NASA/CR–2010-216861

Optimizing Air Transportation Service to Metroplex Airports

Part II: Analysis Using the Airline Schedule Optimization Model (ASOM)

George Donohue, Karla Hoffman, Lance Sherry, John Ferguson, and Abdul Qadar Kara
Center for Air Transportation Systems Research, George Mason University, Fairfax, Virginia

October 2010

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Prepared for Langley Research Center
under Cooperative Agreement NNX07AT23A

October 2010

Available from:

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EXECUTIVE SUMMARY

Context

This report summarizes work done for NASA Langley Research Center as part of the Airspace Systems Program (Airportal Project), under Contract number NNX07AT23A.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). The failure to increase capacity at the same rate as the growth in demand will result in unreliable service and systemic delays (BTS, 2010). Estimates of the impact of delays and unreliable air transportation service on the economy range from $32B/year (NEXTOR, 2010) to $41B/year (Schumer, 2008).

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) 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) infrastructure. A $37B modernization program, known as NextGen, 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, and super-dense operations will increase the number of flights that can be handled during peak-periods. Estimates 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. This approach incentivizes 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 number of scheduled flights 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.

Problem

Currently there is not enough emphasis is being placed on the third approach, improved utilization through increased aircraft size.

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 - 81 per hour (1/18/2008), EWR - 81 per hour (5/21/2008), LGA - 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.

Objective & Method

This report describes the results of an analysis of airline strategic decision-making that affects: (1) geographic access, (2) economic access, and (3) airline finances. This report extends the analysis of these factors using historic data (provided in Part 1 of the report).

The Airline Schedule Optimization Model (ASOM) was used to evaluate how exogenous factors (passenger demand, airline operating costs, and airport capacity limits) affect 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 costs of operation 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 affected by airfare changes.

Results

Two analyses were conducted. The first experiment examined airline strategic decision-making in response to the introduction of airport capacity limits for three fixed passenger demand and operating costs scenarios (i.e. Gross Domestic Product and Hedged Fuel Prices). The design of the experiment included 45 possible treatments (five airports times three capacity levels times three demand and operating cost changes).

The second experiment examined airline strategic decision-making in response to the introduction of airport capacity limits for varying operating cost conditions (i.e. hedged fuel prices) for fixed passenger demand (based on a given economic situation as described by Gross Domestic Product). The design of the experiment, summarized in the table below, included 18 possible treatments (one airport times three capacity levels times three hedged fuel prices times two values for Gross Domestic Product).

Statistically significant trends with a confidence interval of 95% were as follows:

Note: The ASOM model is based on the assumption of a benevolent monopolist. Thus, this is the best that one can expect in terms of up-gauging. With competition among airlines, it is likely that the demand will be shared among airlines and up-gauging will be somewhat reduced.

Geographic Access. The number of markets with direct Metroplex airport service is determined by passenger demand, operating costs, and airport capacity limits (R2=83%). The number of flights per day to a market is also determined by passenger demand, operating costs, and airport capacity limits (R2=88%).

1. The growth/decay in demand for air transportation is often attributed to economic conditions. A proxy for overall National economic health, changes in Gross Domestic Product (GDP)), is used to examine changes in impact to the number of markets served and scheduled flights per day. A linear regression on the results of the ASOM showed that for every incremental increase in the GDP index, there is an increase of 1.8 in the number of markets with direct service. Similarly, a linear regression showed that for every incremental increase in the GDP index, there is an increase of 17.3 in the number of scheduled flights per day across all markets.

2. The fluctuations in hedged fuel prices (which impacts airline operational costs) also impacts markets served and flights per day. A linear regression showed that for every $1 increase in hedged fuel prices, there is a decrease of 1.9 in the number of markets with direct service and a decrease of 17.8 in the total number of scheduled flights per day across all markets

3. The introduction of Capacity Limits (as measured by limits on number of operations per hour) is a determinant of the number of markets served and scheduled flights per day. A linear regression showed that for every additional operation per hour allowed, there is an increase of 0.1 in the number of markets with direct service and an increase of 2.4 in the number of scheduled flights per day across all markets.

Economic Accessibility. Passenger accessibility to air transportation is determined by airfares. Changes in the economy affect demand for air transportation. Changes in fuel prices reflected in changes in airfares also affect the demand for transportation. In general, the model results indicate that an economic downturn has an order of magnitude greater effect on airline airfares than does the change in airlines' operating costs.

1. 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 show passenger demand to be relatively elastic.

2. The change in airfare was driven by changes in hedged fuel prices (which impacts airline operational costs) (R2=83.1%). At the five airports studied (LGA, JFK, EWR, PHL, and SFO), every $1 increase in hedged per-gallon fuel prices resulted in an average of $16 increase in airfares, which yielded an average reduction in passenger demand of 1.5%. This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.

Airline Profitability. Airline profitability for the routes serviced at these five airports is a complex phenomenon driven by demand for air transportation, passenger's responses to airfare, and airline operating costs.

Changes in airline profits are driven by changes in economic conditions (as measured in this study by GDP), operational costs (as measured in this study by hedged fuel prices), aircraft size, and flights per day (R2=94.9%). For example for passenger demand and operations at EWR, daily airline profits were increased $456K for every $1 increase in hedged fuel prices, increased $423K for every incremental increase in the GDP index, reduced $8K for every seat increase in aircraft gauge, and increased $6K for every additional flight per day. This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.

Note that airline profits are affected by the airline's ability to: (1) increase airfares as fast as hedged fuel prices increase, (2) shed less profitable markets in order to improve profitability, and (3) right-size aircraft to maintain profitability as demand changes.

Air Transportation Efficiency: Air transportation efficiency is measured by the throughput of passengers through the network based on aircraft size (i.e. number of seats) per runway/airspace. A linear regression showed that for every incremental increase in the GDP index, there is a 12.5 seat increase in the average aircraft size flown. Also, for every $1 increase in hedged fuel prices, there is a 6.4 seat increase in the average aircraft size flown.

Note: These results are not consistent with the observed historical data. The historical data did not show the up-gauging results from the ASOM model. There are several explanations for this, including: airline competition, fleet inflexibility, and airline pilot union scope clauses.

Implications of Results

The results of the analysis using the ASOM have the following implications:

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

- For a fixed passenger demand and hedged fuel price, as capacity limits are imposed (e.g. -10%), markets are reduced (-5%) and scheduled flights decrease (-8%), profit decreases (-4%). In this scenario average aircraft size increases (1%).

- For a fixed passenger demand and fixed capacity limits at the airports, as hedged fuel prices increase (e.g. +43%), markets are reduced (-3%), scheduled flights per day decrease (-6%), profit increases (+4%). In this scenario average aircraft size increases (+10%). This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.

2. Airport Capacity limits have no negative effects: when regulatory authorities choose to impose capacity limits on runway access in order to reduce congestion, little impact is seen on geographic access, economic access, and airline profits. Aircraft size does not change, but congestion and delays are significantly improved. Note: even in a model that does not take into consideration an airline's likelihood to continue access to markets during economic downturns for strategic (competitive) reasons, little to no change in markets served is observed when capacity restrictions are imposed.

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

For example, for a fixed passenger demand and fixed capacity limits at the airports, as hedged fuel prices increase (e.g. +43%), markets are reduced (-3%), scheduled flights per day decrease (-6%), profit increases (+4%). In this scenario average aircraft size increases (+10%). This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.

3. In the presence of increased passenger demand (and in the absence of cut-throat airline competition) airlines will increase aircraft size. However, the ability to up-gauge in the real-world is restricted by additional factors not modeled: (1) 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 structure for pilots, which is significantly higher for larger aircraft than for regional jets.

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1 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 (+4% annual growth), resulting in unreliable service and systemic delays.

Estimates of the impact of delays and unreliable air transportation service on the economy range from $32.3 B/year (NEXTOR, 2010) to $41B/year (Schumer, 2008).

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

(1) Increasing Infrastructure Capacity,
(2) Increasing Effective-Capacity and Productivity, and
(3) Increasing Runway/Airspace Efficiency by Increasing Seat Capacity per slot.

Increasing Infrastructure Capacity

Several initiatives are underway to increase the capacity of the airports and airspace to handle additional flights. The Airport Improvement Plan (2010) 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 Airports Improvement Program (AIP) is administered by the FAA and funded from the Airport and Airway Trust Fund (A&ATF). The A&ATF is created from user fees (e.g. 7.5% ticket tax) and fuel taxes.

