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Innovative Applications of O.R.

Airport utility stochastic optimization models for air traffic flow management

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ABSTRACT

The complexity of air traffic flow management has its groundwork at an airport and increases with the number of daily aircraft departures and arrivals. To adequately contribute toward an accelerated air traffic flow management (ATfM), multivariate statistical models were developed based on airport utility. The utility functions were derived from daily probabilities of airport delay and inefficiencies computed using parameterized statistical models. The estimates were based on logistic and stochastic frontier models to derive distribution functions from which daily airport utilities were estimated. Data for testing and model simulations are daily aggregates spanning a five year period, collected from Entebbe International Airport.

The utility models show that there was a 2 percent difference between daily aircraft operations at departures (92 percent) and at arrivals (94 percent). These findings confirm the likelihood that events leading to departures are more rigid compared to those observed at aircraft arrivals. Simulation results further confirmed that lowering delays at departure and arrival would result into higher airport utility. Airport utility was found to decrease consistently with an increase in the air-to-ground cost ratios. Airport utility analyses were most stable at a delay threshold of 60 percent and an air-to-ground cost ratio of 1.6 for both departures and arrivals. Therefore, for better outcomes of airport utility studies, this study recommends different treatments between departure and arrival analyses. The models developed are flexible and easily replicable with little adjustments to reflect airport specific characteristics.

1. Introduction

Management of air traffic flow has its groundwork at an airport and its complexity increases with the increase in the number of daily aircraft departure and arrival operations. The problem of air traffic flow management (ATfM) (Agustin, Alonso-Ayuso, Escudero, & Pizarro, 2012; Lulli & Odoni, 2007) becomes more complex when determinants of air traffic departure and arrival delays are not fully identified and elaborated. To adequately contribute toward an improved air traffic flow management (ATfM), multivariate statistical models and airport utility functions were developed. Many studies have endeavored to identify and assess timeliness of aircraft arrivals and departures (Agustin, Alonso-Ayuso, Escudero, & Pizarro, 2012; Mukherjee, 2004) while others suggest a standard of additional 15 minutes after scheduled time to be able to compute delayed aircraft delay duration. However, there is no rule of thumb because in scheduling of aircrafts, a statistical error bound would already have been assigned in schedule time estimation. Thus, for purposes of modeling in this study, any departure or arrival time beyond the scheduled time was considered a delay.

In this study, utility-based stochastic optimization models for airport departure, arrival and aggregation were developed and validated with airport's actual operational data as well as data simulations to ascertain model efficacy. Airport daily delay probabilities and inefficiencies were generated from parameterized statistical models; their distributions were estimated and aggregated to develop airport utility functions (Cook, 2007; Lulli & Odoni, 2007). From the demand side, improved airport utility would generate more income as more passengers often consider airport utility to adjusting their travel programs. Optimum utilities were then contingent upon the daily probabilities of delay with daily airport inefficiency levels. Human intervention can be enhanced in air traffic flow management when based on concrete statistical evidence, an area this study contributes to through developing airport utility models (Clarke, 2003; Kirwan, Rodgers, & Schäfer, 2005; Li & Cai, 2004; Washington, Karlaftis, & Mannering, 2003). In many international airports, especially those in developing countries, automation of air traffic flow management is being implemented as a requirement by the global air navigation plan (GANP) albeit little effort is undertaken to empower human intervention. In its 2013–2028 strategic plans, the GANP provides a comprehensive

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Table 1
Aviation and meteorological study parameters.

Parameter no.	Parameter	Variable type	Daily aggregated data range	
			Minimum value	Maximum value
1	Air temperature	Scale, continuous	19	25
2	Aircraft arriving on time (percent)	Scale, discrete	1	42
3	Aircraft delaying arrival (percent)	Scale, discrete	0	93
4	Aircraft delaying departure (percent)	Scale, discrete	10	89
5	Aircraft on-time departure (percent)	Scale, discrete	0	81
6	Chartered flights	Scale, discrete	0	50
7	Dew point temperature	Scale, continuous	16	21
8	Freighters	Scale , discrete	0	12
9	Non-commercial flights	Scale, discrete	0	57
10	Persons on board-in	Scale, discrete	138	3128
11	Persons on board-out	Scale, discrete	130	3277
12	Queen's nautical height	Scale, continuous	975	1098
13	Scheduled flights	Scale, discrete	5	55
14	Visibility	Scale, continuous	7558	9999
15	Wind direction	Scale, discrete	107	329
16	Wind speed	Scale, discrete	2	9
17	Year	Scale, discrete	2004	2008

