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THINKING OUTSIDE THE BOX: THE HUMAN ROLE IN INCREASINGLY AUTOMATED AVIATION SYSTEMS

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Rapid advances in automation are enabling transport systems to operate in an increasingly autonomous manner. From time to time, these systems encounter operational conditions that fall outside a "competency box" of scenarios and environments for which the system was designed. Human operators add resilience because they can see and act outside the automation's competency box. Advanced aviation concepts envision fleets of highly automated air vehicles providing on-demand transport for people and goods. We examine one such concept, Urban Air Moblity (UAM) and explore how humans can best be incorporated to maintain resilience. A human-autonomy teaming approach is suggested.

Advances in automation are changing many aspects of everyday life, including the way goods and people are moved from place to place. Remotely-operated trains, robotic warehouse delivery systems, and "self-driving" cars are showing us what a future transport industry might look like. The urban air mobility (UAM) concept is such a case. Several companies are proposing UAM systems in which electric-powered vertical takeoff and landing aircraft (eVTOL) would routinely transport people and products.

In recent years, some proponents of automation have envisioned future transport systems that will operate with limited or no oversight from a human operator. Proponents of UAM note that this final state reduces cost as well as eliminating pilot error, identified as a contributing factor in many aircraft accidents (e.g., Uber Elevate, 2016). This viewpoint ignores the possibility that human operators add resilience because they can perceive and act outside the "competency box" of the automation. We use the term "competency box" to refer to the scenarios and environments within which the automated system has earned trust that it can operate safely without the need for human intervention. This is similar to the "competence envelope" discussed by Hoffman and Hancock (2017) and the system boundaries discussed by Woods (2015). During the design process, the intended competency box may be expressed explicitly in terms of performance specifications, but some aspects of the intended competency box may also remain unstated. As operational experience accumulates, the actual competency box will sometimes turn out to be smaller than intended, as the system fails to deal with scenarios and environments, including some anticipated by the designers. In other cases, the system might fail to deal with scenarios and environments that had not been anticipated. A safety critical system possesses resilience when it is able to adjust its functioning to maintain safety in the face of expected and unexpected conditions (Hollnagel, 2015). We propose that achieving a resilient UAM system must involve the complementary capabilities of automation and humans working together.

An automated system's capabilities can be expanded over time with modifications to software, sensors, and other components. A characteristic of machine learning is that automated systems have the potential to expand their capabilities as experience is accumulated. However, even the most capable automated systems have limits, and it is unclear at what point, if ever, the competency box becomes large enough to safely eliminate the role of the human operator. The designers of UAM systems face the challenge of how to make the best use of intelligent automation, while also leaving room for the resilient performance potential of humans.

The UAM Concept

The FAA UAM Concept of Operations (ConOps; FAA, 2020) covers operations occurring in dedicated corridors in urban environments. This ConOps envisions an initial stage of UAM operations in which aircraft operated by an on-board pilot fly within the current air traffic management (ATM) system. Pilots would exert direct "within the loop" control of the automated systems, much as they do today. The next stage, referred to as ConOps 1.0, would involve aircraft flying in UAM corridors that are not under direct control of air traffic controllers (ATC). ATC would, however, have the authority to open and close these corridors. An on-board pilot would monitor systems and would have the ability to take control when required or desired, under a "human-on-the-loop" supervisory control model. The necessity of carrying an on-board pilot clearly reduces the carrying capacity of the vehicle and would probably make this stage economically unviable for high tempo operations (Uber Elevate, 2016, p38). With the corridors in place, the ConOps 1.0 stage is envisioned as one where automation can mature, operational tempo can increase, and use cases can evolve. The FAA ConOps envisions a mature stage with remote pilots who "passively monitor" aircraft and are prompted to take action in situations outside the automation's competency box ("human-over-the-loop" operations). Below we discuss how a human-automation teaming approach can aid in defining the competency box of the automation and help to reveal the extent to which automated systems can safely conduct flights under the full range of operational and environmental conditions, including gradually changing conditions and sudden threats.

A Human-Automation Teaming (HAT) Approach

The field of Human Computer Interaction (HCI) has often viewed task decomposition in terms of assigning some tasks to automation and others to human operators; often with a background assumption that Machines Are Better At some things while Humans Are Better At others (MABA-HABA; Fitts 1951). The HAT philosophy is to break down those roles in much the same way as Crew Resource Management (CRM) sought to break down the strict hierarchy of mid-twentieth century flight decks (Shively et al., 2018), allowing both "partners" to contribute to the performance of any given task. The term "teaming" is aspirational; it indicates a desired objective, but not necessarily the current state of affairs.

