

# Forecasting Airline Scheduling Behavior for the Newark Airport in the Presence of Economic or Regulatory Changes

John Ferguson<sup>i</sup>, Karla Hoffman<sup>ii</sup>, Lance Sherry<sup>iii</sup>, George Donohue<sup>iv</sup>, and Abdul Qadar Kara<sup>v</sup>  
*Center for Air Transportation Systems Research, George Mason University, Fairfax, VA 22030*

Governments have been exploring approaches such as technology (e.g. SESAR/NextGen), and market-based methods to address the pervasive delays in the air transportation system. Resistance to some of the proposed market-based strategies are based on uncertainties on the societal and economic outcomes; specifically, there is a concern that fewer markets might be served, that service might be decreased, that airfares might rise significantly and that airline profitability will suffer. This paper describes the results of an analysis using an optimization model to determine possible airline responses (in the aggregate) to increasing in operating costs and in changes to capacity limits at Newark airport. Preliminary results of the model indicate that most markets that were profitable during 2007 remain profitable even during significant increases in operating costs, as reflected in higher fuel costs. As capacity is decreased, through slot controls, airlines are likely to remain in most markets currently served but reduce frequency to smaller markets.

## I. Introduction

The air transportation system is a significant driver of the U.S. economy providing safe, affordable, and rapid transportation. During the past three decades airspace and airport capacity has not grown in step with demand for air transportation which is projected to grow at average annual growth of +4% (BTS, 2010)<sup>1</sup>. The failure to increase capacity at the same rate as the growth in demand will result in unreliable service and systemic delays (BTS, 2010)<sup>2</sup>. Estimates made on the impact of delays and unreliable service on the economy range from \$32 B/year (NEXTOR, 2010)<sup>3</sup> to \$41B/year (Schumer, 2008)<sup>4</sup>.

Government and industry are collaborating to address the capacity-demand imbalance via three approaches:

1. **Increasing the capacity of the airports and airspace to handle additional flights.** The Airport Improvement Plan (2010)<sup>5</sup> is designed to relieve the bottlenecks at U.S. airports by adding runways, taxiways, gates, terminal buildings and service facilities to key nodes of the air-transportation system.

The impact of these initiatives on the most capacitated airports is limited due to the lack of additional real-estate to accommodate needed infrastructure (e.g. additional runways). Special use airspace (e.g. military use only) is also being made available to increase the number of flights that can be handled during periods of peak demand. Plans are also underway to improve landing and takeoff technologies that will allow “all weather” operations.

2. **Modernization of U.S. Air Traffic Control (ATC).** A \$37B modernization program, known as NextGen<sup>6</sup>, will improve productivity and the utilization of existing airspace. This will yield increases in the effective-capacity of the airspace and airports. Improvements in flow management, airborne re-routing, 4-D coordination of flights,

---

<sup>i</sup> Ph.D. Candidate, Center for Air Transportation Systems Research, 4400 University Drive, Fairfax, VA 22030, AIAA Member

<sup>ii</sup> Professor, Center for Air Transportation Systems Research, 4400 University Drive, Fairfax, VA 22030.

<sup>iii</sup> Assoc. Professor, Center for Air Transportation Systems Research, 4400 University Drive, Fairfax, VA 22030, AIAA Member.

<sup>iv</sup> Professor, Center for Air Transportation Systems Research, 4400 University Drive, Fairfax, VA 22030, AIAA Member.

<sup>v</sup> Ph.D. Candidate, Center for Air Transportation Systems Research, 4400 University Drive, Fairfax, VA 22030, AIAA Member.

And super-dense operations will increase the number of flights that can be handled during peak-periods. Estimates made for increasing effective capacity at the bottlenecks range from a total increase of 10% to 30%. These increases are significantly lower than a compounded 4% annual growth rate in demand.

**3. Increase Passenger Capacity per Flight.** Regulators are also considering incentives for airlines to increase the size of aircraft to transport more passengers per runway/airspace slots. To create these incentives, the government or port authority regulates the scheduled operations to match the number of runway slots and gates available. The slots are allocated to ensure competition between airlines to maintain competitive airfares and service, as well as to provide economies of scale and network integrity for airline networks. Allocation schemes range from administrative (e.g. grandfathering, voluntary agreements between airlines and the FAA, or political allocations) to market-based mechanisms (e.g. congestion pricing, auctions). Care must be taken to ensure the most efficient economic and socio-political use of the slots, and to ensure competition.

The idea of improved utilization of runway/airspace capacity through increased aircraft size gained some traction in 2007 and 2008. A Department of Transportation initiative coordinated capacity limits at the three New York airports (JFK<sup>vi</sup> - 81 per hour (1/18/2008), EWR<sup>vii</sup> - 81 per hour (5/21/2008), LGA<sup>viii</sup> - decreased from 75/hour + 6 unscheduled to 71/hour + 3 unscheduled (1/15/2009). The slots at each of the airports were allocated by grandfathering. The concept of auctioning the slots to maximize the economic efficiency in the allocation and to ensure competitive airfares and service met strong criticism and was withdrawn.

The objections to the concept were based on concerns that the introduction of capacity limits and market-based allocation schemes would affect:

1. Geographic access to air transportation service (i.e. elimination of service at smaller markets)
2. Economic access to air transportation service (i.e. increased operational costs could lead to increased airfares, that might be too costly for certain segments of the population).
3. Airline finances in a negative manner (i.e. reduced profits due to additional costs of operation)
4. Air Transportation Efficiency as measured by the seats per runway/airspace slot (also known as aircraft size or aircraft gauge), by the total arrival and departure seats, and by the total available seat miles scheduled in and out of the target airport.

