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An evaluation of departure throughputs before and after the implementation of wake vortex recategorization at Atlanta Hartsfield/Jackson International Airport: A Markov regime-switching approach

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ABSTRACT

This paper utilizes a Markov regime-switching model to decompose airport departures into two regimes and to investigate the change in departure throughputs before and after implementing wake recat at ATL. Although analysts may not always know with certainty which regime prevails and how long it may last, they can compute the transition probabilities and expected duration of each regime. After the implementation, there was a 91% chance that departure throughputs would remain unconstrained (up from 86% before implementation) and a 37% chance that departure throughputs would become constrained (up from 35% before implementation).

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1. Introduction

Separation standards are designed to mitigate wake vortex turbulence—swirling air columns from the tips of the wings that can destabilize trailing aircraft. Previously, aircraft weight determined the separation between aircraft. With wake turbulence recategorization or 'wake recat', air traffic controllers can minimize inter-departure times by reducing required separation between aircraft.[1] The table in Appendix A specifies the wake separation standards at the threshold. Wake recat is important for large congested airports that cannot expand capacity through new runway construction. Moreover, airlines and airport operators advocate reduced separations as a tool to increase airport capacity and throughputs.[2]

On June 1, 2014, the air traffic controllers implemented new inter-departure standards at Atlanta Hartsfield/Jackson International Airport (ATL). With a daily average of 2379 takeoffs and landings, ATL was one of the busiest airports in the world in 2014 based on the Federal Aviation Administration's Operations Network (OPSNET) data. The FAA is planning to extend the implementation of wake recat in a phased approach at a selected group of airports to cut the two- to three-minute wait time between departures.

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[1] FAA Order 7110.308 provides for a reduction in wake separations in the case of independent operations when (1) runways are spaced less than 2500 feet and (2) small or large aircraft are leading in the dependent pair. See Re-categorization (RECAT) of FAA Wake Turbulence Separation Categories at Specific Airports, SAFO12007, Flight Standards Services, Federal Aviation Administration, October 22, 2013. The original order and the three subsequent changes can be retrieved at the following website: http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentID/73631.

[2] Federal Aviation Administration, NextGen Performance Snapshots, "On a roll with NextGen", September 2014, https://www.faa.gov/nextgen/snapshots/stories/?slide=34.

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Airport operations usually alternate between peak and non-peak periods. This paper utilizes a Markov regime-switching model to decompose airport departures into two regimes and to investigate the change in departure throughputs before and after implementing wake recat at ATL. In this analysis, we assume that departures switch between two states, also referred to as 'periods', or 'regimes': unconstrained (regime 1) and constrained (regime 2) departure throughputs. Two key considerations motivated the use of Markov regime-switching models in the present study. First, airport and airline operators cannot determine with certainty what regime prevails at any given time. Second, they do not know how long a regime will last. Nevertheless, it is possible to compute the probability that departure throughputs will transition from one regime to another. The stochastic nature of regime switch makes the application of Markov regime-switching models appropriate for the analysis of departure throughputs. According to Frühwirth-Schnatter (2006:316), "an important aspect of [the Markov regime-switching model] is that the time of change-point occurrence is random."

Although Markov regime-switching models are popular in finance and economics, there is no application to airport operations and capacity. This paper attempts to fill this gap and to illustrate how airport and airline analysts can utilize Markov regime-switching models in airport performance evaluation and forecasting. Markov regime-switching models present several benefits, which makes them relevant in this case study:

- They are designed to model high frequency data, such as quarter-hourly records in the present case, and they allow for quick adjustments after the departure throughputs change regime.
- Analysts can derive the probability that departure throughputs transition from one regime to another or stay in a specific regime.
- The regime switching means can serve as the lower and upper bound values of departure throughputs. Such information can be utilized in sensitivity analysis and simulations.
- Airport and airline operators can infer the impact of "some imperfectly predictable forces that produced the change", as Hamilton (2005:3) put it. The random effect of underlying variables such as separation reductions can only be inferred through differences in the variable estimates between each regime. Some air traffic control actions are not directly observable in data, but they will affect departure throughputs. For instance, an airport can meter departures when surface or airspace is congested. Air traffic control may increase separation to minimize airborne delays in case of enroute congestion. Although the wake recat *program* was implemented at ATL, it does not necessarily mean that air traffic controllers or pilots are implementing reduced separations at all times.

Compared with Markov regime-switching models, queueing models do not focus on the relationship between endogenous and exogenous variables. Moreover, queueing models require the identification of several parameters such as the departure and service process distribution, the number of runways (servers) in use, the maximum number of aircraft allowed in the queueing system, and the queue discipline. An alternative to a Markov regime-switching model may be a threshold model, which implies setting boundaries within data. However, the selection of thresholds is arbitrary and creates static groups. Campbell et al. (1997:473) argued that "the Markov model does not suffer from some of the statistical biases that models of structural breaks do; the regime shifts are 'identified' by the interactions between the data and the Markov chain, not by a priori inspection of the data."

This study proposes to evaluate whether three regime-varying variables (i.e. delayed departures, departure demand, and taxi-out time) may have impacted the variability of departure throughputs in regime 1 and 2, before and after the implementation of wake recat. Airport and airline operators, as well as regulators, can utilize transition probabilities and regime duration to anticipate periods of congestion and delays, as well as to evaluate the impacts of wake recat implementation in post-implementation reviews. A Markov regime-switching model can also help aviation practitioners understand the process that governs the time at which departure throughputs transition from one regime to another and the duration of each regime.

2. Literature review

Quandt (1972) and Goldfeld and Quandt (1973) introduced the Markov regime-switching model. Hamilton (1989) presented his autoregressive variant designed to forecast periods of economic recession and expansion and he developed a non-linear filter for forecasting. Frühwirth-Schnatter (2006) provided an overview of dynamic linear models in the forms of serially correlated errors and lagged endogenous variables such as the model presented in this case study. In the model with lagged endogenous variables, regime shifts follow a hidden Markov chain that affects all parameters, including the regression coefficients (Frühwirth-Schnatter, 2006; McCulloch and Tsay, 1994).

Markov regime-switching models have been mainly applied to economics and finance in order to detect the conditions underlying economic growth, volatility in demand, and cyclical phases. The analysis of economic data over time often reveals alternating periods of contraction and expansion with abrupt and dramatic breaks. Hamilton determined that economies as dynamic entities may switch from one regime to another in a Markov process.

Markov regime-switching models are part of the finite mixture models also used in biometrics, medicine, biology, and marketing. According to Frühwirth-Schnatter (2006:6), the goal of finite mixture models is to "find homogenous groups among the data" when they are not readily identifiable. Although these groups are 'concealed' in data, assumptions about the distribution of data within these hidden groups make it possible to derive statistics such as mean and standard deviation.