To 4DT or not 4DT: Is there really a question?

By Frank L. Frisbie and Suzette Matthews[1]

The latest shiny object enchanting the world of aviation is Artificial Intelligence, or "AI".[2] That is, simulation of the intelligence of sentient beings (e.g. humans) in machines that are programmed to think like sentient beings and mimic their actions. Some products of AI science can imitate—sometimes exceed—natural performance. But should human-centric operations—even enhanced with AI—be the goal for NextGen air traffic control when better constructs and technologies are available, or within reach? ATM managers, designers and engineers should avoid being mesmerized by the idea of AI for live aircraft control, when an infinitely better ATM construct already is contemplated in the form of Four Dimensional Trajectory Management, or "4DT". Here's why.

Deterministic versus Nondeterministic Systems in ATC

The goal of AI science is to replicate human functionality. But for all their miraculous qualities, people also are innately limited, fallible, and unpredictable. Given the same conditions and events, various individuals act, and react, in various, unpredictable ways—inherently a "non-deterministic" system.[3] Unpredictability and variability are problematic—even dangerous—in air traffic control services. "Non-deterministic" systems based on AI all have the same weaknesses and are therefore impossible to certify as safe, given the prevailing safety evaluation paradigm which requires a technology to reliably and consistently replicate outcome. Moreover, attempts to apply AI to ATC continue along the current engineering pathway of offering increasingly capable controller

You say "tom·a·to", I say "to·mah·to"

One difficulty the authors encountered in writing the instant paper was that there is considerable variability and, frankly, a lack of theoretical discipline in the way we as ATC specialists use terminology related to AI. At the very least, readers should recognize that there is not universal agreement on the meaning of these terms, many of them have diverse meanings, and they all seem to overlap to some extent. As a consequence, every discussion on the application of AI to aviation should begin with a very precise definition of terms as they are being used in the specific context. Here are some of those terms, including their associated definitional nuances:

Artificial Intelligence (AI), in simplest terms refers to "the capability of a machine to imitate intelligent human behavior." https://www.merriamwebster.com/dictionary/artificial%20intelligence

Intelligent Agent "refers to an autonomous entity which acts, directing its activity towards achieving goals (i.e. it is an agent), upon an environment using observation through sensors and consequent actuators (i.e. it is intelligent). Intelligent agents may also learn or use knowledge to achieve their goals. They may be very simple or very complex. A reflex machine, such as a thermostat, is considered an example of an intelligent agent." https://en.wikipedia.org/wiki/Intelligent_agent

Autonomous Computing (AC): "The AC system concept is designed to make adaptive decisions, using high-level policies. It will constantly check and optimize its status and automatically adapt itself to changing conditions. An autonomic computing framework is composed of autonomic components interacting with each other." https://en.wikipedia.org/wiki/Autonomic_computing#:~:text=Autonomic%20computing%20(AC)%20refers%20to,complexity%20to%20operators%20and%20users.

Machine learning (ML) "is the study of computer algorithms that improve automatically through experience.... Machine learning involves computers discovering how they can perform tasks *without being explicitly programmed to do so*. It involves computers learning from data provided so that they carry out certain tasks." https://en.wikipedia.org/wiki/Machine_learning

Automation "describes a wide range of technologies that reduce human intervention in processes. Human intervention is reduced by predetermining decision criteria, subprocess relationships, and related actions — and embodying those predeterminations in machines." https://en.wikipedia.org/wiki/Automation

Decision Support System (DSS) is "any system that might support decision making, and some DSS include a decision-making software component, … an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, and personal knowledge, or business models to identify and solve problems and make decisions."

https://en.wikipedia.org/wiki/Decision_support_system.

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[2] "It is the sense of Congress that the Administration should, in consultation with appropriate Federal agencies and industry stakeholders, periodically review the use or proposed use of artificial intelligence technologies within the aviation system and assess whether the Administration needs a plan regarding artificial intelligence standards and best practices to carry out its mission." § 548, Pub. L. 115-254 (Oct. 5, 2018), 132 STAT. 3378.

[3] A function is considered deterministic if it always returns the same result set every time when it is populated with the same set of input values. A function is considered nondeterministic if it does not return the same result set every time when populated with the same set of input values.

decision support tools or other roles are welcome improvements, but do not really change its human-centric premise.

4DT Air Traffic Management, on the other hand, is predicated on "deterministic" processes. Given the same inputs, the 4DT system will always deliver the same result. All four dimensions of every aircraft's actual position (latitude, longitude, altitude, time) are employed by the system, which uses conventional mathematical computations to separate each aircraft from all others for whom the same data are known. Same inputs, same response every time. Predictable, consistent, and uniform. Definitely a revolutionary paradigm change in real time ATC.