This paper describes the results of an analysis that examines how the airline industry in the aggregate may react to changes in operational costs and reductions in runway access.

The Airline Schedule Optimization Model (ASOM) was used to evaluate how exogenous factors (passenger demand, airline operating costs, and airport capacity limits) effect geographic access (markets-served, scheduled flights, aircraft size), economic access (airfares), airline finances (profit), and air transportation efficiency (aircraft size).

This analysis captures the impact of the implementation of capacity limits at the airports, as well as the effect of increased costs of operation (i.e. hedged fuel prices). The increases in fuel costs can serve as a proxy for increased costs per flight that might occur if auctions or congestion pricing are imposed. The model also incorporates demand elasticity curves based on historical data that provide information about how passenger demand is impacted by airfare changes.

This study examines airline responses to altering airport capacity limits, to varying operating cost conditions, and to varying passenger demand because of changes in economic conditions. In the model the impacts of operating costs are examined by varying fuel prices, and use data on passenger demand that reflect the distribution of prices (demand curves) paid by passengers to each market served during a good economic period (Summer, 2007) and during a recession (Summer, 2009). The design of the experiment, summarized in the table below, included 18 possible treatments (1 airport (EWR) x 3 capacity levels x 3 hedged fuel prices x 2 passenger demand curves for alternative economic conditions).

---

<sup>vi</sup> John F. Kennedy International Airport

<sup>vii</sup> Newark Liberty International Airport

<sup>viii</sup> LaGuardia Airport

	Objections to incentivizing airlines to up gauge	Results from analysis of Newark Liberty International Airport		
		Reduction in 4 ops/ hr (Capacity Limits)	\$0.45 increase in Hedged Fuel Prices per Gallon (~ doubling landing fees)	1% increase in unemployment rate (ref. BLS)
Geographic Access	Airlines will eliminate service to markets	-.5 market & -10 Flights/ day	-.6 markets & -10 Flights/ day	-.7 markets & -8 Flights/ day
Economic Access	Airlines will increase airfares	N/A	\$7.24 increase in airfare	N/A
Airline Finances	Airlines will lose profits	Loss of \$67K per day	N/A	N/A
Air Transportation Efficiency	Airlines will not up gauge	N/A	Up gauging +3.8 seats/ scheduled aircraft	Down gauging -5 seats/ scheduled aircraft

**Table 1. Comparison of analytical results to objections for incentivizing airline up gauging.**

Table 1 compares the results of this analysis for Newark Liberty International Airport to objections for incentivizing airline up gauging. The implications of this analysis are summarized below:

**1. The Air Transportation System is robust:** Geographic access, economic access, airline profitability, and air transportation efficiency exhibit relatively stable relationships:

- For a fixed passenger demand and, as capacity limits are imposed (e.g. -4 operations per hour, i.e. a reduction of 5%), markets are reduced (-0.5 markets, i.e. a reduction of .7%) and scheduled flights per day to all markets decrease (-10 flights per day, i.e. a reduction of 1.4%), daily profit decreases (-\$67K, i.e. a reduction of 1.3%).
- For a fixed passenger demand and fixed capacity limits at the airports, as hedged fuel prices increase \$.45 per gallon (e.g. equivalent to doubling landing fees from \$1000 to \$2000 per operation), markets are reduced (-.6 markets, i.e., a reduction of 0.8%), scheduled flights per day to all markets decrease (-10.1 flights per day, i.e. a reduction of 1.4%) and average aircraft size increases (+3.8 seats per operation, i.e., a reduction of 3.1%).
- For fixed hedged fuel price and fixed capacity limits at the airports, a 1% increase in the national unemployment rate reduces profitable markets (-0.7 markets, i.e., a reduction of 0.9%), reduces scheduled flights per day to all markets (-8.0 flights per day, i.e. a reduction of 1.1%), and decreases average aircraft size (-5.0 seats per operation, i.e., a reduction of 4.0%).

**2. Airport Capacity did not exhibit any negative effects on markets served or profitability.** Aircraft size does not significantly change, but congestion and delays are significantly improved. The model results are consistent with the observed historical data for Newark Liberty International Airport.

**3. When airline operating costs increase significantly, or when the economic health of the nation changes dramatically, significant impact on airline behavior is observed.**

**4. In the presence of increased passenger demand and in the absence of significant airline competition the airline industry will increase aircraft size.** However, the ability to up-gauge in the real-world is restricted by additional factors not modeled: (1) the capital costs of purchasing new aircraft since there is a lack of available aircraft at the 90-120 seat size (2) the airline’s preference toward frequency (in order to maintain market share and provide passengers with more time-specific options), and (3) labor cost structures for pilots that are significantly higher for larger aircraft than for regional jets.

This paper is organized as follows: Section II describes the study’s methodology, Section III describes the study results, and Section IV summarizes the conclusions from the study.