The AIP provides about 18% of the capital funds for improvements that include enhancements of capacity, safety, and other aspects of airport infrastructure. AIP funds are also applied toward projects that "support aircraft operations including runways, taxiways, aprons, noise abatement, land purchase, and safety, emergency or snow removal equipment" (Kirk, 2003; p. 3). To be eligible for AIP funding, airports must be part of the National Plan of Integrated Airport Systems (NPIAS), which imposes requirements on the airport for legal and financial compliance (Wells & Young, 2003; p. 329).

The NPIAS has two goals: To ensure that airports are able to accommodate the growth in travel, and to keep airports up to regulatory standards (FAA, 2008; p. v).

The AIP funds are distributed to passenger, cargo, and general aviation airports, in two categories (Kirk, 2003; pp. 6-7):

1. Formula funds: Formula funds (also known as "apportionments") are apportioned according to formulas based on the volume of throughput (e.g. enplaned passengers) and location. The formulas vary depending on the type of airport.

2. Discretionary funds: Discretionary funds are approved by the FAA and are distributed based on factors such as project priority and congressional mandates. Although it is not the sole determinant factor, project selections are based on a project's score in the National Priority Rating (NPR) equation, which assigns projects a rating from 0 to 100 (high or 100% aligned with agency goals) (Federal Aviation Administration, 2000; p. 5). Projects with safety and security purposes receive higher ratings than those focused on capacity (Dillingham, 2000; p. 32).

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.

The impact that these initiatives will have on system-wide bottlenecks at the most capacitated airports is limited due to the lack of additional real-estate to accommodate needed infrastructure.

Increasing Effective-Capacity and Productivity

Modernization of U.S. Air Traffic Control (ATC), known as NextGen, is a $37B program. NextGen will improve productivity and the utilization of existing airspace yielding increases in the effective-capacity of the airspace and airports. Improvements in flow management, airborne re-routing, 4-D coordination of flights, and super-dense operations will increase the number of flights that can be handled during peak-periods.

NextGen is an umbrella term for the ongoing, wide-ranging transformation of the National Airspace System (NAS). At its most basic level, NextGen represents an evolution from a ground-based system of air traffic control to a satellite-based system of air traffic management. This evolution is vital to meeting future demand, and to avoiding gridlock in the sky and at the nation's airports (Federal Aviation Administration, 2010; p. 4).

NextGen will realize these goals through the development of aviation-specific applications for existing, widely-used technologies, such as the Global Positioning System (GPS) and technological innovation in areas such as weather forecasting, data networking and digital communications. Hand in hand with state-of-the-art technology will be new procedures, including the shift of certain decision-making responsibility from the ground to the cockpit.

When fully implemented, NextGen will allow more aircraft to safely fly closer together on more direct routes, reducing delays and providing unprecedented benefits for the environment and the economy through reductions in carbon emissions, fuel consumption and noise.

FAA estimates show that by 2018, NextGen will reduce total flight delays by about 21 percent while providing $22 billion in cumulative benefits to the traveling public, aircraft operators and the FAA. In the process, more than 1.4 billion gallons of fuel will be saved during this period, cutting carbon dioxide emissions by nearly 14 million tons. These estimates assume that flight operations will increase 19 percent at 35 major U.S. airports between 2009 and 2018, as projected in the FAA's 2009 traffic forecast.

Estimates 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% growth rate in demand.

Increasing Runway/Airspace Efficiency by Increasing Seat Capacity per slot

This approach incentivizes airlines to increase the size of aircraft to transport more passengers per runway/airspace slots. To create these incentives the government or port authority: (i) regulates the number of runway slots and gates available to match the available supply, (ii) allocates the available slots through some combination of administrative (e.g. grandfathering) and market-based mechanisms (e.g. congestion pricing, auctions). The allocation of slots must be accomplished in a way that ensures the most efficient economic and socio-political use of the slots, and avoids monopolies by guaranteeing competition.

Problem Statement

Currently there is not enough emphasis is being placed on improved utilization of the air transportation system through increased aircraft size.

The idea of improved utilization of runway/airspace capacity through increased aircraft size is mired in uncertainty about the impacts on the stakeholders and unintended consequences.

In 2008, the concept of market-based methods gained some traction at the congested New York airports. The Departments of Transportation (DOT) proposed a rule to limit the number of arrivals and departures at the New York airports and to allocate some of the slots via an auction (Federal Registry volume 73, pages 60544-60601).

The rule was designed to establish procedures to address congestion in the New York City area by assigning slots at airports in a way that allows carriers to respond to market forces to drive efficient airline behavior. Specifically the rule:

- extended the capacity limit on the operations at the three airports
- assigned the majority of slots at the airports to existing operators,
- develops a robust secondary market by annually auctioning off a limited number of slots in each of the first five years of this rule.

Auction proceeds would remain within the aviation industry and be used to mitigate aviation congestion and delay in the New York City area. The rule also contained provisions for minimum usage, capping unscheduled operations, and withdrawal for operational need. The rule had a ten year period at which time it would sunset. This rule was due to go into effect October 2009, but was rescinded in May 2009 (Federal Registry volume 74, page 22714) for JFK and EWR and in October 2009 (Federal Registry volume 74, pages 52132) for LGA.

The rule introduced the notion of market-based allocation of slots by proposing that the FAA auction 10% of slots at EWR and JFK and 15% of the slots at LGA above the 20-slot baseline annually for the first 5 years of the rule. As a result, 96 of the total 1,219 slots at the airport would be auctioned over the 10-year span of the proposal; between 91 and 179 slots out of 1,245 total slots at JFK would be affected.

Three categories of slots were proposed: Common Slots, Limited Slots and Unrestricted Slots. Most would be Common Slots, which would be leased for ten years and revert to FAA when the rule sunsets. Carriers would have property rights to Common Slots, allowing the slots to be collateralized or subleased to another carrier for consideration, but Common Slots would revert to FAA under the rule's minimum usage provision and could be withdrawn for operational reasons. Limited Slots would consist only of slots operated on a daily, year-round basis, and leases for Limited Slots would also be assigned by cooperative agreements between the FAA and carriers. However, during each of the first 5 years of the rule, a percentage of Limited Slots would be made available by auction, at which point they would be converted to Unrestricted Slots, which are slots leased directly from FAA under the auction process.

Five official protests were filed on August 14, 2008 by airline carriers. On the same date, a protest also was filed by the Air Transport Association. Two additional protests were filed by the Port Authority of New York and New Jersey on August 28, 2008 and another by the New York Aviation Management Association (NYAMA) on August 29, 2008. The NYAMA protest was dismissed as the organization is not considered a legitimate stakeholder.

The protests presented legal arguments contending that the FAA lacks legal authority to conduct the slot auction. According to the protesters, the slots are not actual "property," and as such, cannot be subject to a lease. According to the protests, the auction transaction involves not a lease, but rather the sale of a license by the FAA to a carrier to use a designated flight departure and/or flight landing time. Arguing that only a license-rather than a tangible property interest-is involved, the protests maintain that the FAA's Property Management Authority does not permit this Auction effort. The protests also contend that the slot auction is not authorized under the FAA's "Airspace Management Authority," which is frequently cited as providing the Administrator's management authority over the United States' navigable airspace (FAA 2008; pg 5.).

Behind the official protests was an uncertainty on the impact of capacity limits and market-based allocation schemes would have on the economies of the regions and the finances of the associated enterprises. There were 4 main objections.

1. Geographic access to air transportation service would be eliminated at some (i.e. smaller) markets
2. Economic access to air transportation service would be reduced to segments of the population. Increased operational costs would lead to increased airfares, to the point where segments of the population could no longer afford to fly
3. Negative financial impact to airlines through additional costs of operation
4. Failure to improve congestion and reliability for direct service as well as the impact on overall National Airspace System (NAS) operations.

In the end, the incumbent airlines reluctantly agreed to setting capacity limits at the three New York airports, after sharp debates about how those capacity limits should be set and about how the limited capacity would be allocated. Capacity limits at JFK were set at 81 per hour (1/18/2008), and at EWR were set at 81 per hour (5/21/2008). The capacity limits at LGA were decreased from 75/hour + 6 unscheduled to 71/hour + 3 unscheduled (1/15/2009). No equivalent capacity restrictions were placed on other congested airports with similar congestion during peak operations (e.g. Philadelphia, Atlanta). The proposal to auction slots was withdrawn.

Objective of this Research

The objective of this research is to inform the policy and, research and technology, decision-makers on the concept of better utilization of seat capacity per runway-slot. Specifically, this research answers the following questions for each stakeholder in Table 1.