Advantages of 4DT

The advantages of 4DT over human centric ATC (even enhanced with AI) for the future NAS are numerous, including the following:

- *Safety and Certification.* As stated earlier, AI is a certification non-starter since safety certification would require the AI to perform consistently to a stated standard. 4DT, on the other hand, makes mathematical computations based on receipt of actual 4D data to deliver deterministic outcomes—same input, same result, every time. Given that the outcomes meet the stated standard, certification can rest on accuracy and dependability of the 4DT machine. FAA standards in terms of failure rates per number operations for such systems already exist.[4]
- *Capacity.* 4DT offers decided capacity and efficiency advantages over the current human-centric air traffic control model, even enhanced with DSS and AI. By managing aircraft movement seamlessly gate to gate, 4DT would dissolve the distinction between strategic and tactical ATC. All traffic--and the NAS generally--would benefit from strategic management all the time, at all levels, and in all environments. No excessive distance buffers between aircraft would be needed to account for "latencies" (time lags) associated with variations in human skills, thought processes, and physical reactions; no temporary adjustments or closures for personnel staffing issues. 4DT would enable maximum "packing" of the NAS, increasing capacity of the system to accommodate more aircraft than any human-centric system can deliver. Moreover, with respect to meeting future ATC capacity needs, it is widely acknowledged that the human-centric ATC paradigm--even if enhanced with AI--has limited expansion capability. It simply cannot meet the increasing volume and variety of traffic already envisioned for the near term, especially Unmanned Aircraft Systems (UAS). The exponential leap in capacity and operational efficiency offered by 4DT is absolutely necessary to serve aviation innovators already knocking on the entrance gates of today's NAS.
- *Equity.* When and where congestion is expected to occur, today's ATC system allocates scarce capacity strategically through aircraft operator collaborative mechanisms (e.g. slot committees and Collaborative Decision Making, or CDM). In the tactical realm, congestion management is left to the skilled judgment of controllers.[5] These procedures are cumbersome and can unfairly disadvantage classes of users, producing "winners and losers."[6] By relying exclusively on operator choices, CDM approaches also can inherently sub-

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[4] *See* FAA System Safety Handbook, Chapter 3: Principles of System Safety (December 30, 2020), https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/risk_management/ss_handbook/media/Chap3_1200.pdf, and Chapter 10: System Software Safety, https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/risk_management/ss_handbook/media/Chap10_1200.pdf .

[5] FAA Controllers' Handbook, ATO Order JO 7110.65Y, Section 2-1-4, https://www.faa.gov/documentLibrary/media/Order/7110.65Y_ATC_Bsc_w_Chg_1_2_dtd_7-16-20.pdf

[6] *See* FAA Joint Planning and Development Office, "Flight Prioritization Deep Dive: Final Report" (2011) https://scholar.rhsmith.umd.edu/sites/default/files/mball/files/flight_prioritization_0.pdf?m=1467366850 ; Evans, et al, "Fairness in

optimize airspace utilization. 4DT automation, on the other hand, could enable automatic management of scarce capacity—even in real time—by employing prioritization rules set in a governmental policy making process. This would assure transparency and fairness among classes of operations and individual operators, while still prioritizing National Defense, EMS, and other public interest flights.

Challenges of 4DT

For over a decade, 4DT has been recognized as the optimal future state of air traffic management.[7] But transition issues can seem daunting. Many of these 4DT issues, however, can be addressed safely, for instance:

- *Participation.* For 4DT to work, all operators in the designated airspace/ecosystem need to cooperate by meeting system requirements. This means that all aircraft need to continuously provide the system with timely, accurate, reliable, and verifiable 4DT data about their own operation (latitude, longitude, altitude, and time). Not only must this data be good, but also the communications transmission medium must be equally dependable and fast. On the most sophisticated level, end state 4DT envisions direct linkage between the aircraft's flight management system and the ATC service provider's 4DT automation.[8] This may cause technical and financial issues for some operators with basic or legacy aircraft, or those who cannot afford the upgrade for interfacing with 4DT. To keep these issues from becoming a barrier to 4DT, good cost/benefit analysis, regulation, and possibly financial incentives and/or mandates may be necessary.[9]
- *Culture.* Real time aviation control systems have historically relied on reversion to human operations as the ultimate safety back up. But humans are incapable of performing the rapid, sophisticated, high volume computations characteristic of 4DT, and would likely be unable to assume operations in a failure situation. The aviation community will have to accept the fact that human controllers will no longer be there in a real time tactical backup role. This is a large psychological leap for many in the aviation community, and truth be told, for some policy makers and the traveling public. To address this skepticism, it will be necessary to convincingly demonstrate not only that the primary system is accurate and reliable, but also that iterative independent 4DT backups are as capable as the primary system.
- *Personnel.* 4DT will require a substantial change in knowledge and skills for people supporting the ATC system. Controllers and ATM specialists will be replaced with 4DT system technology designers, engineers and maintainers. This progression already is happening on the aircraft side, with aircraft operators more and more relying on automated systems for virtually all aspects of flight planning and flight performance.