## II. Methodology

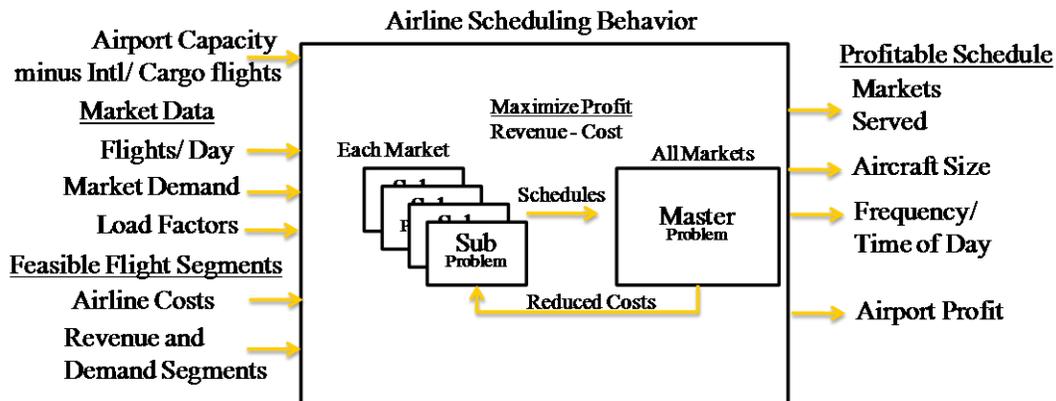
This section describes the Airport Schedule Optimization Model (ASOM) and the analytical methods used in the analysis of the model results.

### A. Airport Schedule Optimization Model (ASOM)

The ASOM is a multi-commodity model that optimizes the schedule of aircraft serving an airport while satisfying market demand. The ASOM, based on an earlier model (Le & Hoffman, 2007)<sup>7</sup> selects an optimal schedule for an airport by selecting profitable markets that can be serviced by the airport, and then allowing the profitable markets to compete for scheduled flights within the fixed capacity of the airport.

The ASOM models the airline industry as a single airline that is an aggregate model of the activities of the entire airline industry. This single airline provides service to all of the markets currently served. The airline is labeled “benevolent” because it: (1) posts prices that are consistent with current competitive prices (i.e. it does not seek monopolistic rents) and (2) attempts to serve as many markets as it can, while remaining profitable. This single “benevolent” airline summarizes the actions of multiple airlines by its pricing and market structure. Because the ASOM model aggregates the airline industry into a single airline, it exhibits the following limitations:

1. The model reflects airline behavior from an operational rather than a strategic viewpoint and therefore does not consider remaining in markets that prove unprofitable, even for a single airline.
2. The ASOM model does not model actions taken for reasons of competition. For example, the single airline would choose to use a larger aircraft in shuttle markets rather than have (as is currently the case) eight departures from LGA to DCA in a single hour.
3. The ASOM model does not consider keeping service in unprofitable markets when the economy is in a recession in order to maintain market share in the future.
4. The ASOM model balances arrivals and departures each period and does not consider how banking might allow more connections to take place.



**Figure 1. Airport Schedule Optimization Model (ASOM).**

The ASOM model is summarized in Figure 1. The inputs to the model are:

- (1) **Airport capacity limits for domestic operations.** The number of scheduled international flights and cargo flight are subtracted from the target airport capacity to obtain the airport capacity for domestic operations.

(2) **Feasible flight segments.** The model only considers airports that have historically been served by the target airport along with scheduled flight times and aircraft types.

(3) **Flights per Day.** The total flights per day by market are obtained by taking the sum of quarterly arrivals and departures by market and dividing the number of days in the quarter.

(4) **International Passenger demand for each time of day.** The total international passenger demand for each market is determined by totaling the number of passengers who are traveling on domestic segments in order to in order to connect to or from an international flight segment quarterly and divide by the number of days in the quarter.

(5) **Market demand** is the average passengers flown daily to and from each market.

(6) **Market Load Factors** is calculated by taking the number of passengers flown divided by the corresponding seats flown to determine average aircraft load factors for each market.

(7) **Airline Operational Costs.** The airline operational costs are averaged by aircraft fleet class to determine average segment flight times, average fuel burn rates and average costs per flight hour by aircraft class. These costs are added to the other operating costs: crew costs, maintenance costs, baggage, ticketing and handling costs, etc.

(8) **Revenue** is calculated by aircraft size using the demand curves that reflect the percentage of passengers that bought tickets at each posted price. Revenue curves for each quarter are considered since ticket pricing is both seasonal and dependent on market conditions. Thus, the revenue curves used for summer 2007 reflect a healthy economy while the revenue curves for summer 2009 reflect a period of economic recession. When calculating total revenue an 80% load factor is assumed. This enables the model to calculate revenue for each market depending on the percentage of the historic market demand that is scheduled to be flown. The model assumes that the “benevolent” airline will continue to post prices consistent with historically competitive prices.

(9) **Demand capacity.** The total demand possible in any period is also based on historical demands during for any given quarter. Passenger demand is assumed not to exceed what was observed within a given 15 minute period. Demand is restricted not to exceed the hourly demand and the morning (12am-12pm), afternoon (12pm-5pm) and evening (5pm-12am) time periods.

The outputs of the ASOM are a profitable, feasible schedule to each profitable market scheduled by Aircraft Size, Frequency of service and Time of Day. The following metrics can be determined from this schedule:

- (1) **Number of profitable markets served**
- (2) **Number of daily flights to all markets**
- (3) **Aircraft Size on each scheduled flight**
- (4) **Number of daily seats flown in and out of the airport**
- (5) **Number of daily available seat miles flown in and out of the airport**
- (6) **Airline daily profits for markets served**

The determination of the profitable schedule within the capacity limits of the airport is a two part problem. The sub-problem, determines the most profitable schedule that meets market demand by selecting the frequency of service and aircraft size based on the value of adding/deleting flights in each time period. These schedules are submitted as inputs to the master problem.

The master-problem then determines an optimal airport schedule by selecting market schedules that maximizes profit for the airport within the operational capacity of the airport. The *dual prices* from this solution are submitted to the sub problems, i.e. they provide the information about the relative value of flying in that time period. The process iterates with the sub-problem continuing to add market schedules (i.e. columns) to the master problem. Thus, the overall approach is called “Column Generation.”