Stakeholder	Question
Congress, Department of Transportation, Department of Commerce, and Department of Justice as advocates for consumers and the U.S. economy	What happens to geographic access to air transportation service by introduction of capacity limits at certain highly-congested airports? With or without additional operations costs (runway access costs), would these changes result in an elimination of service at smaller markets?
Congress, Department of Transportation, Department of Commerce, and Department of Justice as advocates for consumers and the U.S. economy	Economic access to air transportation service as a result of increased operational costs. Would this in turn lead to increases in airfares to the point where a segment of the population could no longer afford to fly?
Airlines	What is the financial impact to airlines when airlines incur additional operational costs of operation because of additional fees, costs of airport usage, or fuel prices?
Congress, Department of Transportation, Department of Commerce, Department of Justice as advocates for consumers and the U.S. economy, Airlines	What is the impact on congestion and reliability of air service

Table 1 Research Questions for each of the Stakeholders

Research Approach

The Airline Schedule Optimization Model (ASOM) was developed to answer questions about how airline operating costs, economic conditions and an airlines' access to an airport impact geographic access, economic access, airline finances and congestion and reliability of service.

Two experiments were conducted with the ASOM to determine the impact of airport capacity limits and the impact of changes in fuel prices. The first experiment examined airline strategic decision-making in response to the introduction of airport capacity limits for three fixed passenger demand and operating costs scenarios (i.e. a given period of time that was described economically by a Gross Domestic Product measure and a Hedged Fuel Price cost). The design of the experiment, summarized in the table below, included 45 possible treatments (5 airports X 3 capacity levels X 3 demand and operating cost changes). The second experiment examined the effect of fluctuations in fuel prices, passenger demand, and capacity limits.

The first experiment is summarized in the factorial design in Table 2. The design of the experiment included 45 possible treatments (5 airports X 3 capacity levels X 3 demand and operating cost conditions.

In this experiment airline behavior is evaluated for three airport capacity levels (high, normal, and low) for five congested airports (LGA, SFO, EWR, JFK, PHL) for three different economic scenarios:

- Third quarter 2007 (3QTR07) with $2 fuel prices and 105 GDP index;
- Third quarter 2008 (3QTR08) with $3.50 fuel prices and 105 GDP index;
- Third quarter 2009 (3QTR09) with $2 fuel prices and 103 GDP index).

The results provide insights on airline behavior in response to capacity changes for different economic scenarios.

		3QTR 2007					3QTR 2008					3QTR 2009				
Airports		LGA	SFO	EWR	JFK	PHL	LGA	SFO	EWR	JFK	PHL	LGA	SFO	EWR	JFK	PHL
Hedged Fuel Prices ($/Gallon)		$2.08					$3.53					$1.92				
Gross Domestic Product (GDP Quantity Index, 2005=100)		104.9					105.3					102.8				
Capacity Limits (Operations/ hour)	Low	64	64	72	72	72	64	64	72	72	72	64	64	72	72	72
	Normal	72	72	80	80	80	72	72	80	80	80	72	72	80	80	80
	High	80	80	96	96	96	80	80	96	96	96	80	80	96	96	96

Table 2 "Design of Experiment" for ASOM experiment #1. This experiment represents 45 of 45 possible treatments.

The second experiment is summarized in the factorial design in Table 3. The design of the experiment included 24 possible treatments (1 airports X 3 capacity levels X 4 hedged fuel prices X 2 Gross Domestic Product). This experiment examines airline behavior for three airport capacity levels (high, normal, and low) and four fuel price levels ($2, $3.5, $5, $8) for one congested airport (EWR) for two different economic scenarios:

- 3QTR07 with $2 fuel prices and 105 GDP index
- 3QTR09 with $2 fuel prices and 103 GDP index

The results provide insights on airline behavior in response to capacity changes and fuel price changes for different economic scenarios.

<table>
<tr><td></td><td></td><td colspan="3">3QTR 2007</td><td colspan="3">3QTR 2009</td></tr>
<tr><td>Airports</td><td></td><td colspan="3">EWR</td><td colspan="3">EWR</td></tr>
<tr><td>Hedged Fuel Prices ($/Gallon)</td><td></td><td>$2</td><td>$3.5</td><td>$5</td><td>$2</td><td>$3.5</td><td>$5</td></tr>
<tr><td>Gross Domestic Product (GDP Quantity Index, 2005=100)</td><td></td><td colspan="3">104.9</td><td colspan="3">102.8</td></tr>
<tr><td rowspan="3">Capacity Limits (Operations/ hour)</td><td>Low</td><td>72</td><td>72</td><td>72</td><td>72</td><td>72</td><td>72</td></tr>
<tr><td>Normal</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td><td>80</td></tr>
<tr><td>High</td><td>96</td><td>96</td><td>96</td><td>96</td><td>96</td><td>96</td></tr>
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Table 3 "Design of Experiment" for Hedged Fuel Price and Capacity Limit experiment. Experiment #2 represents 18 of 18 possible treatments.

It should be noted that, although these experiments include analysis of hedged fuel prices of $5/gallon and $8/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 would undergo significant changes that have not been experienced (or modeled). See Appendix B for a full discussion.

Benefits of This Research

Multiple stakeholders for the US air transportation system can benefit from modeling and understanding airline behavior in the presence of economic, regulatory, & technological changes.

Government policy-makers will be provided a quantitative analysis of impact of changes to airline scheduling and pricing behavior from changes in economic conditions like Gross Domestic Product and fuel prices. The government policy-maker will also be provided insight into how airline scheduling and pricing behavior changes with changes in airport capacity limits or with additional fees. This model built on 5 years analysis of historical data will provide the ability to forecast expected airline scheduling and pricing behavior for non-historical economic and regulatory scenarios.

Research Managers (e.g. NASA) will be provided insights into impacts of improved technologies (e.g. aircraft fuel efficiency). And understand technology's role in increasing NAS capacity through providing airlines the economic incentives to up-gauge. This research will complement the NextGen research, since 49 of 131 NextGen OI's involved upgrade in aircraft capabilities (Sherry, 2007). Airline up-gauging increases effective-capacity to the system just like the NextGen initiatives do through improvements in air traffic flow management, reduced airline separation and more efficient use of current TRACON airspaces.

2 Functional Model of Airline Strategic Decision-making

Airlines are continuously adjusting their operations in the presence of economic, regulatory, & technological changes. Figure 1 provides an abstracted summary of the system under investigation. Demographics, social-values, and the economic benefits of rapid, affordable transportation afforded by airlines determine the demand for airline operations. Regulatory changes incentivize and curtail operations. Technological changes increase productivity and the range and performance of the air transportation service.

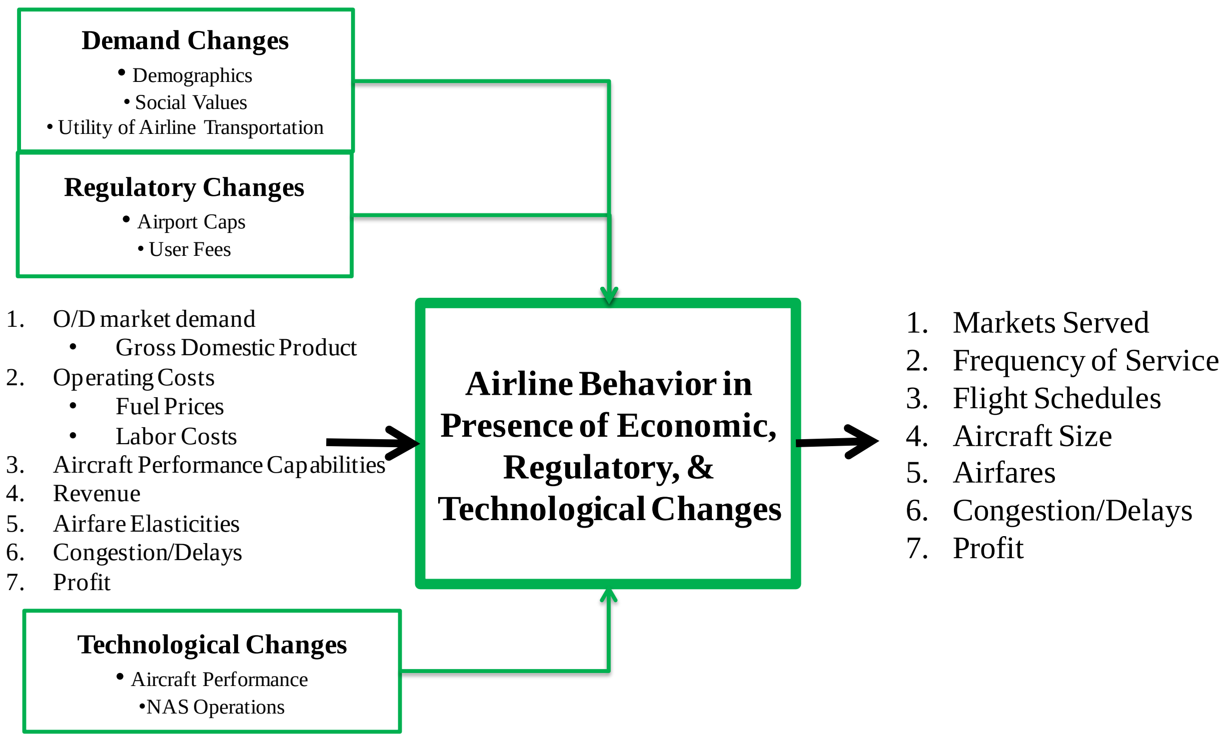

Figure 1 Airline behavior in the presence of demand, regulatory, and technological changes

