as for future flight decks with reduced crew operations (RCO).

In the joint project, another use case is investigated, namely the support of the flight deck crew during the approach briefing with the use of Automatic Speech Recognition (ASR). In a noisy environment such as a flight deck, the use of ASR entails challenges that need to be overcome in order to create a robust and reliable speech recognition model (see Bollmann et al. [2] for more information).

In this work, a survey of pilots with different levels of experience was conducted on their thoughts and perceptions of the use of artificial intelligence in aviation, as well as the day-to-day challenges in using and interpreting NOTAMs in their daily work. Artificial Intelligence is used as a comprehensive term for all methods in this field, including e.g., machine learning and deep learning. This was chosen to simplify communication with the subjects.[1]

2 Research on the challenges and enhancement of NOTAMs and current AI certification efforts in aviation

The challenges that pilots and other aviation stakeholders have to overcome in their daily work with NOTAMs has been engaging various research groups and pilot associations for a several years now. Only recently, however, has there been an increased interest in the potential certification of AI and ML methods in aviation. The use of such methods could be an approach to increase the usability of NOTAMs and facilitate their handling.

2.1 Research efforts and projects on NOTAM challenges and facilitation approaches

A variety of aviation research groups and organizations aim to simplify the handling of NOTAMs or improve the concept in general [3]. One example is the OpsGroup, which addresses the challenges of the daily work with NOTAMs not only for pilots but also for dispatchers and other operational staff [4]. Various approaches have been explored to simplify and enhance aspects of NOTAMs for users (e.g., automated NOTAM processing for graphical depiction on an airport map [5], rule-based notification systems [6], semantic filtering [7] or enrichment [8] or visualization concepts [9–11]). The d-NOTAM project, funded by the Federal Ministry for Digital and Transport (BMDV), deals with the digitization of NOTAMs using available data in order to easily display them on the Electronic Flight Bag (EFB) [12].

This concise selection of research efforts and projects shows that NOTAMs still complicate the everyday life of pilots and dispatchers today, can be hazardous for flight operations and constitute a major need for improvement.

2.2 Current artificial intelligence certification efforts in aviation

In 2020, the EASA published its roadmap with the intermediary steps to the certification of artificial intelligence in aviation, in which they divided the implementation areas and functions into three levels [13]. Level 1 applications should only assist humans, Level 2 applications collaborate with the humans and Level 3 applications are highly automated to fully autonomous AI [13]. This guideline was in part guided by the ethics guidelines for trustworthy AI issued by the High-Level Expert Group on AI (AI HLEG) [14]. The first concept paper on the lowest level followed in the following year, which introduces a first set of objectives and anticipated means of compliance (MOCs) [1]. Furthermore, EASA works closely with research partners and companies that are working on AI applications and guidelines. This includes, among others, the ViCKI joint project, but also, for example, Daedalean AG, which has published two reports on design assurance for neural networks in collaboration with EASA (see [15, 16] for their joint reports).

The U.S. aviation authority, the Federal Aviation Administration (FAA), is also working on exploring and investigating AI and ML in aeronautical applications [17], e.g., a convective weather avoidance model to predict pilot behaviors in certain weather situations or improving traffic flow [18].

The global standards organizations EUROCAE and SAE International collaborate in the development of standards and guidelines regarding artificial intelligence in aeronautical systems. Both EASA and FAA as well as the

[1] The authors are aware that the solutions proposed by the participants do not necessarily require AI-based methods.

International Civil Aviation Organization (ICAO) participate in these activities (see [19, 20] for additional information).

3 The qualitative user study: design and sample description

A semi-structured interview was conducted with ten participants. The length of each interview was about 60 min. The interviews were conducted online via video call. Every interview was audio recorded and transcribed. The transcriptions were then processed to classify the answers.

