Roadmap for Intelligent Systems in Air Traffic Management

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Air traffic management (ATM) is concerned with planning and managing airspace resources (e.g., routes and airports) to ensure the safety and efficiency of air traffic operations in the National Airspace System (NAS). ATM can be classified into two categories: 1) air traffic flow management (ATFM) which deals with balancing air traffic demand with available resource capacities, typically with longer look-ahead horizons (2-15 hours), and 2) air traffic control (ATC) which is concerned with the tactical guidance control of aircraft within the NAS, typically with shorter look-ahead horizon of up to 2 hours.

Today’s air transportation system has many inefficiencies, as reflected by frequent delays, especially during days with significant weather impacts. The next generation air transportation system (NextGen) aims at improving the efficiency of the ATM, through smart technologies and new procedures. Intelligent systems, which integrate technologies from artificial intelligence, adaptive control, operations research, and data mining, are envisioned to play an important role to improve ATM and provide significant contributions to NextGen.

In this document, several key challenges to automate the future ATM are identified. The state of the art technologies for the use of intelligent systems in ATM is then summarized. Finally, the vision of future development is provided as a basis for discussion in the Intelligent Systems Workshop in Dayton (August 7-8).

**Challenges**

1. **Robust Management Solutions under Uncertainties**

The NAS is subject to a variety of uncertainties, such as take-off time delays, unscheduled demand, inaccurate weather forecasts, and other types of off-nominal events. When traffic demands are close to available resource capacities, these uncertainties can significantly disrupt the performance of the airspace system. Among these impacts, convective weather and the uncertainty associated with its impact is the leading reason for large delays in the NAS. In order to best allocate resources to address the uncertainties, strategic ATFM is considered to be critical. Robust ATFM design is highly challenging, due to the large-scale of the problem, strict safety
requirements, heavy dependence on human decision making, and the unknown nature of some of these uncertainties. Intelligent ATFM solutions integrated into human decision making processes and procedures are required to address these issues in real time.

2. Growing Heterogeneity
With the potential of an increasing number of unmanned aerial vehicles (UAVs) entering the airspace, ATM is facing the challenge of growing heterogeneity and integrating manned and unmanned operations into the NAS while maintaining current safety standards. In addition to traditional manned flights, the airspace will also be shared with UAVs which fulfill a variety of military and civilian missions. The diverse aircraft characteristics, missions, and communication capabilities complicate the management procedures. The limited resources of human traffic controllers will not meet the management needs of such diverse traffic types and heavy traffic loads. As such, diverging from the traditional ATM led by centralized human controllers, part of the airspace may be dedicated to self-separating traffic with aircraft equipped with the intelligence to sense and coordinate.

3. Practical Issues for Automation
Automation is the core of the NextGen to improve the efficiency and safety of the NAS. However, beyond technical barriers to automation, practical issues are also critical to the successful implementation of automation solutions. For instance, multiple stakeholders of the NAS (e.g., dispatchers, traffic controllers, and airport operators) may have conflicting objectives. The automation solutions must be fair to individual stakeholders, making it hard to quantify and validate the optimization goals. In addition, due to the safety concerns of implementing any new process, significant costs of time and budget are required before any new ATM automation solution can be put into practice. New methods to quickly validate potential technologies are needed. Finally, human operators (pilots, controllers and ground operators) may be reluctant to accept new automation solutions for multiple reasons, including limited trust to automation, learning curve to work with automation tools, and job security. Human factors in the automation process need to be better understood.

The State of the Art
Significant research efforts have been conducted over the years to improve ATM, with the development of tools and procedures for en route collision avoidance, departure and arrival runway taxiway management, and Terminal Radar Approach Control (TRACON) automation among others. Some of the advances have been successfully tested and implemented, among which the most significant is the automatic dependent surveillance-broadcast (ADS-B), which establishes the foundation for enhanced communication and navigation capabilities.
Significant studies on ATFM are needed to optimize resource allocation in the NAS at the strategic time-frame. The daily coordination of flow and resource management is currently being implemented through a call meeting between Air Traffic Control System Command Center (ATCSCC) and other stakeholders, including the airlines, Air Route Traffic Control Centers (ARTCCs), and others. The decision is made based on human experiences and subjective judges, which are effective overall but have the room for improvement. Significant research is needed to understand human intelligence in high-level resource planning and provide automation tools to support the decision-making.

**Vision of the Future Development in Coming Decades**

Intelligent systems are playing a crucial role in automating air traffic management procedures to improve safety and efficiency of operations in the NAS. Some potential future developments are listed here. Some research efforts have been devoted in these areas, but more development is needed to eventually lead to their implementation.

1. **Strategic ATFM under Uncertainties**
   Strategic ATFM identifies critical regions of resource-demand imbalance and robustly redistribute resources to resolve such imbalance under uncertainties. While computers are excellent at tuning for precise optimized values in reduced-scale problems, they are not good at finding global patterns and prominent features in large-scale problems, critical to strategic ATFM. Machine learning and data mining techniques will find their values to mimic human vision and intelligence to facilitate robust strategic ATFM under uncertainties. These technologies will be able to look at historical data and correlate airline schedules, weather, ATC tower interactions and possibly identify patterns to enable efficient pre-planning and predict trouble spots.

2. **Multiple Stakeholder Decision-making**
   Ensuring fairness in automation solutions is critical for their successful implementation. Artificial intelligence, game theory, and reinforcement learning techniques will help understanding the current negotiating process among multiple stakeholders of the NAS in implementing ATFM and AM plans. Such understanding will help to define and implement equity objectives in automation solutions that are acceptable by multiple stakeholders.

3. **Human-Machine Interaction**
   Automation solutions are not aimed to replace human, but instead to assist human with information and algorithms in making better decisions. Intelligence system techniques will help us to understand how human and machines interact and evaluate the performance of human-
machine interaction. Ultimately, such studies will help to improve the friendly interface of automation solutions, and to improve human training programs to facilitate a seamless human-machine interaction.

4. Decentralized Air Traffic Management in the Heterogeneous Airspace
Decentralized air traffic management is a major research direction in the NextGen. Equipping UAVs and more general flights with the intelligence to sense, coordinate and control will significantly reduce the work loads of human controllers on the ground and improve the efficiency of resource usage in the NAS. However, safety requirements are challenging to achieve, considering the complicated NAS environments and the decentralized nature of such management solutions. Innovative intelligent system algorithms that mesh advances from multiple disciplines will significantly enable NextGEN to tackle this complex problem.

5. Miscellaneous New Directions
Rich new directions are enabled by new technologies in multiple domains. Examples include: 1) Advanced planning solutions integrated with aircraft to support Trajectory Based Operations, 2) Integration of large sensing networks into future decision support tools, including aircraft based sensor data, and 3) Airborne networks to transmit data over multiple hops. Intelligent systems concepts and tools will find new applications in these miscellaneous applications.