Mechanical Engineering Doctoral Defense

Artificial Intelligence-enhanced Predictive Modeling in Air Traffic Management

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Abstract

National Airspace Systems (NAS) are complex cyber-physical systems that require swift air traffic management (ATM) to ensure flight safety and efficiency. With the surging demand for air travel and the increasing intricacy of aviation systems, the need for advanced technologies to support air traffic management and air traffic control (ATC) service has become more crucial than ever. Data-driven models or artificial intelligence (AI) have been conceptually investigated by various parties and shown immense potential, especially when provided with a vast volume of real-world data. These data include traffic information, weather contours, operational reports, terrain information, flight procedures, and aviation regulations. Data-driven models learn from historical experiences and observations and provide expeditious recommendations and decision support for various operation tasks, directly contributing to the digital transformation in aviation.

This dissertation reports several research studies covering different aspects of air traffic management and ATC service utilizing data-driven modeling, which are validated using real-world big data (flight tracks, flight events, convective weather, workload probes). These studies encompass a range of topics, including trajectory recommendations, weather studies, landing operations, and aviation human factors. Specifically, the topics explored are (i) trajectory recommendations under weather conditions, which examine the impact of convective weather on last on-file flight plans and provide calibrated trajectories based on convective weather; (ii) multi-aircraft trajectory predictions, which study the intention of multiple mid-aircraft in the near-terminal airspace and provide trajectory predictions; (iii) flight scheduling operations, which involve probabilistic machine learning-enhanced optimization algorithms for robust and efficient aircraft landing sequencing; (iv) aviation human factors, which predict air traffic controller workload level from flight traffic data with conformalized graph neural network. The uncertainties associated with these studies are given special attention and addressed through Bayesian/probabilistic machine learning. Finally, discussions on high-level AI-enabled ATM research directions are provided, hoping to extend the proposed studies in the future.

This dissertation demonstrates that data-driven modeling has great potential for aviation digital twins, revolutionizing the aviation decision-making process and enhancing the safety and efficiency of ATM. Moreover, these research directions are not merely add-ons to existing aviation practices but also contribute to the future of transportation, particularly in the development of autonomous systems.

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