This process continues until either there is no improvement in the total profit (objective function) or no new schedules are generated. Once the problem is solved to linear optimality, if the solution obtained is not integer, a

tree search is invoked to prove integer optimality using the same column-generation approach on each branch of the tree.

Previous analysis and papers describe the ASOM in greater detail.<sup>8</sup>

## B. Data Sources

The BTS<sup>ix</sup> and ASPM<sup>x</sup> data was preprocessed for Newark Liberty International Airport for third quarter 2007 and third quarter 2009 to determine calculate the inputs for the ASOM. The ASOM input data is preprocessed from the following databases; the ASPM Individual Daily Flight, the T100 monthly flight summaries, the DB1B quarterly passenger itineraries, the P52 quarterly airline costs and the CATSR<sup>xi</sup> airport and aircraft data databases.

## C. Design of Experiment

The results of the ASOM experiment, summarized in the factorial design in Table 2, examined how the airline schedule behavior changed for each of the factors in the design by recording (a) aircraft size, (b) flights per day, and (c) markets served and (d) airline profitability.

		3QTR 2007			3QTR 2009		
Airports		EWR			EWR		
Hedged Fuel Prices (\$/Gallon)		\$2	\$3.5	\$5	\$2	\$3.5	\$5
Gross Domestic Product (GDP Quantity Index, 2005=100)		104.9			102.8		
Capacity Limits (Operations/ hour)	Low	72	72	72	72	72	72
	Normal	80	80	80	80	80	80
	High	96	96	96	96	96	96

**Table 2. Design of Experiment” for Hedged Fuel Price and Capacity Limit experiment**

This experiment examines airline behavior for *three* airport capacity levels (high, normal, and low) and *three* fuel price levels (\$2, \$3.5, \$5) for *two* different economic scenarios (3QTR07 and a 4.6% national unemployment rate and 3QTR09 and a 9.6% national unemployment rate) for Newark airport. The results provide insights on airline industry behavior in response to capacity changes, fuel price changes, and economic conditions.

Note: These experiments include analysis of hedged fuel prices of \$5/gallon. Historically, fuel prices have not exceeded \$3.70/gallon (07/2008). The analysis showed that the airline decision-making response remained linear throughout the full range of fuel prices allowing the use of the data for derivation of the linear regression equations. These results are reported, but it should be recognized that above \$4/gallon the economy and passenger demand may undergo significant changes that have not been experienced (or modeled).

## D. Statistical Analysis

The following outputs of the ASOM were analyzed: (1) the number of profitable markets served, (2) the daily domestic flights by market, (3) aircraft class and time of day, and (4) the airline profits for the airport examined.

<sup>ix</sup> Bureau of transportation statistics (BTS)

<sup>x</sup> Aviation System Performance Metrics (ASPM), Federal Aviation Administration (FAA)

<sup>xi</sup> Center for Air Transportation Systems Research (CATSR), George Mason University

The controls or exogenous factors for the model are fuel prices, airport capacity limits and historical national unemployment rates from (BLS)<sup>xii</sup>.

The analysis of statistically significant trends between the exogenous factors and the ASOM outputs required the following multi-step process:

(1) The ASOM output data was processed into the metrics of interest at the airport level.

(2) A correlation analysis of factors was done to identify the individual relationships between factors. The Pearson product moment correlation coefficient is used to measure the degree of linear relationship between two variables. The correlation coefficient assumes a value between -1 and +1. If one variable tends to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive.

(3) A step-wise regression was performed to identify the factors that most impact the independent variable. Stepwise regression adds variables sequentially, choosing the most significant variable first and continues until the adding of another variable degrades the relative R<sup>2</sup> coefficient (i.e. the R<sup>2</sup> adjusted for the number of independent terms in the regression equation).

### III. Results

#### A. Geographic Access

The ASOM considers the competition among markets for airline resources and chooses schedules that optimize the benevolent airline's profitability using prices that were set historically in a competitive environment. Thus, if a market loses service, it is either because, under current economic conditions, it is no longer profitable to serve the market or because when restrictions on runway access are imposed, it is more profitable to use that access in other markets.

Capacity limits at airports resulted in a small reduction in markets served and flights per day.

1. Increases in hedged fuel prices (which impacts airline operational costs) is the primary determinant of the number of markets served. A linear regression showed that for every \$1 increase in hedged fuel prices, there is a 1.4 (1.8%) decrease in the number of markets with direct service and a decrease of 22.3 (3.1%) scheduled flights per day across all markets.

2. Demand for air transportation is impacted by the economic conditions. The regression analysis uses the national unemployment rate as the dependent variable that compares the difference between the two economic scenarios (summer, 2007 when the unemployment rate was 4.6% and summer, 1009 when the unemployment rate was 9.6%). A linear regression on the results of the ASOM showed that for every percentage increase in the national unemployment rate, there is a 0.7 (0.9%) decrease in the number of markets with direct service. Similarly, a linear regression showed that for every percentage increase in the national unemployment rate, there is a decrease of 8 (1.1%) scheduled flights per day across all markets

3. Capacity Limits on runway access (i.e. the number of slots available per hour) slightly impact the number of markets served. A linear regression showed that for each slot reduction per hour there is a there is a 0.1 (0.1%) decrease in the number of markets with direct service and a 2.5 (0.3%) decrease in the scheduled flights per day across all markets.

