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EXAMINING THE CHANGING ROLES AND RESPONSIBILITIES OF HUMANS IN ENVISIONED FUTURE IN-TIME AVIATION SAFETY MANAGEMENT SYSTEMS

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Advances in technology are enabling new concepts of operations that will transform aviation including increasingly autonomous capabilities to handle evolving complex dynamic ecosystems like those associated with Advanced Aerial Mobility. A major challenge is how to ensure today's safety levels are maintained as the system scales for rapid detection and timely mitigation of safety issues. NASA has developed a concept of operation for In-Time Aviation Safety Management Systems (IASMS) that represents a system-of-system perspective on interconnected capabilities needed to proactively reduce risk in complex operational environments where unknown hazards may exist. As a result, NASA research priorities include understanding how the balance between humans and automation changes in such envisioned systems, which may lead to novel human-machine interaction paradigms and human-autonomy teaming for informed contingency management.

Advances in technology are enabling new concepts of operation that will transform aviation. The innovations for the future air transportation system will span increasingly autonomous capabilities to handle very complex, dynamic ecosystems comprised of a widening mix of vehicles and technologies, urban air mobility, and unmanned and traditional operations. The purpose of this paper is to discuss key considerations for the roles of human operators in the design of an In-time Aviation Safety Management System (IASMS) concept of operations (ConOps) to account for these innovations and their implications (Ellis et al., 2021).

The temporal parameter of in-time safety means quickly managing known operational risks in real- or near-real-time, quickly identifying unknown risks to be managed, and quickly informing system design as risk patterns are identified. As explained by the National Academies, "real time" pertains to events that occur at the same time or near real time, whereas other parts of a Safety Management System (SMS) operate over a longer period of time for identifying trends that cannot be identified in real time (2018), i.e., real-time safety assessment is but one aspect of a broader IASMS.

Future Vision of Emerging Aviation Domains

Demand for high-speed mobility, transformative advances in autonomous capabilities and emerging aviation sectors are enabling new future concepts. Advanced aerial mobility (AAM) is a concept of operation enabled by envisioned technological innovations imagined leading to on-demand, passenger carrying air taxi, small package delivery, autonomous cargo delivery, and emergency and disaster response (Patterson, 2021).

The FAA's Vision 2035 concept poses that in the future the vehicle and its missions will drive the services required and tailored for flight performance characteristics (MITRE, 2020). The Vision poses basic principles including that human-machine teaming with smart systems is pervasive.

Scalability for Autonomous Systems and Operations

A major challenge is how to ensure today's aviation safety levels are maintained as the system scales in volume and complexities (Holbrook et.al., 2020; Pritchett et.al.,2018; Shively, et.al., 2018). Another major challenge considers that as autonomy takes on increasing responsibilities, humans and machines will be required to work together in new and different ways. AAM's path forward is through design of responsible autonomy that embraces innovation while respecting its safety tradition. The digital transformation to assimilate AAM includes use of satellite, cell, and web capabilities for surveillance, required navigation performance, digital communications, machine learning and artificial intelligence for flight management replacing automated decision support tools, and prognostic safety assurance.

In-Time Aviation Safety Management System

As new entrants transition into the airspace system, maintaining safety will require more proactive risk mitigation of emerging safety issues before they become hazards. The IASMS concept of operations goes beyond today's SMS by addressing the design of new in-time safety systems and services, enhanced tools and technologies, increased access to data and data fusion, improved integrated data analytics, enhanced in-time risk monitoring and detection, hazard prioritization and mitigation, and safety assurance decision support.

The IASMS represents a system-of-system architecture of services, functions and capabilities (SFCs) for vehicle, airspace, and operators. SFCs monitor conditions, assesses data, and perform or inform an in-time mitigation action. A set of coordinated and collaborative in-time safety assurances together make up an in-time aviation safety management system. At the vehicle level, example SFCs include detect-and-avoid and contingency management. Example SFCs for the operator include people below flights as third-party risk, weather risk, and safety reports. Example SFCs for airspace include airspace conformance, constraints, and traffic dynamic density. Example SFCs at the infrastructure level include safety data repositories and vehicle post-flight operations data reduction and analysis.