3.1 Sample description

A total of $N = 10$ participants ($n = 1$ female, $n = 9$ male) were interviewed for the user study. Their ages ranged between 30 years and 61 years (mean (M) = 51, standard deviation (SD) = 10.16). Out of these, nine participants were pilots with experience on the Airbus A320 family and one participant was a beginner pilot with only two hours flight experience. Except this, the experience ranged from 1.200 to 23.000 flight hours (M = 15.056 and SD = 6.852,02).

3.2 Interview structure

The interview was structured in three sections: pilots' personal experience in dealing with NOTAMs (seven questions), acceptance of artificial intelligence regarding NOTAMs (eleven questions), and NOTAMs design in terms of actual presentation and future development (five questions). These questions, 23 in total, were selected by a group of five individuals with different academic backgrounds (namely psychology, mechanical engineering, computer science and pilot training). They were derived according to the Unified Theory of Acceptance and Use of Technology (UTAUT), more precisely the refined version UTAUT2 (see [21]). The identified questions were then grouped into the named topics and subsequently discussed with an independent aviation expert. The aviation expert ensured that the questions were understandable as well as complete for the research goal of this work.

3.3 Answer processing and analysis

Each interview was recorded with the consent of the participant and conducted by the same interviewer. Afterwards, the interviews were transcribed by another author. Based on these, an initial coding was selected, applied to the transcriptions and reviewed by all authors independently and iteratively adjusted. These codings are used in the following chapter to divide the answers into categories.

3.4 Definition of used terms

In the following section, terms were used which might not be consistent in literature. Therefore, the following definitions were used for the coding of the interviews:

Transparency refers to the principle of making the decisions and outcomes of certain systems understandable to users and stakeholders. Considerations include the traceability of a solution and the path to a certain decision, the explainability of these decisions and outcomes as well as an open communication to the user (according to [14]).

There is no consistent definition of workload or mental workload in literature nor a commonly used one [22, 23]. In this context, workload is defined as the human's mental demands executing certain tasks [23]. These include cognitive and perceptual demands [24]. In this study, this concept is solely subjective.

Emergency support is the support in any situation that causes pilots distress or urgency as defined in FAA's pilot and controller glossary [25].

4 Results of the qualitative user study

The results were thematically divided into three main categories: their personal experience in working with NOTAMs, acceptance of AI-based methods specifically applied to NOTAMs, and possible approaches to enhancing and facilitating the handling of NOTAMs. AI is used as a comprehensive term for all related fields.[2]

4.1 Users' personal experience in dealing with NOTAMs

The participants were asked about their experiences with NOTAMs. To explain the current experiences of the participants, mentioned points of criticism as well as positive aspects were compiled. The core challenges stated by the subjects are summarized in Table 1.

4.1.1 Vagueness and ambiguity

All participants described difficulties in the readability of NOTAMs. Both abbreviations and numbering of the NOTAMs are not consistent in some cases. Also the NOTAM formatting appears in some cases confusing. Here, a renewed preparation would make sense. The

[2] In the following sections, it is frequently referred to as 'AI NOTAMS' or 'the AI'. This is the wording used by the subjects and is adopted as such for the purpose of simplification. The authors are aware that there is no such thing as 'one AI'.

Table 1 The primary challenges identified by the subjects in regards to their personal experience with NOTAMs

Category	Number	Statement
Vagueness and ambiguity	C1	Difficulties in the readability of NOTAMs
	C2	Inconsistencies in abbreviations and numbering
	C3	Geographically depicted NOTAMs are not always more comprehensible
	C4	Current prioritization systems do not always classify the importance as expected
	C5	Temporary validity of NOTAMs can be unclear
Time criticality and information overload	C6	Amount of information is too large
	C7	Relevance of the displayed information varies
	C8	Type of information shown varies greatly
	C9	Time pressure due to the amount of information

various sources of information would lead to confusion, which would require more time for checking. Geographically mapped NOTAM systems already in use would also be too confusing in some cases. Current prioritization systems would not always correctly classify the importance of certain NOTAMs. Participants also indicated that the temporary validity of NOTAMs is sometimes unclear, resulting in NOTAMs being displayed that are not yet valid. Specifically, NOTAMs regarding construction sites are divided into different phases, and it can be unclear which phase is currently valid. The current display of validity periods is also classified as ambiguous. Often NOTAMs have a long validity and are therefore displayed for a long time. This can lead to difficulties in information processing.