Airlines make the following choices:

- Markets Served
- Frequency of Service
- Flight Schedules
- Aircraft Size
- Airfares
- Congestion and Delays (indirectly)
- Profit

These decisions are made in the presence of:

- National Gross Domestic Product and fuel prices
- Airport capacity limits
- Aircraft Performance Capabilities and Operating Costs (Fuel, Labor, Maint, etc)
- Origin and Destination market demand, revenue, airfare vs demand elasticicities

Figure 2 shows a functional representation of airline business planning, scheduling, and operational functions and decisions. The diamonds in the figure represent strategic decisions. The arrows show the functions and decision impacted by strategic decisions.

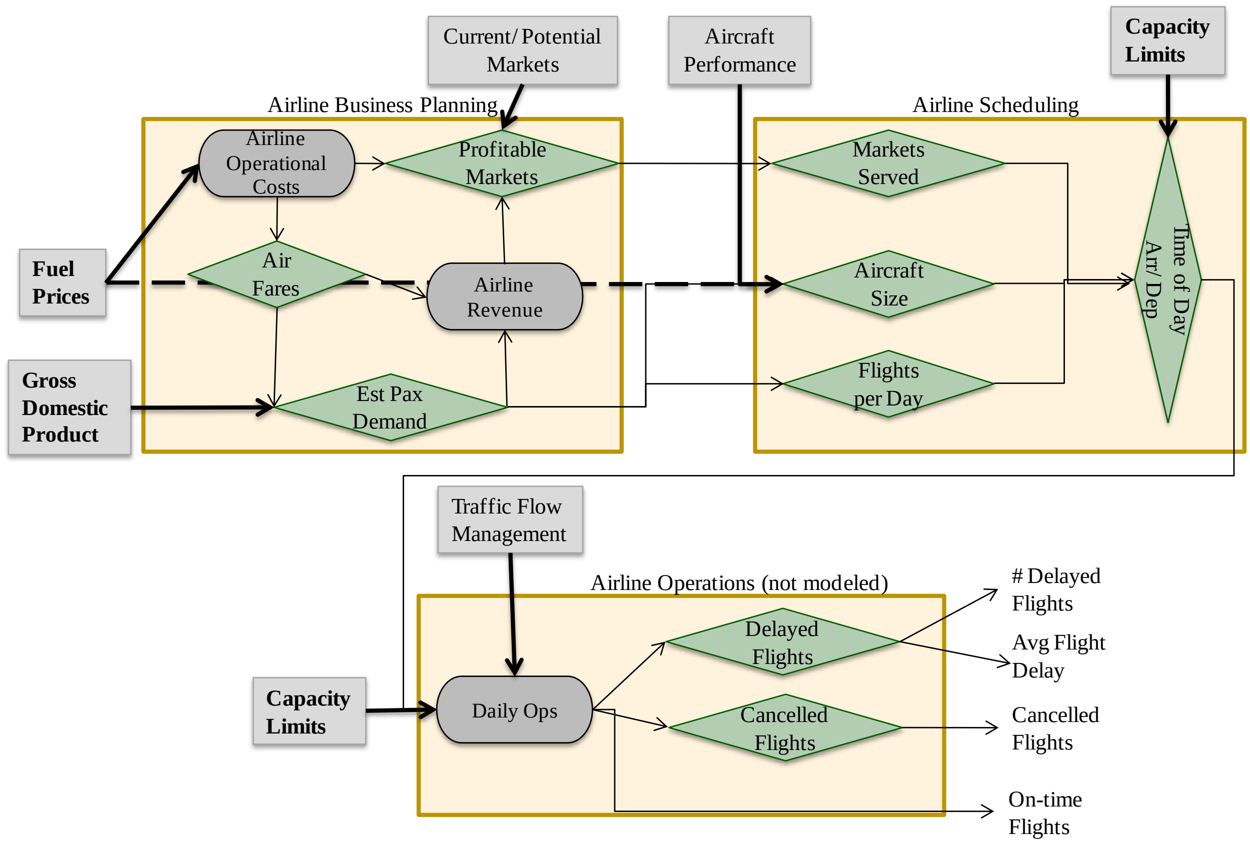

Figure 2 Airline decision-making: Business Planning, Scheduling, and Operations

The Airline Business Planning function sets airfares based on expected operational costs and estimated demand. Increases in fuel prices affect airlines in their operational costs, thus the airlines absorb additional operational costs by trying to increase revenue through increased airfares.

Since demand is related to airfare based upon market price elasticity curves by passenger type, the airlines typically cannot recover all additional costs through their fares.

As the figure shows there is a two way relationship between airfare and the airlines' estimated market demand. Demand is also influenced by the national Gross Domestic Product. When the economy is good, potential travelers have more disposable income to buy airline tickets.

After the airlines determine the price elasticity and potential demand for the markets, the potential revenue and costs can be examined to determine the profitable markets that can be served.

With profitable markets identified, passenger-demand forecasts for these markets coupled with the associated operational costs will determine the frequency of service to the market as well as the aircraft gauge. The best aircraft available from inventory is selected to meet passenger demand based upon individual aircraft performance and fuel prices.

The number of flights per day is determined by the estimated passenger demand and type of passenger demand. Business travelers require more frequent service and are willing to pay for that frequency, while leisure passengers will not pay for the more frequent service.

Next in this scheduling process, the times for these flights need to be scheduled based upon historic patterns in passenger demand, available operating slots (15 min period) at the airport and airport capacity limits. Once these decisions on aircraft type and number of flights per day by time of day are resolved, the schedule will reflect all of the markets that will be served. This schedule and its associated prices are announced three to four months prior to service and prices are then altered during the period to account for changes in demand and competition.

3 Method

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

3.1 Airport Schedule Optimization Model (ASOM)

The ASOM is a multi-commodity flow model that optimizes the schedule of aircraft serving an airport while satisfying market demand. The ASOM, based on an earlier model (Le & Hoffman, 2007) 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 generates a schedule for a single airline that provides service to all of the eligible markets to maximize the profit generated by scheduled operations while meeting the demand. The parameters of the model associated with profit are set such that the "benevolent" single airline: (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.

3.1.1 ASOM Overview

The ASOM is summarized in Figure 3. 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 list of airports that have historically been served by the target airport along with scheduled flight times and aircraft types
(3) Flights per Day. Daily flights by market represented by sum of quarterly arrivals and departures by market.
(4) International Passenger demand for each time of day. The total passengers traveling on domestic segments originate or terminate their domestic travel at one of the airports examined in order to connect to or from an international flight segment.
(5) Market Load Factors
(6) Aircraft costs. The aircraft is grouped into aircraft fleet classes to determine average segment flight times, average fuel burn rates and average costs per flight hour by aircraft class.
(7) Market demand vs Revenue curves. Demand versus revenue positions or options for each 15 min time of the day and for the morning (12am-12pm), afternoon (12pm-5pm) and evening (5pm-12am) time periods.

The output of the model is a profitable, feasible schedule defined by the following:

(1) Number of markets served
(2) Schedule for service to each market defined by Frequency and Time of Day
(3) Aircraft Size on each scheduled flight
(4) Airline 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, for each market, 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, this process is called Column Generation.

The Master-problem then determines an optimal airport schedule by selecting market schedules that maximize profit for the benevolent airline 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 having flights added/removed from that time period. This provides the information back to the sub-problem that will determine if it pays to keep the flights at their current times or move them because there is “cheaper” capacity at an alternative time.

This process continues until the profit objective function does not improve or there are no new schedules generated.

