Dynamical-Network Evaluation and Design Tools for Strategic-to-Tactical Air Traffic Flow Management

Yi Zhou (student) and Yan Wan (PI), Electrical Engineering, University of North Texas
Mengran Xue (student) and Sandip Roy (PI), Electrical Engineering, Washington State University
Yi Cao (student) and Dengfeng Sun (PI), Aeronautics and Astronautics Engineering, Purdue University

Abstract

The objective of the project is to develop tools for comprehensive design and optimization of air traffic flow management capabilities at multiple spatial and temporal resolutions: a national airspace-wide scale and one-day time horizon (strategic time-frame); and at a regional scale (of one or a few Centers) and a two-hour time horizon (tactical time-frame). The key challenges include 1) tractable probabilistic weather prediction at the strategic time-frame, 2) modeling, analysis, and design of strategic management strategies at a NAS-level in the presence of uncertain weather, 3) the integration of management plans at different time scales. During year 1, the three institutions have achieved advances in addressing each of the above three challenges. These advances are summarized below.

Designing cyber- decision-support capabilities for large-scale infrastructures critically requires, as a preliminary step, tractable modeling of environmental uncertainties that may impact the physical and/or cyber- components of the infrastructure. Motivated specifically by strategic decision-support needs for the air traffic network, we have developed a simple stochastic model that captures spatio-temporal propagation of weather impact on National Airspace System-relevant parameters (e.g., Sector capacities, airport acceptance rates) over a 2-24 hr time horizon. The model formulation draws on a tractable stochastic-automaton known as the influence model, which facilitates 1) parameterization from ensemble weather forecasts, 2) rapid generation of weather-impact scenarios and representative scenarios; and 3) statistical analysis and reduced-order modeling of weather impact at a few critical locations. We believe that our modeling approach, though developed for air transportation applications, is well-suited for managing other large-scale infrastructures, including for electric-power system management and disease control.

The stochastic models of the NAS and the preliminary approach for a tractable analysis of the NAS performance in the presence of weather uncertainty have been developed. Specifically, the dynamical queuing network model captures the transient dynamics of the NAS in response to dynamical weather uncertainties, which in turn holds promise for a systematic analysis and design of a variety of management actions NAS-wide. The model has the following features: 1) allowing the evaluation of dynamical uncertain weather impact; 2) capturing the impact of a series of management actions in practice or potential for use such as MIT/MINIT, GDP, TBM, Routing, and AFP; 3) representing traffic as stochastic flows while capturing realistic route structure, and 4) reasonably interfacing with operational practice and easily being parameterized from data. Moreover, we have studied the arriving of traffic flows to a weather zone, and developed a novel jump-linear approach to predict backlog statistics in the presence of dynamical uncertain weather. In this approach, a flow restriction is modeled using a linear relationship, with parameters modulated by a Markov chain describing the evolvement of uncertain weather. This jump-linear approach allows the evaluation of dynamical backlog statistics under uncertain weather, and holds promise for the evaluation of NAS performance under weather uncertainty.

The Linear Dynamics System Model (LDSM) is now integrated with the Large Capacity Cell Transmission Model, CTM(L), as a starting point for design of strategic-to-tactical Traffic Flow Management strategies. Using historical air traffic data and jetway information, a nation-wide air transportation network at a Center level is built for the LDSM, and inside each Center, a detailed subnetwork is built for the CTM(L). The two models are meshed together and the performance of the meshed model, in terms of comparing the predicted aircraft counts with historical data, is also validated.