Transitioning to increasingly complex AAM operations necessitates new roles for human operators. A possible evolution of AAM operations, shown in Figure 1, poses transitioning from today's simplified pilot operations to a future when the human remotely manages and later remotely supervises operations. Across AAM epochs, SFCs will improve situation awareness with vehicle-to-vehicle and vehicle-to-infrastructure communications across vehicles, systems, Unmanned Aircraft Systems (UAS) Service Suppliers (USS), and Supplemental Data Service Providers (SDSPs). Vehicles will exchange information about their current state and planned trajectory, and users will have access to information about the operating environment.

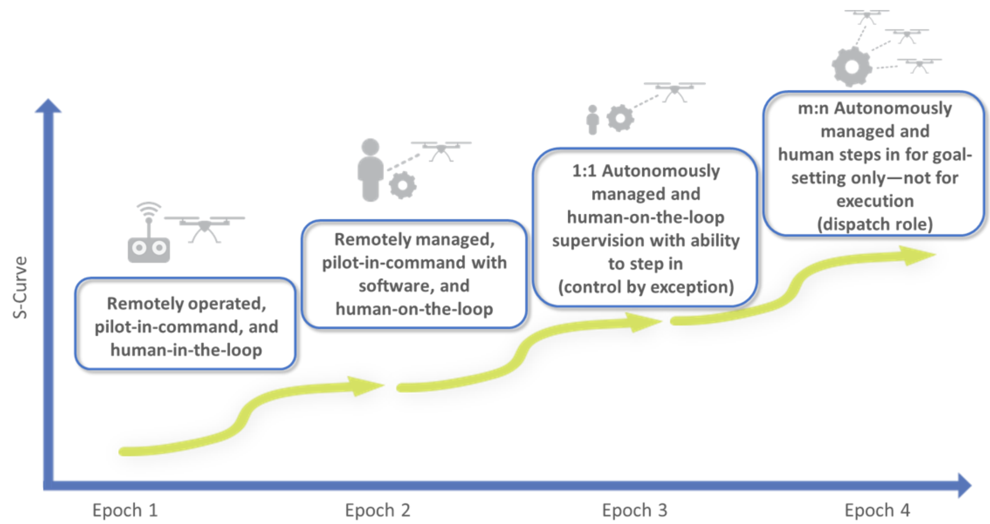

Figure 1. Evolution of AAM Operations and Safety.

Envisioned New Human Roles

AAM and the future National Airspace System (NAS) pose new roles for humans with shared responsibility for safety assured through continuous, real-time monitoring of operations and emergent risks. A key challenge is that today certification and safety assurance assume pilots and air traffic controllers are in-the-loop for operational safety. To realize AAM, innovations are needed to include paradigm changes in designing human-system architectures and considerations for safety assurance. Moving from simplified vehicle handling qualities to properly designed, resilient and capable automated systems may require phased implementation of autonomy that moves safely from today's highly capable pilot, to a pilot operating a simpler vehicle, to a passenger who can act during an emergency.

Defining human roles flows from the functions they perform. Sheridan and Parasuraman identified five human functions for supervisory control including planning off-line, monitoring the automation's execution of the plan, and intervening to abort or assume control as necessary (2005). Just as the IASMS uses the functions of monitor, assess, and mitigate to address safety risk, the human operator can be conceived to perceive, assess, and act on risk based on the human information processing model by Wickens (1992).

Automated systems capable of complete autonomy do not yet exist for aviation and future designs should avoid repeating problems and errors of the past. The Performance-Based Aviation Rulemaking Committee (PARC) and the Commercial Aviation Safety Team (CAST) examined modern flight deck systems for flight path management (2013). Automation concerns included that pilots sometimes rely too much on automated systems and may be reluctant to intervene and auto flight mode confusion errors continue to occur.

Managing safety risk across varied operations and services will require deep human-machine teaming to best use the increased volumes of information being exchanged (MITRE, 2020). These smart systems will analyze a situation and make decisions based on the available data in a predictive or adaptive manner. For instance, flight deck-based capabilities like Aircraft Health Monitoring Systems will proactively detect and mitigate undesirable aircraft states such as high energy on approach before they result in safety incidents.

Challenges and Mitigations in Human-Automation Teaming

Understanding the balance between humans and automation and how they seamlessly work together in increasingly complex operations may lead to novel paradigms for human-autonomy teaming (HAT) including contingency management. Part of the challenges in human-automation teaming resides with the capabilities and limitations of human operators assessed through cognitive models, and another part corresponds to the automation and the SFCs the operator relies upon. The in-time safety assurance SFCs were developed with these considerations in mind.