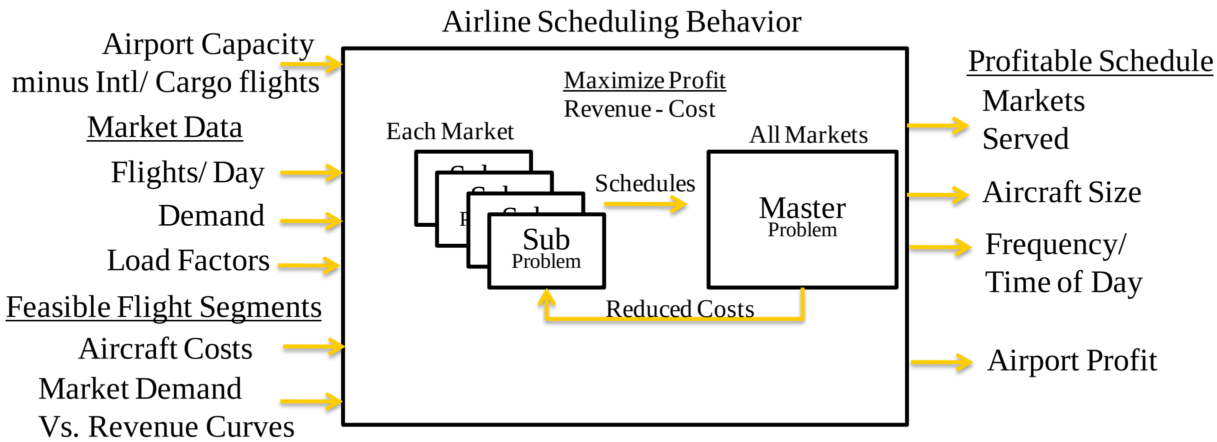

Figure 3 Airport Schedule Optimization Model (ASOM)

3.1.2 ASOM Scope and Assumptions

The ASOM generates profitable schedules for non-stop daily domestic markets. The schedules allow only one flight per 15 min to or from each market. The domestic markets are not static but compete for the airport’s capacity.

Aircraft that have historically been used for domestic flights are grouped into fleet classes at increments of 25 seats. For example, aircraft between 88 seats and 112 seats would be in the 100 seat fleet class as shown in Table 4. As this table shows 92.14% of the passengers flown and 81.53% of the departures were performed on seven fleet classes for aircraft between 13 and 187 seats. Since the ASOM selects only aircraft for each market’s schedule based on aircraft historically flown to each market, the model will be for the most part choosing between these seven fleet classes to determine the most profitable aircraft class to meet the demand.

Fleet Class	# of Aircraft types	seat range	% Departures	% Passengers
0	42	<13	5.27%	0.24%
25	17	13 - 37	16.86%	3.15%
50	6	38 - 62	41.65%	15.80%
75	11	63 - 87	50.24%	22.35%
100	4	88 - 112	51.89%	24.07%
125	9	113 - 137	76.48%	56.88%
150	6	138 - 162	92.62%	83.12%
175	4	163 - 187	98.40%	95.30%
200		188 - 212	98.40%	95.30%
225	1	213 - 237	98.79%	96.36%
250	1	238 - 262	99.53%	98.50%
275	10	263 - 287	99.96%	99.87%
300	2	288 - 312	99.97%	99.91%
325		313 - 337	99.97%	99.91%
350	1	338 - 362	99.97%	99.91%
375	1	363 - 387	100.00%	100.00%
400	1	388 - 412	100.00%	100.00%
425		413 - 437	100.00%	100.00%
450	1	438 - 462	100.00%	100.00%

Table 4 Summary of seat-capacity grouping of aircraft historically used for domestic operations

Flight demand is not captured at the 15 min level of fidelity, market demand by time of day is assumed to be proportionally equal to supply (seats) by time of day. The aircraft selected in the schedule is assumed to have a load factor of 80% or better. The airline will need to obtain sufficient revenue to have the flight profitable at an 80% load factor, or the optimization will choose a smaller aircraft size or move the flight to an alternative time period. The model allows demand to spill into different time slots, but restricts demand from moving between morning, afternoon, or evening time periods. This is done by nesting demand into 3 periods (12am-12pm, 12pm-5pm and 5pm-12am) to ensure the sum of the 15 minutes demand does not exceed the demand from the period.

The ASOM assumes that the price/demand data provided in the BTS DB1B database is representative and is a good model of the price sensitivity that exists in that market.

When such an airline is “benevolent” it posts prices that are consistent with current competitive prices (i.e. it does not seek monopolistic rents) and attempts to serve as many markets as it can, while remaining profitable. The quarterly passenger demand versus airfare relationship is assumed consistent for all days and times of day.

The ASOM builds the network of potential flights based on arrivals from the cluster airport to the direct non-stop market airport. The ASOM then assumes a 45 minute turnaround time for all fleets before a departure is allowed back to the cluster airport.

Since the databases used do not include all airlines, the ASOM assumes that the data from reporting carriers is representative of behavior from all carriers.

3.2 Data Sources

This sub-section summarizes the databases that were used as sources for input data for the ASOM.

The **Airline Origin and Destination Survey (DB1B)** is a 10% sample of airline tickets from reporting carriers collected by the Office of Airline Information of the Bureau of Transportation Statistics. Data includes origin, destination and other itinerary details of passengers transported. This database is used to determine air traffic patterns, air carrier market shares and passenger flows. The Survey is collected primarily on the basis of a stratified, scientific sample of 10 percent of tickets in all domestic and in all international city-pair markets. The Survey data are taken from the selected flight coupons of the tickets sampled: single-coupon or double-coupon round trips where the ticket serial number ends in zero (0).

The **T-100 Domestic Segment** database contains domestic non-stop segment data reported by U.S. air carriers, including carrier, origin, destination, aircraft type and service class for transported passengers, freight and mail, available capacity, scheduled departures, departures performed, aircraft hours, and load factor when both origin and destination airports are located within the boundaries of the United States and its territories.

The **schedule P-52** database contains detailed quarterly aircraft operating expenses for large certificated U.S. air carriers. It includes information such as flying expenses (including payroll expenses and fuel costs), direct expenses for maintenance of flight equipment, equipment depreciation costs, and total operating expenses.

The **Aviation System Performance Metrics (ASPM)** is an integrated database of air traffic operations, airline schedules, operations and delays, weather information, runway information, and related statistics. The ASPM data comes from ARINC's Out-Off-On-In (OOOI), Enhanced Traffic Management System (ETMS), US Department of Transportation's Aviation Airline Service Quality Performance (ASQP) system, weather data, airport arrival and departure rates (15-interval), airport runway configurations, and flight cancellations.

The Aviation System Performance Metrics (ASPM) online access system provides detailed data on Instrument Flight Rules (IFR) flights to and from the ASPM airports (currently there are 77 ASPM airports); and all flights by the ASPM carriers (currently 22 carriers), including flights by those carriers to international and domestic non-ASPM airports. ASPM also includes airport weather, runway configuration, and arrival and departure rates. This combination of data provides a robust picture of air traffic activity for these airports and air carriers. Preliminary next-day ASPM data is used by the FAA for close monitoring of airport efficiency and other aspects of system performance, and finalized ASPM data is invaluable for retrospective trend analysis and targeted studies.

The ASPM database is compiled piece by piece beginning with basic flight plan and other message data for flights captured by the Enhanced Traffic Management System (ETMS), enhanced with next-day OOOI data for a key set of airlines, updated with published schedule data, and further updated and enhanced with BTS Aviation System Quality and Performance (ASQP) records which include OOOI data, final schedule data, and carrier-reported delay causes for the largest U.S. carriers.

ASPM flight records fall into two groupings: Efficiency counts and Metrics counts. ASPM Efficiency counts include the full set of ASPM records, including those that are missing one or more pieces of key data. In contrast, ASPM Metrics counts only include complete records and records for which accurate estimates are possible for the few pieces of missing data. Metrics counts exclude most General Aviation and Military flights, as well as records for international flights that only include data associated with the arrival or departure to/from the U.S. airport. Flight cancellations and diversions are excluded from both Efficiency and Metrics Counts. The purpose of these two groupings is to allow for a more complete traffic count (Efficiency Counts) while ensuring that only records with fully specified flight information are used for calculating delay and other metrics.

The **Center for Air Transportation Systems Research (CATSR)** Databases contains airport time zone data needed to develop feasible flight segments and aircraft seat configuration data required to assign aircraft to different aircraft classes.

The ASOM input data is preprocessed from several databases as shown in Figure 4. The inputs for the model are preprocessed (1 in figure) 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 airport and aircraft data databases.