In a well-functioning human team, all members of the team share an understanding of the goal. In contrast, we expect that for the foreseeable future, in human-automation teams, only the human will understand the context of the high-level goals. Nevertheless, current automation can work jointly on tasks with human operators, each monitoring the other's performance and negotiating task assignments, resulting in more efficient and resilient performance than if either were to perform the task alone. Shively et al. (2017) proposed three tenets of Human Automation Teaming (HAT): Bi-Directional Communication, Transparency, and Dynamic Delegation (which they call Operator Directed Interface). The first two of these tenets serve to enable joint task performance, while the third serves to maintain the operator's situation awareness and ensure that the automation is assigned tasks within its competency box.

Bi-directional Communication

Bi-directional communication is central to the concept of HAT. For there to be joint task performance, the automation and the human operator must be able to share information, goals, and strategy. As noted above, the automation does not have the same deep understanding of the system goals that the operator does (e.g., why are we going to Gilroy?); however, it can have information about what is necessary to achieve the goals (strategy) and the states that it must achieve on the way (sub-goals). It can display this information, along with reasons one strategy is preferable to another, give feedback on operator proposed strategies, and take into account information that the operator has that it may not be able to independently sense. Perhaps most importantly, the automation must be able to inform the human when it has encountered conditions that fall outside (or may be approaching) the limits of its competency box. Such a "call for help" from the automation triggers a non-normal state for the human operator.

Transparency

In some cases, we delegate a function to automation (e.g., an electronic engine controller) and leave the machine to perform its function, only informing the human if the system fails. However, if we expect humans and automation to work interactively, the human needs to be able to perceive *what* the automation is doing, and *why* the automation is doing it. With this understanding, the operator can judge if the automation is missing information or insight, or, conversely, whether the automation has information that the operator was unaware of. While this may seem obvious, automation is not always particularly transparent to the human operator. This lack of transparency can be the result of interface design choices, but it can also be the result of machine learning algorithms that obscure the cues used by the automation in making decisions.

Dynamic Delegation

In contrast to a static division of tasks between the human and automation, dynamic delegation involves a more flexible allocation of work, taking into account factors such as workload and time pressure. While, traditionally, automation operates with a particular level of human oversight (e.g., Sheridan & Verplank, 1978), a feature of dynamic delegation is that working agreements (Gutzwiller et al., 2017) allow the level of human oversight to vary according to the conditions. In particular, automation can be restricted to acting autonomously only under conditions that are clearly within its competency box. For example, automation might be trusted to land an aircraft autonomously on an unoccupied landing pad but require operator verification before landing on a pad with concurrent operations. Importantly, as automation earns increasing trust, the range of conditions within the competency box increase and the need for operator oversight decreases. Shively et al. (2017) propose that dynamic delegation can also involve predetermined sets of actions that are grouped together so that they can be quickly implemented, referred to as "plays." In aviation they act much like a checklist or quick reference handbook, in that they define the tasks needed for a particular situation; however, they also contain working agreements governing the level of automation expected for each task.

Applying HAT to UAM

The success of a mature UAM system will depend on its ability to demonstrate resilience in the face of anticipated and unanticipated conditions. We maintain that when highly automated systems operate in complex environments, human operators contribute to system resilience via their ability to see and act outside the competency box of the automation. HAT principles can help humans perform this role. The FAA UAM ConOps outlines several functions and roles where human operators' ability to see and act outside the competency box of the automation, may protect the system while allowing automation to earn trust where appropriate.

Pilot in Command (PIC)

The PIC is the only role called out by the FAA's UAM ConOps that is clearly assigned to a human. The Code of Federal Regulations states that "the pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft" (14 CFR 91.3a). The evolution of UAM envisioned by the ConOps is largely the evolution of this position from an onboard pilot who is in the loop on flying the aircraft, in much the same way as helicopter pilots are today, to a remote pilot, operating "over the loop" (HOVTL), managing contingencies for multiple aircraft. While the responsibility of the remote pilot remains unchanged, their ability to exert authority when operating HOVTL relies on appropriate bi-directional communication between human and automation. Ideally, an automated system would have the capability to alert the pilot when it is about to encounter a condition that falls outside its competency box. Transparent automation enables the human operator to understand how the automation will respond. In contingency conditions, dynamic delegation can ensure that responses are assigned to the entity most able to appropriately respond in the time available. In order to achieve HOVTL operations, further increases in automation will be necessary with most routine operations becoming fully automated. That automation will need to be trusted, and that trust will need to be earned. The HAT paradigm discussed above gives us an incremental path for verifying this automation in an operational environment.