planning tool to support a harmonized global air navigation system. Different systems blocks especially those in the developed countries have taken advantage to enhance their navigation solutions such as SESAR in Europe, NextGen in the United States, CARATs in Japan, SIRIUS in Brazil and others in Canada, China, India and Russian Federation (Hotham & Tsujino, 2005; Miyamoto, Wickramasinghe, Harada, Miyazawa, & Funabiki, 2013; Redeborn, 2013). However, there is none for Africa, the world's second biggest continent! Realizing that human intervention is a key factor in every industry, statistical models are constantly being developed to provide evidence for enhancing sustainable air traffic management in the era of technological development. It is noted from the literature that most studies that relate to airport utility do so only in relationship to passenger airport choice (Tsai, Hsu, & Chou, 2011; Yang, Lu, & Hsu, 2014). None, however, has attempted to derive airport utility to support traffic flow management while considering the parametric determinants of departure and arrival delay.

Airport utility is a proxy for the intrinsic structural and operational preparedness of an airport to optimally allocate airport resources during aircraft departures and arrivals while controlling for all key determinants. Therefore, in developing airport utility models, the following questions were key indicators to determine airport's level of utility and analyses: what is the daily probability of delay for the airport? What is the airport's daily inefficiency level? What is the estimated probability density function? How can the interaction of daily airport's probability and inefficiency be used to derive its utility? What is the recommended threshold level of proportion for a delay day? What is the recommended air-to-ground cost ratio to obtain reliable model output? A question of what basis delay decisions could be made to maximize total utility attributed to the airport formed the crux of this study. Subsequently, the specific objective was to derive models that estimate airport's daily utility during aircraft departures, arrivals and aggregate under the prevailing circumstance (Oster & Strong, 2007). Thus, the question of how much the uncertainties prevalent in aviation and meteorological parameters affect the timeliness of aircraft departures and arrivals and thus airport utilities was concurrently explored (Hadjaz, Marceau, Savaent, & Schoenauer, 2012).

To achieve the study objectives, data from Entebbe International Airport, the only international airport in Uganda, a landlocked country found in the Sub-Saharan Africa were used (Wesonga, Nabugoomu, & Jehopio, 2012). Like all developing countries, maximization of the meagre resources to generate a unit output is a key indicator for development (Coltman & Devinney, 2013). Airport utility is considered an important ingredient in the national development endeavors; hence efforts aimed at its optimization greatly relate and support national development. Utility models were derived for airport departures, arrivals as well as an aggregate to provide utility estimates on a scale of 0 to 1 (Verma, Louviere, & Burke, 2006). The fundamental ingredients in determining the airport's utility were parameters for aircraft departures and arrivals. Delayed aircrafts, however, were found to affect not only the operational efficiency of the airport, but also increased levels of customer dissatisfaction that negatively affects revenue for national development. An aircraft delay was measured by computing the difference between the actual and expected time for departure and arrival respectively. The airport efficiency was derived by identifying and examining the stochastic parameters that operationally affect aircraft during departures and arrivals, and subsequently, the resulting stochastic optimization models.

The rest of the paper is structured as follows; Section 2 presents the methodology and data, where insights into computations of daily airport probability and daily airport inefficiency are presented. It is in this section, Section 2.3 where stochastic optimization models for departure, arrival and daily airport aggregates are presented, specifically in Eqs. (15), (16) and (17) respectively. Section 3 presents the findings based on operational daily airport data, experimental data for model validations and stochastic optimization model analysis. In Section 4 conclusions and recommendations are presented.

2. Methodology and data

Statistical programming using R language on both historical and experimental data was done for model fitting and testing. Historical data represented daily records for the five year period (2004–2008) on parameters of aviation and aeronautical meteorology so as to derive airport efficiencies and probabilities of delay. Table 1 shows the parameters used and their aggregates. Proportions of aircrafts that delayed per day to arrive and depart were customized for use as dependent variables.

2.1. Model data flows

Data obtained from the airport covering both aviation and meteorological parameters as presented in Table 1 were used to develop the statistical models that resulted into airport utility-level statistics. Fig. 1 shows the entry levels of the required data for determining the probabilities of departure and arrival delay and also for computing the inefficiency levels at aircraft departure and arrival. It should be noted that although probability of delay could be correlated with