Once preprocessed, the inputs are placed in an access database for the model to read, and then the ASOM is run (2).

The outputs are then post-processed (3) to examine trends in markets served, flights per day, average aircraft gauge, and airline profit expected with this schedule.

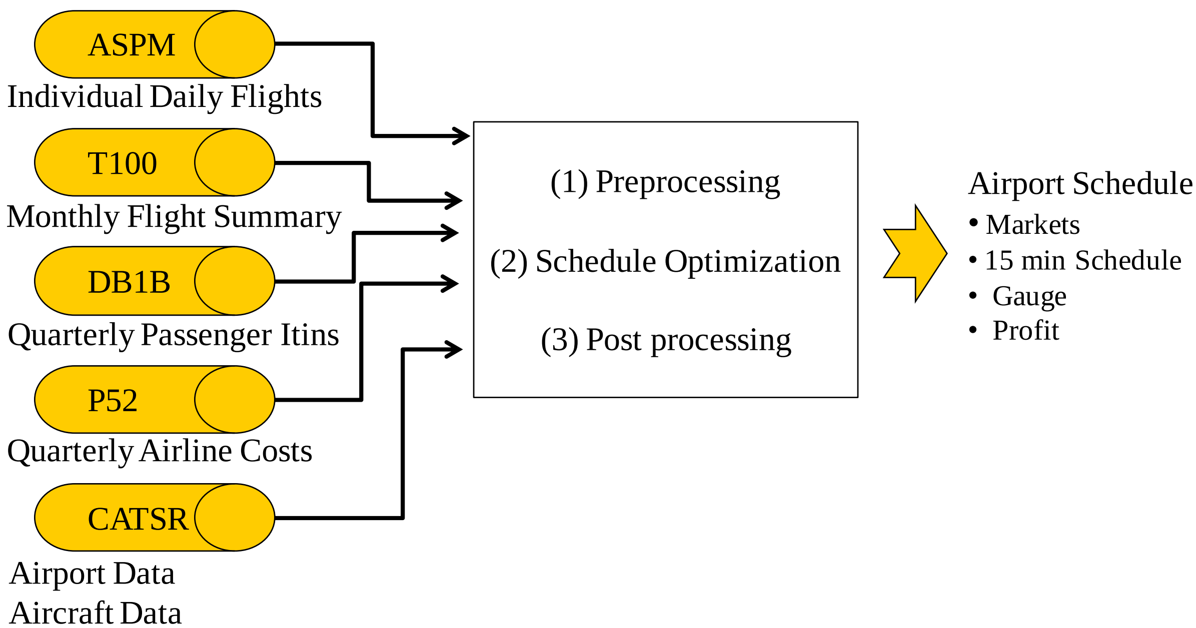

Figure 4 ASOM inputs are preprocessed from 5 primary data sources

The BTS and ASPM data was preprocessed for New York, San Francisco and Philadelphia airports for the following timeframes:

- Air Carrier Financial (Schedule P-52): 1QTR07-3QTR09
- Origin and Destination Survey (DB1BMarket): 1QTR07-3QTR09
- Air Carriers (T-100 Segment): Jan 07 – Dec 09
- Aviation System Performance Metrics (ASPM): Jan 07 – Dec 09

3.2.1 ASOM Preprocessing

The inputs for the ASOM are; (1) International and Domestic Market Demand, (2) Market flights per day, (3) Market load factors, (4) Airport Capacity minus International and Cargo flights, (5) Feasible flight segments, (6) Market Demand versus Revenue Curves, and (7) segment costs by aircraft class.

Figure 5 shows how all of these inputs are preprocessed from the DB1B, T100, ASPM, CATSR and P52 databases. The ASOM control for adjusting airfares for fuel price increases and for airline additional fees is performed during preprocessing. The ASOM control for adjusting segment costs by aircraft class for fuel price changes and for landing fee adjustments is performed during preprocessing. These controls are highlighted in green on Figure 5.

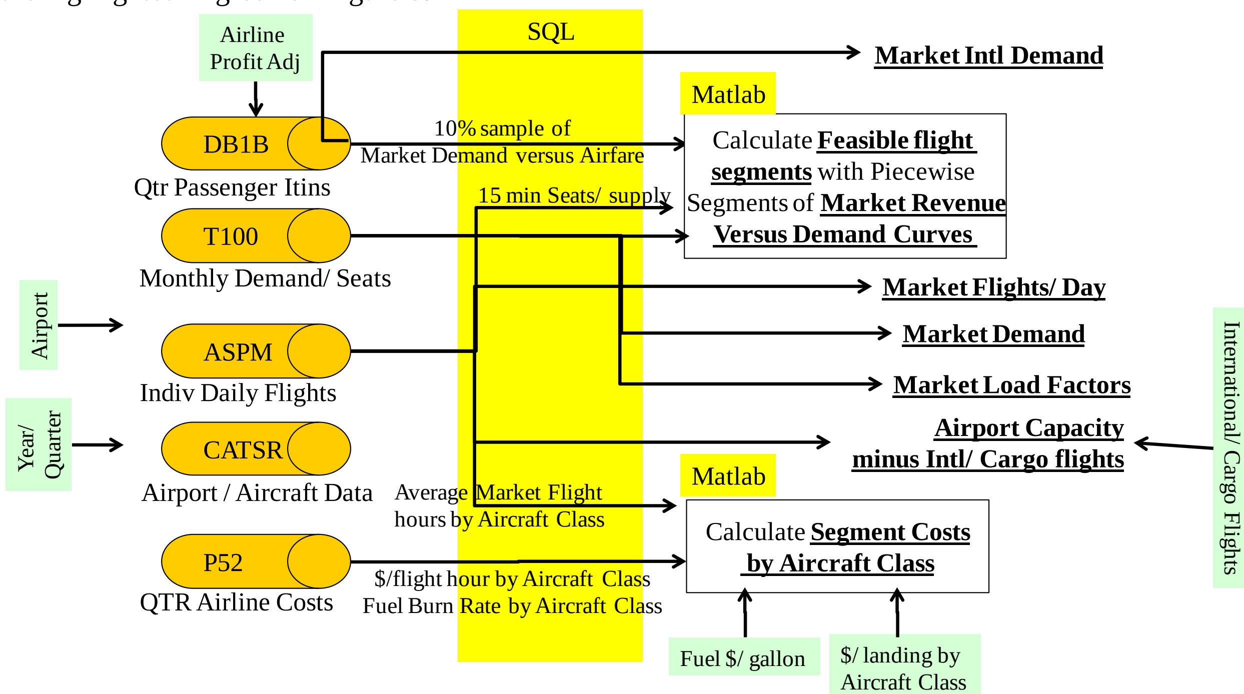

Figure 5 ASOM Inputs are calculated through SQL and Matlab scripts (in Yellow). Several ASOM controls are adjusted in the preprocessing of the inputs (in Green).

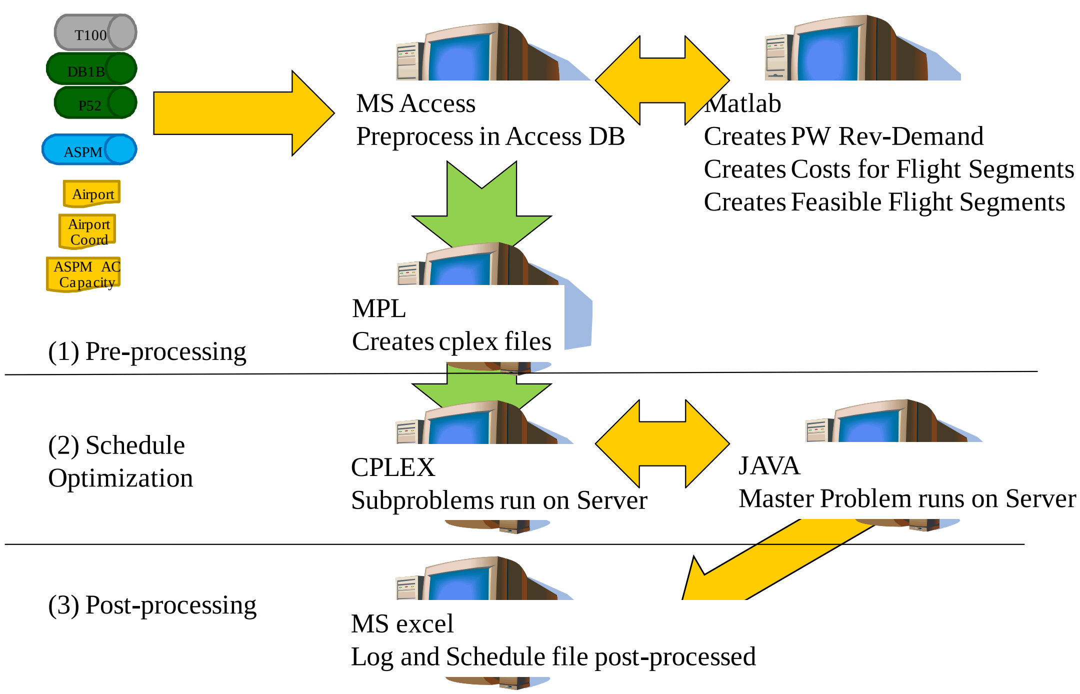

Figure 6 The ASOM model is run through on several software packages in order to preprocess, optimize and evaluate results.