Air Traffic Control (ATC)

The FAA ConOps envisions a significant change in the role of ATC between the initial operations stage, which, similar to current helicopter route operations, require the PIC to interact with ATC, and the ConOps 1.0 stage, where UAM vehicles operate within corridors with minimal ATC interaction. The FAA ConOps specifies that ATC will "respond to UAM off-nominal operations as needed" (FAA, 2020). This is a potentially difficult task (particularly if there were to be any large-scale system failure) and it is to be added to ATC's normal workload managing aircraft. Controllers could be aided in performing this task through appropriate system transparency that allows them to gain situation awareness as rapidly as possible, and a play structure that allows them to quickly organize and delegate the tasks necessary to mitigate contingencies safely. Further, ConOps 1.0 could be implemented in an incremental way by the gradual delegation of tasks from ATC to automation. For example, corridors could start off as default flight paths, and assignment of aircraft to corridors could initially be manual with automated recommendations or mixed initiative depending on working agreements. This incremental development would serve several purposes: Testing the automation while controllers are still in (or at least on) the loop, developing and calibrating trust in the automation, and creating a hierarchy of plays that operators can fall back on under off-nominal conditions.

Operator

UAM operators are commercial entities that are responsible for regulatory compliance and all aspects of UAM operation execution. Prior to a flight, the UAM operator obtains information such as weather conditions and aerodrome availability, plans the flight, and provides the information necessary to operate in a UAM corridor. It is envisioned that for larger "airline" operations, the operator would also perform a role coordinating individual aircraft operations, akin to modern day dispatch. Setting the high-level goals and policy are intrinsically human roles; however, these roles are increasingly informed by automated interactive computer modeling. The dispatch-like roles are likely to be highly automated, even in initial operations, however, these roles will involve mitigating contingencies, and thus tasks that are likely to be at or beyond the borders of the automation's competency box. To maintain safety and efficiency we expect human operators will typically delegate dispatch-like tasks to automation; although under dynamic delegation, a human will need to be more closely involved in these operations at times.

Provider of Services for UAM (PSU) & UAS Service Supplier (USS)

As defined in the FAA UAM ConOps, PSUs and USSs are the information integration and dissemination backbone envisioned for UAM. They collect intent information for aircraft, availability information for air corridors and landing sites, weather information, and other operationally relevant information, provide this information to operators and assist with scheduling flights. PSUs and USSs may be automated, although this is not specified in the FAA's ConOps. Presumably someone will have to manage PSUs in off-nominal situations. Building PSUs and USSs to be transparent and creating plays that allow human operators to take control without handling all network traffic would seem to improve system resilience.

Aerodrome Managers

The FAA UAM ConOps specifies that UAM aircraft takeoff and land at "aerodromes"; although others refer to these as "vertiports." While the ConOps does not specify human interaction at these aerodromes, some human interface is likely required, as aerodrome operations will periodically present conditions that fall outside the competency box of automated systems. Loading and unloading aircraft is somewhat unpredictable, which, in turn, adds unpredictability to the availability of the aerodrome. Unlike buses or subways where a car can simply wait when arriving at an occupied station, battery capacity on UAM aircraft is unlikely to allow for extended hovering. Dynamic delegation will be critical, as aerodrome managers will likely be required to recognize the state of the aerodrome, assist in smoothing traffic flow, and interface with the PIC and PSU about availability windows.

Conclusion

As progress towards a future UAM system continues, designers must not overlook the positive contribution made by human operators to system resilience. A challenge facing designers of UAM systems is to integrate the characteristics of humans and automation to produce an effective human-automation team. Rather than assigning tasks in a static manner to either automated systems or humans, future UAM systems are likely to involve a flexible approach to task delegation. This will require operational personnel to possess an appropriate awareness of the functioning of automation and be equipped to monitor performance, anticipate conditions that will fall outside the automation's competency box, and respond as necessary. A HAT framework may be useful in achieving a resilient UAM system that involves the complementary capabilities of automation and humans working together.

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