4.1.2 Lack of time and information overload

When asked about their personal experience with NOTAMs, all pilots pointed out that the amount of information with which pilots are confronted was too large. However, the reduction of the amount of information is also where the greatest potential for supporting pilots is seen. The reading time required to acquire the NOTAM information in the briefing package was also criticized. The time available to read NOTAMs was also found to be too short to remember all the information. As a result, pilots can only roughly process the information from NOTAMs. This makes it difficult to assimilate the information in detail, partly because information that is less relevant is displayed. The existing pre-sorting system would partially solve this problem. Due to the mass of information, it could happen that relevant information from the NOTAMs is overseen. In addition, it was criticized that all kinds of information are available in the NOTAMs. Whether it is necessary to display everything in the NOTAMs or whether it is possible to concentrate on the essentials was put up for discussion.

4.1.3 Positive status Quo

In addition to criticisms, many pilots also noted positive aspects of the current display and processing of NOTAMs. The existing pre-sorting of NOTAMs represents significant progress. With the help of the weather data, the relevant NOTAMs could be displayed directly and a repetition of these was guaranteed. The color coding and highlighting of the keywords as well as the possible filtering by date are also improvements. The actuality of the NOTAMs is rated as good. It should be emphasized that the presentation and preparation of NOTAMs varies between different providers and airlines and that improvements are already being made in the preparation and presentation of NOTAMs.

4.2 Acceptance of artificial intelligence methods regarding NOTAMs and applications opportunities

The participants' answers were classified into four categories to describe their views on AI acceptance and application opportunities.

4.2.1 Transparency

Participants stated that the information provided by AI should be comprehensible and the information should not be too deep and make the system too complex. In terms of acceptance, the transparency of how the system works seems to be important for trust. Thus, it must be disclosed what decision the system has made and why, and presented in a plausible way. At the same time, this should be presented in such a way that the pilot's task does not consist of having to question the whole thing again. A back-up system is also desired to increase trust. On the other hand, one participant stated that transparency is only relevant for the approval process and if the system works well, it does not necessarily have to be comprehensible to pilots how

Table 2 Expectations and design requirements of artificial intelligence based methods in aviation

Category	Number	Statement
Transparency	A1	Comprehensible information, not adding complexity to the system
	A2	Transparency of how the system works is needed to create trust
	A3	Decisions and decision-making processes have to be disclosed
	A4	Transparency is only relevant for the certification and approval processes [1]
	A5	Functionality and operating principles of the system need to be taught in pilot training
Responsibility	A6	Pilots should not be held responsible for errors of the system or mistakes made by the system
	A7	If pilots are held responsible, the system should only work as a support

[1] A4 contradicts with the other statements from the Transparency category. This shows that even among pilots there is no consensus on transparency and the amount of information pilots should obtain from the systems

the system works. All participants stated that if AI were to be used on the flight deck, it would have to be understood beforehand what the AI system is doing.

4.2.2 Responsibility

All participants emphasized the importance of responsibility when working with AI based systems, e.g., NOTAMs. Since pilots have to take responsibility in the end, a system should not intervene directly and only work in a supportive way. Three participants stated that it is questionable who takes responsibility for errors made by the system, or if the errors really lie with the system, pilots should not be held responsible for them. Moreover, it has been stated, that the regulatory work must be reconsidered in order to clearly define responsibilities.

Table 2 summarizes the participants' expectations and design requirements towards AI based systems in aviation.