The ASOM model requires several systems and software to pre-process the data, to run the schedule optimization and finally to post-process the output from the model, as shown in Figure 6.

One of the complexities in combining the data into a format usable for the optimization model is the fact that the lack of fidelity in most of these data sources require assumptions to made in order to fill these data holes. The red blocks in Table 5 highlight the data holes that need to be filled.

	QTR	Month	Daily	15 min	Aircraft	Market	Source
Seats	Avg Seats * # Flights = Seat Supply				X		CATSR
Flights	X	X	X	X	X	X	ASPM
Demand	X	X	Demand ~ Seats		X	X	T100
Demand	X	Extrapolated to T100 demand				X	DB1B
Revenue	X	PW Revenue vs Demand ~ Seats				X	DB1B
Cost	X	Avg $/hr *Block hrs = segment $/market/aircraft			X		P52
Block Hrs	X	X	X	X	X	X	ASPM
Load Factors	X	X	Avg LFs used		X	X	T100
Intl Flights	X	X	X	X	X	X	ASPM
Intl Demand	X	For Intl Flights				X	DB1B

= Data Hole (red)

Table 5 The ASOM preprocessing fills data holes from the lack of fidelity in available data sources (in Red).

Airport Capacity minus International and Cargo flights is preprocessed from the ASPM database by summing the quarterly international and cargo arrivals and departures for every 15 minutes of the day. This data is then normalized to represent daily international and cargo arrivals and departures for every 15 minutes of the day. The master problem uses this data to adjust daily 15 min capacity available for domestic flights.

Many Cargo flights at an airport are typically flown at night and early morning hours and do not compete for the same flight hours as the passenger flights. For those cargo flights that do compete for runway capacity with passenger flights, the runway capacity is adjusted to allow all such cargo flights to remain as scheduled. Therefore, the profitable domestic markets compete for the available capacity that remains after international and cargo flights are removed.

The model described is adjusted to account for the effects of international flights and domestic passengers connecting to and from international flights on domestic schedules. The ASOM models only domestic markets because international markets are controlled by treaty, are very profitable, and their departure and arrival times cannot be changed. Thus, all flights to international markets are assumed to remain. To assure that there is sufficient runway capacity for these flights, the capacity for each time period is reduced by the number of international and cargo flights that will be departing and/or landing in that time period.

International Market Demand is preprocessed from the restricted DB1B database by summing the total passengers traveling on domestic segments originating or terminating their domestic travel at one of the airports examined in order to connect to or from an international flight segment. This quarterly demand is then normalized to a daily international demand for all of the domestic markets connecting passengers to international markets. The international arrival and departure banks are determined in ASPM to assure that passengers arrive at the airport in sufficient time to connect. Thus, for example, for international flights departing at 5pm, domestic passengers have to arrive at the departing airport by 4pm.

Domestic Market Demand is preprocessed from the T100 database by summing the quarterly demand by market. This is also an input to Matlab to determine the market demand versus revenue curves.

Market flights per day are preprocessed from the ASPM database by summing the quarterly arrivals and departures by market. These quarterly flights are then normalized to represent daily flights by market.

Market load factors are preprocessed from the T100 database by summing the quarterly demand and seats by market. This quarterly demand is then divided by the quarterly amount of seats flown to provide the ASOM load factors for markets flown.

The **feasible flight segments** are calculated in Matlab by providing airport markets from the T100 database, airport time zone differentials and aircraft seat sizes from the CATSR database and average flight times by aircraft fleet class from the ASPM database. The aircraft are grouped into aircraft fleet classes to determine average segment flight times and feasible aircraft for different markets as an input to Matlab's calculations. The aircraft is assumed to have a 45 min turn around. So based on this information all feasible market and reverse market flight segments are provided to the ASOM.

Matlab creates all possible departure and arrival pairs to the markets from the airport being modeled. This includes factoring the turn-around time for these aircraft before they can fly back to the original airport. The average block hours for the different markets for all different aircraft which have flown these markets are derived from the ASPM database. Given these average block hours by aircraft class for all the markets, Matlab can identify all potential departures and arrivals that can operate at the airport modeled between 6am and 10pm.

These feasible flight segments are determined by using Microsoft Access for the non-stop segments of the airport or metroplex being analyzed. This enables the scheduling model to determine optimal schedules from feasible roundtrip flights, to ensure the balance of flow of the different aircraft types and produce a typical daily schedule.

Market Demand versus Revenue Curves are calculated in Matlab by providing airport quarterly market demand from the T100 database, Market demand by segment fare from the DB1B database, and seats flown by time of day at 15 minute intervals from the ASPM database. Matlab provides the ASOM piecewise segments from market demand versus revenue curves by time of day at 15 minute intervals and for morning (12am-12pm), afternoon (12pm-5pm) and evening (5pm-12am). This enables the ASOM to nest demand into these three periods (12am-12pm, 12pm-5pm and 5pm-12am) to ensure the sum of the 15 minutes demand does not exceed the demand for the entire period.

Before this data is provided to Matlab DB1B airfares are adjusted to eliminate discount fares and to reflect extra airline revenue from bags and change fees, to reflect itinerary taxes and charges which don't go to the airlines, and to provide revenue offsets for fuel price changes.

In order to develop these market demand versus revenue curves per flight segment the quarterly demand from the DB1B and the monthly demand from the T100 have to be allocated for an average daily schedule for each 15 min time of the day. In order to do this passenger demand is assumed to be distributed by time of day proportional to seats flown. The 10% sample of quarterly demand from the DB1B quarterly demand (3 months worth of data) is extrapolated to the T100 level of demand, then the demand is divided by the number of days in the quarter to get the average daily demand and is multiplied by the percentage of quarterly seats flown in each 15 min period to get the average passenger demand for each 15 min period of the day for each market.

From the DB1B data cumulative demand versus airfare curves are approximated for each market. Finally piecewise linear segments are created to represent different demand versus revenue positions or options for the optimization model to choose from for each 15 min time of the day and for the morning (12am-12pm), afternoon (12pm-5pm) and evening (5pm-12am) time periods.

The **segment costs by aircraft class** are calculated in Matlab by providing airport quarterly cost data from the P52 database, aircraft seat sizes from the CATSR database and segment flight times by aircraft type from the ASPM database. The aircraft is grouped into aircraft fleet classes to determine average segment flight times, average fuel burn rates and average costs per flight hour by aircraft class.

In order to create the feasible flight arc with associated airline costs to fly these arcs, cost factors are developed for aircraft by 25 seat classes (thus aggregating over one hundred different aircraft types into less than 15 general classes of aircraft). All of the flight legs previously determined are costed out for any aircraft class which has serviced the market in the past 5 years. This is done by multiplying the block hours by the cost per hour for direct (minus fuel) costs from the P52 database to operate the specific class of aircraft. Fuel costs are determined by multiplying the selected fuel price times the aircraft classes fuel burn per hour and then multiplying by the block hours for each market aircraft combination.

3.2.2 ASOM Control Adjustments in the preprocessing

Changes in the historical quarter or the airport being examined require all preprocessing to be redone. All of the sub problem optimization software files will need to be updated to reflect these changes; these files then need to be moved to the server so the ASOM can be rerun to give new results based on the changed parameters.

Changes in airfare and revenue from fuel price changes, extra baggage or cancellation fees and from taxes and charges the airlines pay through the airfares are made in the DB1B data before being processed in Matlab. These kinds of changes require the market demand versus revenue curves to be recalculated in Matlab. All of the sub problem files will need to be updated to reflect these changes; these files then need to be moved to the server so the ASOM can be rerun to give new results based on the changed parameters.

Changes in aircraft operational costs from fuel price changes or landing fees are made in the Matlab code. This requires the Matlab network costing function to be rerun to create a new flight segment costs. All of the sub problem files will need to be updated to reflect these changes; these files then need to be moved to the server so the ASOM can be rerun to give new results based on the changed parameters.

