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Editorial

Models and tools for strategic air traffic flow management: Special issue overview

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During its history, the air transportation system has evolved continuously through the integration of new technologies. During the last 20–30 years, revolutionary advances in cyber- (computing, communications, control) technologies have been pervasively translated to the airspace system, bringing about significant improvements in system performance as well as changes to operational paradigms. These new technologies are quite diverse in scope and function, ranging from Required Navigation Performance (RNP) hardware/software to decision aids for air traffic controllers, new weather radar systems, and connectivity for aircraft passengers and crew. Taken as a whole, the new technologies being deployed in the airspace system have the potential to enable system-level autonomy and coordination to a far greater extent than in the traditional system.

Despite the extensive integration of cyber technologies in the airspace system, **strategic traffic management** (i.e., coordinated management of traffic flows at a system-wide scale and a multi-hour look-ahead time horizon) largely remains a manual process. For instance, in the United States National Airspace System (NAS), personnel from the Air Traffic Control System Command Center (ATCSCC), Air Route Traffic Control Centers (ARTCCs, or Centers), and the airlines collaborate on a strategic plan via an early-morning teleconference, and communicate revisions as needed throughout the day. While traffic-management personnel have some basic forecasting tools available to them for the strategic horizon, strategic-plan development is largely driven by historical knowledge, operator expertise, and the (sometimes competing) interests of the stakeholders involved in the teleconference. The relative lack of automation in strategic traffic management, as compared to other aspects of air transportation operations, is understandable for several reasons. First, traffic management has traditionally been primarily a regional exercise, with the need for strategic (system-wide, long-term) management only developing gradually as traffic densities increased. In addition, strategic management only indirectly impacts safety and instead is driven by longer-term operational and economic considerations, while automation in air transportation has naturally been focused on safety- and time- critical problems. Third, the strategic management problem is enormously complex, requiring coordination and control of multiple regional authorities and thousands of aircraft, suffering from large uncertainty (due to weather, departure-time variations, etc.), entailing design of specialized legacy management mechanisms, and involving multi-faceted and ill-defined performance metrics.

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As airspace congestion and complexity increases, however, there is a growing need for decision-support capabilities for strategic traffic flow management (STFM) that can assist human operators in comparing and designing management strategies. At its essence, increasing sophistication and congestion in the airspace implicate that disruptions have longer-range impacts in both space and time, necessitating STFM. In addition, new complexities including space-vehicle operations and increased reliance on cyber technologies make the system prone to more diverse disruptions that must be managed in advanced. Due to these changes, there has been considerable interest in the air traffic control and management community on developing forecasting, decision support, and automation tools for STFM. Currently, several exciting research-and-development efforts are underway to design decision-support tools for STFM, for the U.S. National Airspace System (NAS), the European airspace system, and Australian and Asian traffic systems. These efforts, which involve government, industrial, and academic partners, are introducing new paradigms for managing air traffic, and yielding models and tools that address challenges in strategic prediction and decision-making. Advances include:

1) New models and tools for forecasting weather impact and demand, and their uncertainties, at the strategic horizon.
2) Models for traffic flows and management initiatives that are at the proper level of abstraction for simulation and analysis of airspace performance under weather/demand uncertainty.
3) Tools for comparing and optimizing strategic traffic management strategies and communicating options effectively through visual interfaces to operational personnel.

The purpose of this special issue is to report on emerging paradigms, models, and tools for STFM. The special issue captures diverse viewpoints and solutions related to STFM, with the aim of 1) facilitating integration and refinement of solution methodologies, 2) identifying outstanding technical challenges and fostering new research in these directions, and 3) providing a tutorial on recent advances.

The special issue includes six papers, which were developed by leading researchers in the field of air traffic management. These papers are structured to broadly sample the research efforts ongoing in strategic air traffic management in the three directions listed above. This issue also aims to merge academic, industrial, and government perspectives, with the papers involving and joining authors from these groups. While the special issue should not be viewed as a complete treatment of the flourishing research effort in STFM, it captures several exciting directions of work that address core STFM challenges, providing promising starting points toward practical decision-making tools for the air traffic system. The papers span three main aspects of STFM research and development: 1) modeling uncertain demand and weather at the strategic scale; 2) simulating and analyzing airspace-wide traffic when management strategies are put in place, under uncertainty; and 3) selecting and tuning traffic management strategies to optimize performance. The following list briefly overviews the six papers, and explains how they contribute to the STFM research arena:

The paper by DeArmon et al. proposes a framework to more accurately predict future traffic demand, both the number of flights intended to depart and the TFM resources they intend to use, using a combination of stochastic models. Methods are developed for reducing the dimensionality of the data, to both improve computation times and reduce sensitivity.

Xue et al. address modeling of weather uncertainty. Specifically, their paper proposes a stochastic, spatio-temporal model capable of generating scenarios of convective weather-impact quickly. By evaluating weather-impact directly – as measured by capacity reduction – the model can capture the correlated development, intensification, or diffusion of capacity-constraining phenomena at TFM resources of concern.

The study by Klein et al. is focused on simulation of air traffic flows and traffic management strategies. The models developed permit fast simulation of airspace-wide traffic under uncertainty and in response to strategic traffic flow management actions.

Toward understanding and improving the design of management strategies, Liu and Hansen examine the factors that influence the initiation of ground delay programs. Variables that influence GDP initiation decisions are identified, and a logistic regression methodology is used to quantify the impacts of these variables. Bloem and Bambos also pursue stochastic modeling of the ground delay program implementation, as a means for forecasting, analysis, and design of management strategies. Two modeling approaches are considered, one based on logistic regression and the other on inverse logistic regression. Both approaches identify a family of factors that influence GDP decision making.

Feron et al. explores the use of multi-agent systems to enable dynamic conflict avoidance and inter-flight organization with the goal of reducing air traffic controller workload and thereby increasing capacity. This can be especially important in areas of the airspace that are impacted by weather, where the normal operating flows have been disrupted which further degrades the capacity beyond areas blocked by weather.

The papers in tandem approach air traffic flow management from a forward-looking perspective, addressing such issues as 4-dimensional trajectory-based traffic management free-flight paradigms for air traffic. In doing so, the papers also advance and integrate methodologies from several other disciplines. For instance, described techniques are related to the state of the art in: 1) stochastic modeling and analysis, 2) operations research and optimization, 3) decision sciences, and 4) network science, among other disciplines. In describing these diverse methods, the special issue also underscores the essentially inter-disciplinary nature of air traffic management research, and hopefully will introduce practitioners and researchers to new techniques and disciplines that have the potential for wider impact in air transportation. Finally, we note that the problems in STFM addressed in the special issue are paradigmatic of strategic decision-making problems that are arising in other critical infrastructures (e.g., the bulk power transmission network and the health-care infrastructure), as they become increasingly stressed as well as cyber enabled. Thus, we hope that the methods and tools developed in the special issue will be portable to other wide-area infrastructure-management problems and, complementarily, foster discourse and collaboration among engineers working on diverse infrastructures.