**Profitable Markets.** The results of the ASOM computer runs show adjusting airport capacity limits has far less effect in changing the number of profitable markets for EWR than does economic conditions, or changes in operating costs, these results are shown in Table 3. The table shows the differences from the Baseline (in parenthesis) of profitable markets for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

---

<sup>xii</sup> Bureau of Labor Statistics (BLS)

<b>EWR Markets</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline 79 markets)	72	-2	-1	-8
	80	-	-1	-9
	96	-	-	-5
<b>EWR Markets</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline 74 markets)	72	+1	-1	-5
	80	-	+1	-1
	96	-	+1	-

**Table 3. Sensitivity of EWR profitable markets to Hedged Fuel Price and Capacity Limits.**

The results from a statistical examination of the changes in the number of markets served shows a significant relationship (95% confidence) between markets served with direct service and three factors: hedged fuel prices, caps on runway access and the national unemployment rate. As capacity limits increase, the number of markets served also increases. The reverse relationship exists for both fuel prices and the unemployment rate, i.e. whenever either of these factors increase the number of markets served decreases. The correlation accounted for 60.4% (i.e. R-squared) of the observed variation in profitable markets served. The regression equation is:

$$\text{Profitable direct Markets} = 74 + (0.122 * \text{Caps}) - (.681 * \text{Unemployment Rate}) - (1.36 * \text{Fuel Price})$$

**Scheduled Flights per Day.** The ASOM model presented similar results for how each of the three factors (Caps, fuel prices and economic conditions) impact scheduled flights per day in table 4. The table shows the differences from the Baseline (in parenthesis) of scheduled flights per day for “Normal” Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

Again the relationship between all three factors and scheduled flights is statistically significant at the 95% confidence level. However, when doing the stepwise regression, a much higher R-squared is found (i.e. 85.5% of the variance can be explained with these three variables). The regression equation is:

$$\text{Scheduled Flights per day} = 625 + (2.48 * \text{Caps}) - (8.0 * \text{Unemployment Rate}) - (22.3 * \text{Fuel Price})$$

<b>EWR Flights</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline 750 flights)	72	-50	-52	-106
	80	-	-12	-86
	96	+44	+6	-62
<b>EWR Flights</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline 672 flights)	72	-34	-56	-92
	80	-	-16	-54
	96	+16	+14	-30

**Table 4. Sensitivity of EWR scheduled flights per day to Hedged Fuel Price and Capacity Limits.**

## B. Economic Accessibility

Airfares are examined to determine how airline airfares increase, as caps are imposed, or as economic conditions change. The airlines adjust airfares in response to changes in operating costs. Similarly, as airport access was tightened or as the economy declined, prices again increased. However, the magnitude of the changes is much more pronounced for this variable. Specifically: Changes in the economy significantly affected demand for air transportation. The economic downturn had an order of magnitude greater effect on airline airfares than did the change in airlines' operating costs (as measured by changes in fuel costs).

Cumulative elasticity at the airports ranged between -3.1 to -1.8 during this period. Specifically, a 1% increase in airfare (e.g. \$300 to \$303) resulted in a 3% reduction in demand for air service at that fare. This result is consistent with prior studies that showed passenger demand to be elastic.<sup>9</sup> The change in airfare was driven by changes in hedged fuel prices (which impacts airline operational costs) (R<sup>2</sup>=83.1%). The regression equation is:

$$\text{Average Airline Airfare} = \$141.62 + (16.42 * \text{Fuel Price})$$

## C. Airline Profitability

The ASOM generates optimally profitable airline schedules and calculates the total revenue and costs from this schedule. Taking operating revenues minus operating costs provides the aggregate industry operating profit per quarter for EWR airport. Airline profitability for the routes serviced is a complex phenomenon driven by demand for air transportation, passenger's responses to price increases, and operating costs. Historically airline profitability is primarily determined by the industry's ability to raise airfares relative to the cost of operations (i.e. when hedged fuel prices were escalating dramatically). The ASOM model does not account for any lag in airline changing airfares in response to changes in the cost of operations.

<b>EWR Profit</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline \$5.884 mil)	72	-.110	+0.934	+1.257
	80	-	+1.030	+1.317
	96	+0.107	+1.110	+1.379
<b>EWR Profit</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline \$6.511 mil)	72	-0.269	0.537	0.569
	80	-	+0.864	+1.071
	96	+0.059	+0.908	+1.096

**Table 5. Sensitivity of EWR Airline Profit to Hedged Fuel Price and Capacity Limits.**

The results of ASOM analysis of airline profit for EWR are shown in table 5. The table shows the differences from the Baseline (in parenthesis) of airline profits per day for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

Statistical analysis of airline profits for EWR shows statistically significant correlation (95% confidence) between Airline Profit and hedged fuel prices, national unemployment rate, and aircraft gauge. Stepwise regression analysis identified airline profit to be a function of capacity limits and aircraft gauge. This relationship was found to be positive for all factors. The correlation accounted for 91.6% (i.e. R-squared) of the observed variation in airline profit. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression model is as follows:

$$\text{Airline Profit} = - 2.09 + (0.0167 * \text{Caps}) + (0.0489 * \text{Gauge})$$

#### D. Air Transportation Efficiency

Air transportation efficiency is measured by the *throughput* of passengers through the airspace network. This study is only examining whether there is upgauging of aircraft and therefore more passengers being able to depart and arrive at EWR. Thus, this section will evaluate whether airlines tend to up gauge or down-gauge under (a) alternative economic conditions, (b) changes in runway capacity and (c) changes in operating costs.

A linear regression showed that for every percentage increase in the national unemployment rate, there is a 5.0 (3.6%) seat decrease in the average aircraft size flown. Also, for every \$1 increase in hedged fuel prices, there is an 8.4 (6.1%) seat increase in the average aircraft size flown. And for each flight operation decrease per hour, there is an increase of 0.1 (0.1%) seats for the aircraft size flown. This statistical relationship explained 96.9% of the variations in aircraft gauge (R<sup>2</sup>=96.9%).