Decentralized Strategic Deconfliction in UTM, Airbus UTM (2018), https://storage.googleapis.com/blueprint/UTM_Fairness_Tech_Report-v1.1.pdf ; Sachs, et al, "Evaluating Fairness in UTM Architecture and Operations," Airbus UTM/Metron Aviation (February 2020), https://storage.googleapis.com/blueprint/Fairness_in_Decentralized_Strategic_Deconfliction_in_UTM.pdf

[7] *See* FAA Joint Planning and Development Office, Concept of Operations V.3.2, p. 2-17 to 2-23 (2011), https://apps.dtic.mil/dtic/tr/fulltext/u2/a535795.pdf ; FAA, "The Future of the NAS", p. 14 (2016), https://www.faa.gov/nextgen/media/futureofthenas.pdf and the "NAS Animated Storyboard 2025", https://www.faa.gov/about/office_org/headquarters_offices/ang/offices/tc/library/storyboard/tbo.html#chapter4 .

[8] *See* S. Ramasamy, R. Sabatini, A. Gardi, T. Kistan, "Next Generation Flight Management System for Real-Time Trajectory Based Operations," Applied Mechanics and Materials, vol. 629, pp.344-349, Trans Tech Publications, 2014. DOI: 10.4028/www.scientific.net/AMM.629.344; A. Gardi, S. Ramasamy, R. Sabatini and T. Kistan, "CNS+A Capabilities for the Integration of Unmanned Aircraft in Controlled Airspace," Proceedings of IEEE International Conference on Unmanned Aircraft Systems (ICUAS 2016). Arlington, VA (USA), June 2016. Print ISBN: 978-1-4673-9333-1.

[9] F. Frisbie and S. Matthews, "The second time around there ought to be a law…," *Journal of Air Traffic Control* (Spring 2020), reprinted at https://www.safeaccess4uas.com/paper-avionics-equipage--second-time-around.html .

Unfortunately, this transition will require significant personnel education for new roles, and potentially significant employment disruption. Unfortunately, ATC skills are not really transferable to the science and engineering knowledge that will be required in 4DT.

- *Transition.* Transition to 4DT will perforce be revolutionary, rather than evolutionary--a radical leap in trust for the aviation community. It may be possible and advisable to introduce 4DT incrementally in discrete ecosystems based on altitude or geography, or aircraft type to generate community the experience and acceptance necessary for widespread implementation.[10]

Conclusion

4DT promises a quantum improvement in safety, capacity, and efficiency in air traffic control. Perhaps equally important is that it offers the system a platform to resolve competing demands for airspace gracefully on the basis of predetermined rules imbedded in the automation. For all its challenges, 4DT must be redefined as the end state for NextGen. The technology is already in hand. But we are enmeshed in an evolutionary pathway. It must be recognized and acknowledged that the transition to 4DT, where implemented, has to be revolutionary.[11] It will take courage, professionalism, and persistence to leap politically, financially, and culturally from our comfortable human-centric paradigm to the automated future that we know is necessary and inevitable. Let's reevaluate where we are on NextGen, and renew our vision and commitment to the best possible future for air traffic control—4DT.

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[10] At this time ecosystems for aircraft types such as UAS are foreseen in aircraft discrete strata. Likewise higher altitudes may be stratified to exploit 4DT aircraft.

[11] "Specifically, both programs [NextGen and SESAR Trajectory Based Operations (TBO)] deal with the same problem, as current Air Traffic Control (ATC) procedures and technologies will not be able to accommodate the increased traffic demand while maintaining the same levels of safety. The solution to this problem will require a radical change in the whole Air Traffic Management (ATM) system. More in detail, the fundamental shift in paradigm will be from clearance-based ATC to trajectory-based ATC operations." G. Enea and M. Porretta, "A Comparison of 4D-Trajectory Operations Envisioned for NextGen and SESAR, Some Preliminary Findings," 28th International Congress of the Aeronautical Sciences (2012), https://www.skybrary.aero/bookshelf/books/2377.pdf

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