Dissertation Title: "Transportation Infrastructure Investment under Uncertainty: Models and Applications in Airport Capacity Expansion Decisions"

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ABSTRACT

Air traffic demand has grown substantially over the past decades. According to a report by the International Air Transportation Association (IATA) in June 2023, global air travel demand is expected to double by 2040, corresponding to an average annual growth rate of approximately 3.4%. In contrast, airport capacity is typically constrained and costly to expand. As demand approaches capacity, congestion and delay costs increase significantly, affecting airlines, passengers, and airport operators. In the short term, airports can rely on operational and pricing-based tools, such as slot controls or higher landing charges, to manage congestion. However, as total potential demand continues to grow, these short-term measures do not resolve the fundamental mismatch between demand and capacity. In the long term, capacity expansion becomes necessary. Such investments are complex, expensive, and often irreversible, while demand projections used to justify major infrastructure projects are frequently inaccurate. These characteristics motivate the need for decision frameworks that explicitly account for long-term demand uncertainty.

This dissertation studies airport capacity expansion decisions under demand uncertainty, with an emphasis on long-term planning and the transition from short-term capacity management to long-term investment. Recognizing that precise long-term demand forecasts are inherently unreliable, the dissertation adopts stochastic process models to represent different demand growth trajectories. The analysis is conducted with a real options framework, which explicitly accounts for uncertainty and irreversibility and allows the joint optimization of investment timing and capacity increment. Across the dissertation, capacity expansion decisions are analyzed under demand uncertainty, while their implications are examined across different demand growth patterns, chances and magnitudes of disruptive events, airline market structure, and passenger demand elasticity.

Chapter 2 is based on my paper, *Runway capacity expansion planning for public airports under demand uncertainty*, published in the *Journal of Air Transport Management*. It presents a novel approach to modeling air traffic demand growth using a jump diffusion process that incorporates two layers of uncertainty. Continuous demand variability is captured by Geometric Brownian Motion (GBM), while a Poisson process is used to capture the impact of crisis events such as natural disasters or public health emergencies. A real options model is developed to jointly evaluate the interrelated factors of optimal runway capacity and investment timing under uncertainty, with investment timing linked to trigger demand. The findings suggest that increased

uncertainty indicates more conservative decision-making. Furthermore, the relationship between optimal investment timing and expansion size is complex: if the expansion size remains unchanged, the trigger demand decreases as the demand growth rate increases; if the expansion size experiences a jump, the trigger demand also exhibits a sharp rise.

Chapter 3 is based on my paper, *Joint optimization of capacity expansion timing and increment in airport terminals: addressing stochastic demand and logistic growth*, published in *Transportation Research Part C: Emerging Technologies*. It proposes a framework that jointly optimizes two related decisions: the expansion timing and the capacity increment, to maximize expected cumulative cost savings under stochastic logistic demand growth. Numerical experiments reveal a congestion effect where added capacity initially reduces congestion and increases cost savings; but as demand approaches the expanded capacity, cost savings decline. Additionally, findings suggest interrelations between variables: a higher demand growth rate correlates with a smaller trigger demand but a larger capacity level, while higher volatility rates result in larger values for both trigger demand and capacity level. Compared to capacity expansion decisions under GBM demand modeling, which tends to overestimate future demand growth, the stochastic logistic framework better captures long-term saturation effects and provides more realistic results.

Chapter 4 is based on my paper under review, *Airport capacity expansion decisions under airport-airline-passenger interactions and stochastic dynamic demand growth with a jump-diffusion model*. It analyzes airport capacity expansion decisions within an airport-airline-passenger system with stochastic dynamic demand growth. The interactions among three agents are explicitly modeled: passengers, who choose whether to travel based on airfare and congestion cost; airlines, which decide their flight volume and airfare; and the airport, which determines charges to airlines. As underlying total potential demand evolves stochastically, a trigger demand exists where capacity expansion becomes desirable for the airport in addition to pricing-based tools, despite the significant investment costs. A jump-diffusion model is developed to jointly optimize the investment timing and expansion increment to maximize the airport's expected profit from the expansion decision. This decision marks the critical transition from short-term capacity management to long-term capacity expansion. A key finding, compared to existing literature, is that the trigger demand for capacity expansion may be unobservable from actual traffic volume. This occurs because once an airport's flight volume reaches its capacity limit, it cannot grow, even as the total potential demand continues to increase.

Overall, the modeling framework and insights developed in this dissertation are not limited to airports. They can be readily extended to other transportation infrastructure investment problems, including ports, road networks, rail systems, and public transit, where long-term infrastructure investment projects are made under uncertainty.