Mechanical Engineering Dissertation Defense

Physics-guided Machine Learning in Air Traffic Flow Prediction and Optimization

School for Engineering of Matter, Transport and Energy

Qihang Xu

Advisor: Yongming Liu

Abstract

The increasing demands of air travel and the escalating complexity of air traffic management (ATM) necessitate advanced air traffic flow prediction and optimization methodologies. This dissertation delves into integrating physics-guided machine learning techniques to address these challenges. By encompassing four pivotal studies, it contributes to the ATM field, showcasing how data-driven insights and physical principles can revolutionize our understanding and management of air traffic density, state predictions, flight delays, and airspace sectorization.

The first study investigates the Bayesian Ensemble Graph Attention Network (BEGAN), a novel machine learning framework designed for precise air traffic density prediction. BEGAN combines spatial-temporal analysis with domain knowledge, enabling the model to interpret complex air traffic patterns in a highly dynamic and regulated airspace environment. The second study introduces the Physics-Informed Graph Attention Transformer, a novel approach integrating graph-based spatial learning with temporal Transformers. This model excels in capturing dynamic spatial-temporal interdependencies and integrates partial differential equations from fluid mechanics, enhancing the predictive accuracy and interpretability in ATM. The third study shifts focus to predictive modeling of aircraft delays, employing Physics-Informed Neural Networks. By utilizing sparse regression for system identification, this approach adeptly deciphers the intricate partial differential equations that dictate near-terminal air traffic dynamics, providing a novel perspective in forecasting flight delays with enhanced precision. The final study focuses on dynamic airspace sectorization, deploying an attention-based deep learning model that adeptly navigates the complexities of workload dynamics. In conjunction with constrained K-means clustering and evolutionary algorithms, it facilitates a more efficient and adaptable approach to airspace management, ensuring optimal traffic flow and safety.

The findings of these studies demonstrate the significant impact of physics-guided machine learning in advancing ATM's safety and efficiency. They mark a shift from traditional empirical methods to innovative, data-driven approaches for air traffic management. This research enhances current practices and charts new paths for future technological advancements in aviation, especially in autonomous systems and digital transformation.

April 2, 2024; 10:00 AM; WXLR A311

Zoom Link: https://asu.zoom.us/j/88076740094

Arizona State University