4.2.3 Workload reduction

It was stated that AI could provide support in stressful situations, but it should not overburden pilots and no additional workload through AI is desired. By help of AI, NOTAMs could be processed in such a way that the information could be accessed more quickly. The pre-sorting of NOTAMs by AI is seen as a major work relief which would go hand in hand with a direct time saving. AI could also be used to be compliant with the regulations. One participant stated that it could help pilots to be sure that they are compliant with current regulations. It was also noted that an AI could be used as a monitoring instance and thus relieve pilots of further work steps and increase in flight safety. AI could also assist in assessing weather phenomena or optimizing climbs and descents.

4.2.4 Emergency support

It was noted that in emergencies, an AI could act as a warning system, e.g., display relevant NOTAMs that would become relevant in the event of an emergency landing and if applicable, displayed on a map. Indications could also be given by pressing a button; in this way, an AI could help with the further procedure. The idea of a signal tone indicating that a certain airport cannot be approached was also mentioned. However, it was also noted that there may not be enough time to display NOTAMs in an emergency situation.

4.3 NOTAMs design and ideas for future development

A total of five questions gave insight into the possibilities of extending and improving the design of NOTAMs. Some of them involved the use of AI. The evaluated answers were classified into nine categories.

4.3.1 Information output and presentation

The auditory output of information was considered difficult in some cases because of the many different channels, such as radio traffic. Haptic information output was partly considered conceivable, as it could address another perception channel, but implementation was found to be unclear. However, haptic information output was also seen as difficult in some cases, as it could be unclear where it comes from. Almost half of the participants preferred an auditory warning system in form of an oral alert only if necessary. However, this could only be done if there is no other auditory output at the same time, as this could otherwise be too demanding, especially in stressful situations. The possibility of having NOTAMs read out was mentioned by two participants as an option for the auditory flow of information, but this would have to be clearly prepared so that it does not become too long. However, the visual channel was clearly preferred by most participants.

4.3.2 Information transfer

Participants emphasized the importance of AI by helping with information overload regarding NOTAM design. One participant stated that AI could tell pilots exactly what is relevant at a particular time and then make that information available. Filtering and automating NOTAMs through AI was considered as conceivable, as it would focus on the important things, but it could be difficult from a legal point of view concerning responsibility. It would also be conceivable to update the NOTAM lists during the flight with valid information or as an output on the display. However, it was also noted that the system could have difficulties in finding out what is really important. An AI could also support the understanding of NOTAMs and the associated contexts.

4.3.3 Regional differences of NOTAMs

Participants stated that despite certain standardization, each country has a different language of NOTAMs, which sometimes leads to misunderstandings. For example, for some regions of the world the NOTAM list would be far less extensive with lower quality. Therefore, a suggestion for NOTAMs improvement could be as follows: one could, for example, click on unclear words and receive an explanation for them again.

4.3.4 Change of display

The presence of several screens used to improve the ergonomics during the flight (e.g., currently in the side window, so that physical movement is necessary) was suggested. Moreover, some participants emphasized the importance of being able to zoom on the display. A warning system via the screen was suggested in order for the problems and messages to be displayed there. The display could also be shown, for example, as a timeline of the flight with the most important information.

4.3.5 Feedback and networking

It was noted, that pilots could give feedback to the system themselves when they have taken note of a warning and at the same time it could be used to inform other stakeholders about possible problems. At the same time, the possibility of a feedback on individual NOTAMs was mentioned, either on the content or to the system regarding pre-sorting. Networking between the systems and between pilots was emphasized as being important and could be supported by the AI.

4.3.6 Color coding and highlighting

It was frequently noted that color coding of the NOTAM list is considered extremely useful. Color coding could also be useful on a map or similar (e.g., marking construction sites, cranes, closed taxiways). In addition, NOTAMs that have been sorted out by the system could also be coded with a certain color. It was also noted that NOTAMs could be sorted according to relevance and the corresponding color (e.g., red = important, yellow or amber = medium). The validity period could also be highlighted in this way.