Note: These results are not consistent with the observed historical data. The historical data did not show the upgauging experienced by the ASOM model.

The change in the total arrival and departure seats is directly related whether the airline up gauges and whether it adds additional direct service. Each additional scheduled flight per day added 128 seats to the total arrival and departure, which represents the average aircraft size. Increasing the average aircraft size by one seat added 684 seats to the total arrival and departure, which represents the average scheduled flights per day.

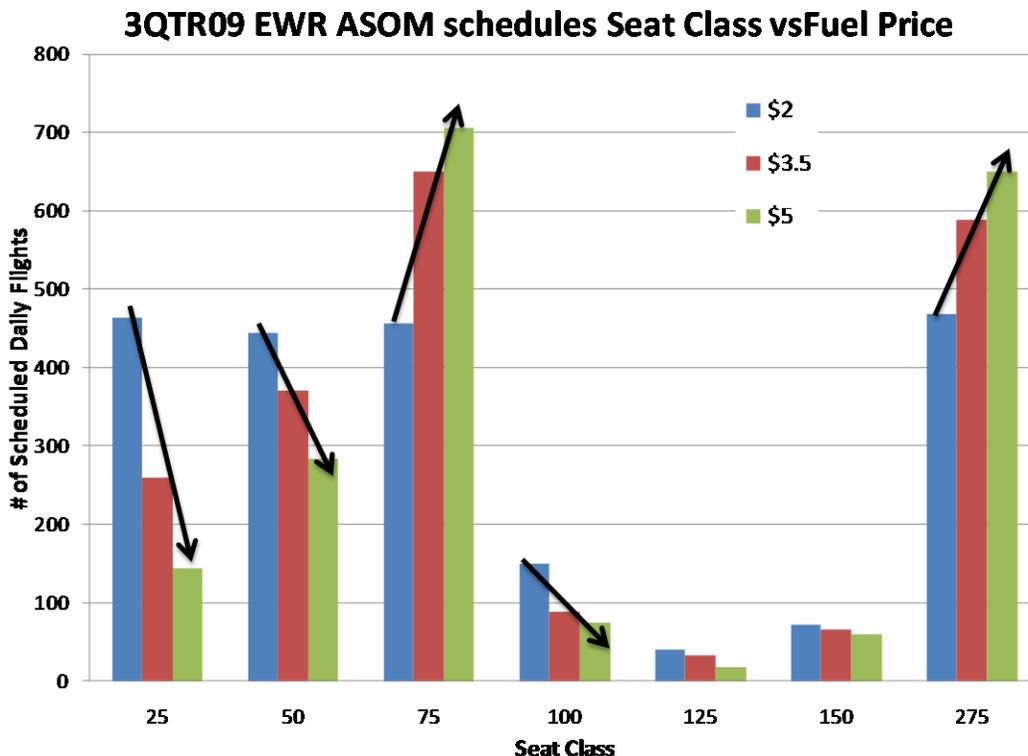
Next seat miles are examined rather than number of seats. Not surprising, the same factors impact this dependent variable. The change in total available seat miles (ASM) scheduled in and out of the airport was driven by changes in hedged fuel prices (which impacts airline operational costs) and by the total arrival and departure seats (R<sup>2</sup>=99.1%). Every \$1 increase in hedged per-gallon fuel prices resulted in a reduction of 1.8 million (1.7%) ASMs. An incremental increase in the total arrival and departure seats resulted in an increase of 1273 (0.0%) ASMs.

**Aircraft Size.** The results of ASOM analysis of the average aircraft size scheduled for EWR are shown in Table 6. The table shows the differences from the Baseline (in parenthesis) of average aircraft gauge for “Normal” Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

<b>EWR Gauge</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline 139 seats/ aircraft)	72	+5	+14	+21
	80	-	+13	+20
	96	-5	+9	+20
<b>EWR Gauge</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline 110 seats/ aircraft)	72	-	+15	+26
	80	-	+17	+30
	96	-4	+15	+30

**Table 6. Sensitivity of EWR Aircraft Gauge to Hedged Fuel Price and Capacity Limits.**

The results show that adjusting airport capacity limits up and down has little effect on aircraft gauge, but significantly increases in fuel prices increases the aircraft gauge. In the table the underlined quantity represents the baseline ASOM results for aircraft gauge for normal capacity limits and fuel prices in line with historic prices for the quarter examined.



**Figure 2. ASOM increases 75 and 275 seat aircraft in EWR’s schedule as fuel prices increase.** Shows the how the ASOM changes aircraft gauge for scheduled daily flights by in and out of EWR as fuel prices are increased

Figure 2 shows the how the ASOM changes aircraft gauge for scheduled daily flights by in and out of EWR as fuel prices are increased. This figure shows that the ASOM increases 75 and 275 seat aircraft in EWR’s schedule as fuel prices increase.