The key challenge for HAT is that the key critical enabler does not yet exist. It is "as envisioned" as shown in Table 1. The Monitor-Assess-Mitigate numbers signify notional increases in capability. This presents a challenge in identifying, developing, and implementing SFCs to provide for in-time safety assurance. This presents an opportunity for clean-slate design to possibly enable collaborative human-machine partnerships.

Table 1. *Maturation Levels of Human-System Interaction.*

Maturity Level	Maturity Description	Monitor	Assess	Mitigate
4	Fully Autonomous Functionality	3	3	3
3	Autonomous Functionality with Human Over-the-Loop	3	3	2
2	Automated Function with Human Fallback (On-the-Loop)	2	2	1
1	Alerting Function for Human	1	1	0

Endsley provided a human-autonomy system oversight model integrating past research (2018). This notional model integrates central design decisions with considerations for adaptive automation, granularity of control, key automation interface features such as information presentation and salience, attention allocation, task demands and competing tasks, automation robustness and reliability, and operator trust based on automation robustness and reliability.

Research has demonstrated the challenge when humans monitor and take over automated systems including when they do not fully understand these systems (Smith & Baumann, 2019). Potential negative effects from automation included reliance on automation as the primary agent to detect problems; reduced attentiveness to deal with automation degradation and failures; fatigue with false alarms; and degradations of skill, situation awareness and teamwork. Strategies for mitigating these effects included using data analytics to learn from past performance, using contingency procedures, designing technology that keeps the user informed and engaged, ensuring consistency across automated systems, and designing displays so the user can view the same data that the automation is using. Mitigations regarding alarm design included designing an interface so status indicators are salient, and information is easy to access. They cautioned that brittle systems can be due to scenarios that occur beyond what was anticipated for the automation to handle, gaps in the model used by automation, and unanticipated emergent behaviors resulting from mismatching interactions between multiple automated systems.

At least during earlier phases of AAM evolution human operators will have a supervisory role such as on-the-loop or over-the-loop. Vehicle SFCs will automatically execute the flight plan, provide health monitoring checks and alerts, and react quickly to trajectory and other deviations. The vehicle would make local decisions about the safety of flight such as loss of C2 link. Automation will develop the flight plan to marry expected flight time with battery life and airspace constraints. The human operator will validate the flight plan prior to departure, make strategic decisions to mitigate risks before departure, quickly respond to alerts and diagnose other exceptions, and re-route the flight because of new airspace constraints.

With AAM the balance between humans and automation goes beyond traditional function allocation. The human operator must remain vigilant when not in-the-loop to possible exceptions that can occur to ensure the automation responds appropriately. Handling an exception requires both sufficient time to intervene and a deep understanding of the system to avoid errors of omission and commission that could prevent mitigation of a risk or making it worse. Training on system design and operations requires a high level of proficiency, but without continual use those skills can degrade. Integrating cognitive modeling for the operator with machine learning and artificial intelligence poses further challenges for HAT. SFCs will provide data exchange as part of in-time risk management between flight operators and service providers.

Future challenges in HAT include understanding the information requirements for human operators and how those change with increasingly complex levels of autonomy and contingency management. Mathematical modeling of cognitive architectures is an approach to examine a hierarchy of autonomous systems (Bhattacharyya, 2015). Information requirements can be envisioned through questions about what the automation is currently doing compared to what it should be doing for particular operations. For example, NASA found in early UTM tests that missing details made it more difficult for crews to establish situation awareness and when more detailed information was available, it was needed more quickly. Results indicated more complex environments required more information to be presented to the pilot but there were too many messages to read. Some terminology was hard to interpret, different units of measurement required crews to interpret, and more time was needed for making complex contingency decisions. Cardosi and Lennertz examined human factors issues with trajectory-based operations and recommended that an assessment of functions performed by the pilot should include what information is needed, when it is needed, and in what format it should be presented (2020).

Summary

HAT offers an important design and operational safety perspective to the IASMS concept. Teaming approaches will scale as the architecture of SFCs, use of inter-dependent automated systems, and operational environments evolve toward greater complexity. This multi-dimensional space for design of an IASMS has implications for changing roles and responsibilities for human operators and fewer skilled operators. The Monitor-Assess-Mitigate functions can inform design decisions about what information the human operators should monitor, when they need to make assessments, and how they need to intervene.

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