4.3.7 Filter function

A NOTAM pre-sorting according to importance for the respective flight was desired (e.g., runway first, then approach, ground information, refueling decision). Participants noted that more information should be displayed with less text. One participant specified, *"the most important things first, briefly, concisely and clearly"*. Currently, there are already pre-sorted NOTAM lists, but these are not always reliable, so that one still has to read over them again. In this case, an AI could provide support and focus on relevant information.

4.3.8 Temporary validity

Participants stated that it is sometimes unclear whether a certain NOTAM affected one at all, since the various temporary validities were sometimes difficult to filter out. Therefore, they stated that the validity should be designed in a clearer manner, so that NOTAMs that are not relevant for e.g., landing would not be displayed when not necessary (especially interesting for long-haul flights). The validity of the NOTAM should be more clearly defined and recognizable.

4.3.9 Interactive map

An interactive map was often mentioned as a possible form of representation to compress the different channels and to create a better overview for pilots. For example, the positions of construction sites, cranes, etc., could be clearly marked on the map and highlighted by color coding. An AI could interpret a NOTAM and insert it into an interactive map so that it could be recognized directly by pilots (position, validity, etc.). This interactive map could also provide in-flight updates of NOTAMs and display them if necessary. Using GPS, area-specific and relevant NOTAMs could be displayed on the map as a pop-up. It was also conceivable that as soon as one clicks on a NOTAM, the exact positions are displayed on a map.

Table 3 Opportunities of AI application in aviation as identified by the subjects

Category	Number	Identified opportunity
Information pre-processing and presentation	O1	Pre-sorting NOTAMs
	O2	Pre-filtering NOTAMs according to relevance or temporary validity
	O3	Highlighting of important information in NOTAMs
	O4	Creation of an interactive map of NOTAMs
Flight operations	O5	Additional monitoring instance
	O6	Weather assessment
	O7	Assessment of impact of NOTAMs on current flight operations, especially in emergency situations
	O8	Climbs and descents optimization
Miscellaneous	O9	Regulatory compliance assistance

4.4 Summary of opportunities identified by the subjects

The subjects identified nine main areas where AI can be applied in specific regards to NOTAMs and in general to make pilots' daily lives easier. Table 3 summarizes these possibilities. Not all opportunities have to be solved with ML or AI methods and suggestions like highlighting important information in NOTAMs (O3) and pre-sorting of NOTAMs (O1) already exist to some extend today. Nevertheless, this offers the opportunity to examine which aspects can be further improved with new advanced methods.

5 Conclusion and future work

The qualitative user study examines pilots' expectations and requirements towards systems based on artificial intelligence and machine learning methods in the context of aviation. Furthermore, everyday challenges of pilots in dealing with NOTAMs are revealed and presented and first ideas on how to improve NOTAMs in the future are suggested. The pilots' statements show that while they have certain demands, e.g., transparency in AI based systems, an overall open attitude exists. Statements like A2 and A3 from Table 2 on the transparency of such systems are in accordance with the requirements of EASA and AI HLEG. However, statement A4 shows that the expectations and requirements that users have are not necessarily consistent and shared among users.

At the same time, the user study shows that there are still challenges in dealing with NOTAMs today which leaves room for improvement. The subjects addressed different design proposals from different problem areas. Some are solvable with deterministic methods, others can benefit from ML or AI methods (be it in complexity, implementation feasibility or general effort). The effort and benefit of using non-deterministic methods must be weighed individually for each use case. Overall, these types of approaches can support the evolution towards future flight operations with a reduced flight deck crew, but could also be deployed and used to support today's crew constellations.

Based on the collected expectations and requirements, the following steps include the final conception, design, and implementation of the assistance system to support pilots in their work with NOTAMs. Finally, the system will be evaluated with subjects in the RCO demonstrator at the Technische Universität Darmstadt. All steps are taken in close consultation with EASA and commercial aviation pilots.

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Declarations

Conflict of interest The authors have no Conflict of interest to declare that are relevant to the content of this article.

Ethical approval All procedures performed in this study were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants involved in the study.

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