Statistical analysis of aircraft gauge for scheduled daily flights for EWR shows statistically significant correlation (95% confidence) between aircraft gauge and hedged fuel prices and national unemployment rate. Stepwise regression analysis identified aircraft gauge to be a function of fuel prices, national unemployment rate, and airport capacity limits. This relationship was found to be positive for fuel prices. And the relationship was found to be negative for airport capacity limits and national unemployment rate. The correlation accounted for 96.9% (i.e. R-squared) of the observed variation in aircraft gauge. The regression model is:

$$\text{Average Aircraft Gauge} = 153 - (0.118 * \text{Caps}) - (5.0 * \text{Unemployment Rate}) + 8.43 * \text{Fuel Price}$$

These results from the ASOM model were not surprising because of the lack of economies of scale related to up gauging. A closer examination of the data shows that 100 and 200 seat classes show poor historic performance (cost per seat-hr). The newest part of the airline industry fleet is regional jets that are more fuel efficient than the larger aircraft in the overall fleet. Thus, as fuel prices increase, there is more incentive for the ASOM to move to smaller aircraft, since the smaller aircraft have better average cost per seat hour. The B787 and A380 are more efficient aircraft but unlikely to be used for many of the markets currently served by these airports since they are relatively large aircraft.

By using smaller aircraft the airlines can assure high load factors, greater frequency. This result has significant implications for future airspace use.

**Total arrival and departure seats.** The results of ASOM analysis of the total arrival and departure seats for EWR are shown in Table 7. This table shows the differences from the Baseline (in parenthesis) of total daily arrival and departure seats for “Normal” Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

<b>EWR Seats</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline 104000 seats)	<b>72</b>	-3350	3100	-1050
	<b>80</b>	-	8300	1400
	<b>96</b>	2350	7600	5300
<b>EWR Seats</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline 77500 seats)	<b>72</b>	-3900	3650	5750
	<b>80</b>	-	9650	13350
	<b>96</b>	-1100	12350	16550

**Table 7. Sensitivity of EWR total arrival and departure seats to Hedged Fuel Price and Capacity Limits.**

The results show that adjusting airport capacity limits up and down has little effect on total arrival and departure seats, but increases in fuel prices increase the total arrival and departure seats. In the table the underlined quantity represents the baseline ASOM results for total arrival and departure seats for normal capacity limits and fuel prices in line with historic prices for the quarter examined.

Statistical analysis of scheduled daily arrival and departure seats for EWR shows statistically significant correlation (95% confidence) between total arrival and departure seats to national unemployment rate, number of direct service markets, and average aircraft gauge. Stepwise regression analysis identified total arrival and departure seats to be a function of scheduled flights per day, number of direct service markets and average aircraft size. This relationship was found to be positive for scheduled flights per day, number of direct service markets and average aircraft size. The correlation accounted for 99.8% (i.e. R-squared) of the observed variation in total arrival and departure seats. The regression model is as follows:

$$\text{Scheduled Departure and Arrival Seats} = - 99427 + (128*\text{Flights}) + (160*\text{Markets}) + (684*\text{Gauge})$$

**Total available seat miles scheduled.** The results of ASOM analysis of the total available seat miles scheduled in and out of EWR are shown in Table 8. This table shows the differences from the Baseline (in parenthesis) of daily available seat miles for “Normal” Capacity Limits (i.e. 80 operations/hour), and passenger demand at \$2/gallon.

The results show that the total available seat miles are sensitive to changes in airport capacity and hedged fuel prices. In the table the underlined quantity represents the baseline ASOM results for total available seat miles for normal capacity limits and fuel prices in line with historic prices for the quarter examined.

Statistical analysis of available seat miles for EWR shows correlation between total available seat miles to national unemployment rate, markets served, scheduled flights per day, aircraft size, and total arrival and departure seats. Stepwise regression analysis identified total available seat miles to be a function of hedged fuel price and total arrival and departure seats. This relationship was found to be positive for total arrival and departure seats and negative for hedged fuel price. The correlation accounted for 99.1% (i.e. R-squared) of the observed variation in total available seat miles. The regression model is as follows:

$$\text{Available Seat Miles} = - 10803115 - (1818714*\text{Fuel Price}) + (1273*\text{Seats})$$

<b>EWR ASM</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2007</b> (baseline 119.1 million)	<b>72</b>	<b>-4.9</b>	<b>-1.2</b>	<b>-7.3</b>
	<b>80</b>	<b>-</b>	<b>5.6</b>	<b>-5.3</b>
	<b>96</b>	<b>1.2</b>	<b>3.7</b>	<b>2.7</b>
<b>EWR ASM</b>	<b>Caps</b>	<b>\$2</b>	<b>\$3.5</b>	<b>\$5</b>
<b>3QTR 2009</b> (baseline 85.4 million)	<b>72</b>	<b>-7.7</b>	<b>-1.9</b>	<b>-0.3</b>
	<b>80</b>	<b>-</b>	<b>10.0</b>	<b>11.7</b>
	<b>96</b>	<b>-0.9</b>	<b>11.7</b>	<b>13.7</b>

**Table 8. Sensitivity of EWR available seat miles to Hedged Fuel Price and Capacity Limits.**

#### IV. Conclusion

The results of the analysis using the ASOM are as follows:

**1. The Air Transportation System is robust:** Within the range of historic data, Geographic access, economic access, airline profitability, and air transportation efficiency exhibit a proportional relationships defined by the linear regressions below:

$$\text{Profitable direct Markets} = 74 + (0.122 * \text{Caps}) - (0.681 * \text{Unemployment Rate}) - (1.36 * \text{Fuel Price})$$

$$R^2 = 60.4\%$$

$$\text{Scheduled Flights per day} = 625 + (2.48 * \text{Caps}) - (8.0 * \text{Unemployment Rate}) - (22.3 * \text{Fuel Price})$$

$$R^2 = 85.5\%$$

$$\text{Average Airline Airfare} = \$141.62 + (16.42 * \text{Fuel Price})$$

$$R^2 = 83.1\%$$

$$\text{Average Aircraft Gauge} = 153 - (0.118 * \text{Caps}) - (5.0 * \text{Unemployment Rate}) + 8.43 * \text{Fuel Price}$$

$$R^2 = 96.9\%$$

$$\text{Scheduled Departure and Arrival Seats} = -99427 + (128 * \text{Flights}) + (160 * \text{Markets}) + (684 * \text{Gauge})$$

$$R^2 = 99.8\%$$

$$\text{Available Seat Miles} = -10803115 - 1818714 * \text{Fuel Price} + 1273 * \text{Seats}$$

$$R^2 = 99.1\%$$

$$\text{Airline Profit} = -2.09 + (0.0167 * \text{Caps}) + (0.0489 * \text{Gauge})$$

$$R^2 = 91.6\%$$

**2. The Air Transportation System is Stable:** Within the range of historic data, Geographic access, economic access, airline profitability, and air transportation efficiency do not exhibit any significant changes in relationships.

- For a fixed passenger demand and, as capacity limits are imposed (e.g. -4 operations per hour, i.e. a reduction of 5%), markets are reduced (-0.5 markets, i.e. a reduction of .7%) and scheduled flights per day to all markets decrease (-10 flights per day, i.e. a reduction of 1.4%), daily profit decreases (-\$67K, i.e. a reduction of 1.3%).

- For a fixed passenger demand and fixed capacity limits at the airports, as hedged fuel prices increase \$.45 per gallon (e.g. equivalent to doubling landing fees from \$1000 to \$2000 per operation), markets are reduced (-.6 markets, i.e., a reduction of 0.8%), scheduled flights per day to all markets decrease (-10.1 flights per day, i.e. a reduction of 1.4%) and average aircraft size increases (+3.8 seats per operation, i.e., a reduction of 3.1%).

- For fixed hedged fuel price and fixed capacity limits at the airports, a 1% increase in the national unemployment rate reduces profitable markets (-0.7 markets, i.e., a reduction of 0.9%), reduces scheduled flights per day to all markets (-8.0 flights per day, i.e. a reduction of 1.1%), and decreases average aircraft size (-5.0 seats per operation, i.e., a reduction of 4.0%).

**3. Airport Capacity Limits Do Not Have Large Scale Negative Effects:** Regulatory authority to manipulate the market through the introduction of airport capacity (and airport capacity limits) has no large scale negative effects. A modest reduction on the order of 4 slots per hour results in a loss of .5 market served and 10 flights per day. By shaving off the least profitable markets and flights per day, the airlines experience a small loss in profitability. Aircraft size does not increase.

**4. Hedged fuel prices and economic health drive air transportation performance:** Regulatory authority to manipulate the market through the introduction of airport capacity (and airport capacity limits) is only one of three factors affecting geographic access, market access, and airline financial stability. Passenger demand for air transportation (measured by national unemployment rate) and airline operating costs (determined by fuel prices) have significant impacts.

**5. Combination of increased passenger demand and increased operating costs directly causes increase in aircraft size.** It is financially viable for airlines to up gauge to service the passenger demand.

### **Future Work**

Further ASOM analysis at the New York, San Francisco, and Philadelphia airports will be conducted to determine if these results are local or represent general models of airline behavior in the presence of exogenous factors. Further analysis of economic and policy impacts on passenger demand will be done so that the ASOM model's passenger demand can be adjusted accordingly.

### **Acknowledgments**

We gratefully acknowledge the support and assistance from Rosa Oseguera-Lohr, Mike Madson, John Cavalowsky, and Michael Bloem of NASA. We would also like to acknowledge the contributions of Jim Gaughn, Norm Fujisaki, Terry Thompson, and Jack Kres of Metron Aviation and Frank Berardino (GRA), Robert Poole (Reason Foundation), and Matt Blake (Sensis). We also are grateful for the database support Guillermo Calderon-Meza provided throughout this research effort. *This research was sponsored by NASA NRA NNX07AT23A.*

## References

- 
- <sup>1</sup> Bureau of transportation statistics (BTS) reports. Accessed March 2010
- <sup>2</sup> Ibid.
- <sup>3</sup> NEXTOR (2010) Total Delay Impact Study: A Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States. Report prepared for FAA Air Traffic organization - Strategy and Performance Business Unit Washington D.C.
- <sup>4</sup> Schumer, C.E., May 2008. "Flight Delays Cost Passengers, Airlines and the U.S. Economy Billions". A Report by the Joint Committee Majority Staff.
- <sup>5</sup> FAA, 2000. Airports Capital Improvement Plan, Available at:  
[http://www.faa.gov/airports/resources/publications/orders/media/AIP\\_5100\\_39A.pdf](http://www.faa.gov/airports/resources/publications/orders/media/AIP_5100_39A.pdf) [Accessed June 27, 2010].
- <sup>6</sup> FAA, 2010. 2010 NextGenImplementation Plan, Available at:  
[http://www.faa.gov/about/initiatives/nextgen/media/NGIP\\_3-2010.pdf](http://www.faa.gov/about/initiatives/nextgen/media/NGIP_3-2010.pdf) [Accessed June 27, 2010].
- <sup>7</sup> Le, Donohue, Hoffma, Chen, 2007. Optimum Airport Capacity Utilization under Congestion Management: A Case Study of New York LaGuardia Airport, Transportation Planning and Technology - Special Issue : Approaches for Developing the Airports of the Future
- <sup>8</sup> Le, Loan, 2006. Demand Management at Congested Airports: How Far Are We From Utopia? George Mason University Dissertation.
- <sup>9</sup> Belobaba, Odoni, Barnhart, 2009. The Global Airline Industry. John Wiley and Sons Ltd.