Changes in international and cargo capacity used at the airport are a direct input into the ASOM file. The file would then need to be updated on the server and the ASOM can be rerun to give new results based on the changed parameters.

Lastly changes in airport capacity are done in the master problem's "settings" file on the server; the ASOM can then be rerun to give new results based on the changed parameters.

So changes in some parameters, like airfare, require almost as much work as developing a whole new scenario for the model.

3.2.2.1 Airline Profits - The model for airline profits includes the additional fees that have been introduced for domestic air travel and accounts for the landing fees the airlines have to pay. Before this data is provided to Matlab, DB1B airfares are adjusted to eliminate discount fares and to reflect extra airline revenue obtained from baggage and change fees. The total revenue is reduced by removing the itinerary taxes and charges which are not part of the airline's revenue. The ticket prices are increased based on a historical analysis so that as fuel prices increase, revenues will increase in a relative way (see Figure 7).

The model includes a per-passenger average increase in revenue based on the current fees charged for baggage, re-scheduling, and in-flight services. The model includes a per-passenger average increase for revenue received from belly cargo (freight and mail). Finally, the ticket/ segment tax and the passenger facility charges (PFCs) were removed from the revenue to more accurately reflect the true revenue realized by the airlines.

Similarly the operational costs are determined based on the airline costs associated with aircraft operations. These costs include maintenance and fuel-burn costs by aircraft type and distance flown, crew costs (also segregated by aircraft type). Landing fees are calculated by aircraft class and added to the cost of operations.

Revenue per Passenger

- Airfare
  - Ticket (-7.5%)[1]
  - Segment Tax (-$3.60)[1]
  - PFC (-$3.63)[2]
  - 911 (-$2.50)[1]
- Freight/ Mail (+2.4%)[3]
- Fees (+$10.17)[4]

BTS Reports[4]		2008**	2009
Ancillary Fees*		$ 7.50	$ 10.17
	Bags	$ 2.09	$ 3.54
	Cancel	$ 2.20	$ 3.08
* Bags, Cancel/Change, Pets, Freq Flyer			
** Based on 3rd & 4th Quarter			

New Airfare = .949(Airfare) + $.44

Direct Cost (per segment)

- Fuel
- Labor
- Maintenance
- Other
- Landing Fees (BTS)[5]
  - Per Landing (+$306.69)
  - Per Klbs (+$2.85)

4QTR09 Revenue[3]		
Passenger	$18,513	70.0%
Regional Affiliates	$5,337	20.2%
Cargo	$633	2.4%
Other Revenues	$1,964	7.4%

3- Aviation Daily Airline Revenue (4QTR09)
4- BTS Airline Revenue Reports (2008-2009)
5- BTS Airline Cost Reports (2007) and BTS T-100 (2007)

1- http://www.airlines.org/Economics/Taxes/Pages/GovTaxesandFeesonAirlineTravel.aspx
2- http://www.faa.gov/airports/pfc/monthly_reports/

Figure 7 ASOM Airline Profit Model.

3.2.2.2 ASOM Fuel Price Adjustments **-** To reflect how airfares change in response to fuel price changes, the airfare versus fuel price relationship was examined for the 20 quarters from the first quarter of calendar year 2005 (1QTR 2005) to 4 QTR 2009. A functional relationship was established and used in the ASOM model to reflect the airline's response to changes in fuel price. This adjustment in airfares ensures the changes in fuel prices were accounted for in airline revenue as well as airline costs, since airlines change airfares to account for fluctuations in operational costs.

As shown in Figure 8, the relationship between hedged fuel prices and airfares exhibits two segments. The breakpoint between the segments is estimated to occur at $2.50 per gallon. Two linear relationships were calculated for changes in fuel price. The first relationship was calculated for changes in fuel price between $1 and $3.50 per gallon, which adjusts airfare $16.42 for every $1 change in fuel price. A second relationship was calculated for changes in fuel price above $3.50 per gallon, which adjusts airfare $8.82 for every $1 change in fuel price.

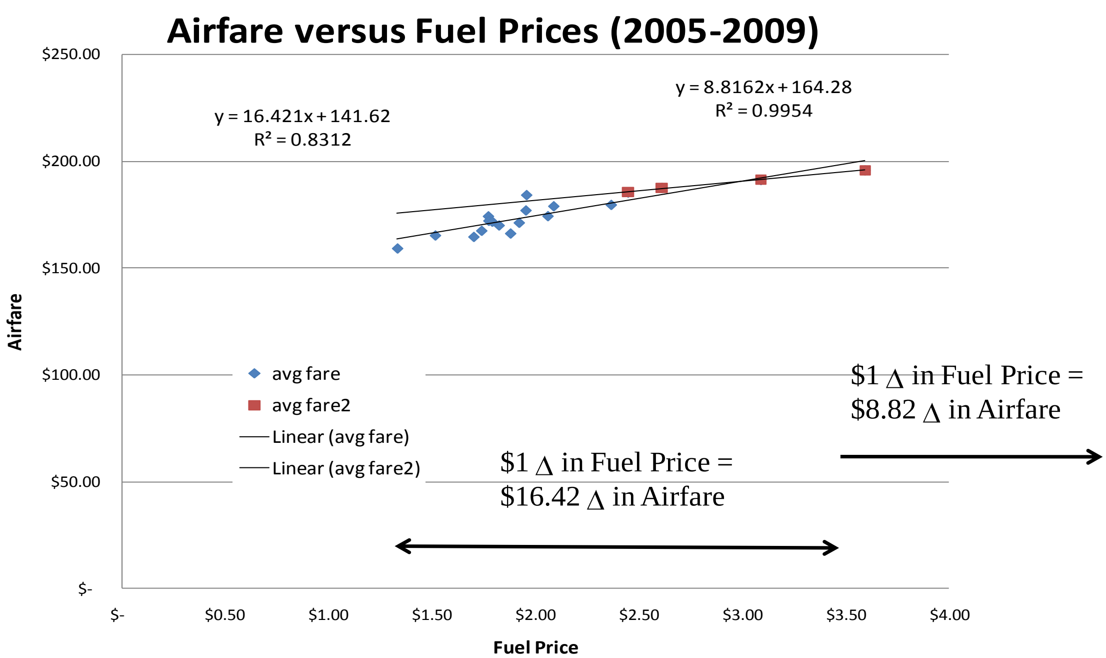

Figure 8 Airfare versus hedged Fuel Price Relationship (2005-2009)

3.3 ASOM Optimization

The Airline Optimization Scheduling Model is divided into two parts, a master problem and a collection of sub problems for each market pair (as shown previously in Figure 6). The master problem is a set packing problem that receives as input multiple alternative schedules for each market pair and chooses the overall profit maximizing schedule for the airline as a whole. The sub problems, one per market pair, determine an optimized schedule for that market given the dual prices that are provided to it from the master problem. In essence, the master problem indicates the value of adding/deleting one flight from a given time period. The sub problems use this information to determine if it there is an alternative schedule for flights to that market that would improve the overall profitability of the airline. The sub problems are multi-commodity flow problems that determine both when to fly and on what size aircraft.

Each sub problem (one per market) generates the most profitable schedule given dual prices that are fed to it from the master problem. An output from a run of the sub problem optimization is either a new schedule that is guaranteed to increase the objective function of the master problem, or an indicator that no such schedule exists.

Given a set of new schedules obtained from the sub problems, the master problem takes these new schedules along with all other schedules previously generated and determines a new overall schedule that considers all markets simultaneously and optimizes the profitability of the benevolent operator. The process is iterative: the solution to the master problem provides new dual prices that are then fed to the sub problems and the sub problems provide alternative individual market schedules to the master problem. The process continues until either the objective function of the master problem is not improved or none of the sub problems produce new schedules. At this point, the algorithm has solved the linear programming relaxation of the master problem. However, if the solution obtained is not integer, then one must begin a branch-and-bound search tree in order to obtain an integer solution. It also outputs new dual prices based on that schedule, and once again return to the sub problems procedure with these new dual prices.

This procedure continues until either the master problem doesn't generate improved schedule from the previous one or there is no new schedule generated from any of the sub problem. When either of these conditions is met, the model then begins a branch-and-bound search tree approach to assure that the solution obtained to the Master Problem is integer. Thus, on each node of the branching tree, steps 1 and 2 are repeated. This process continues until the entire branching tree is fathomed.

3.3.1 ASOM Master Problem

The master problem is presented in the Figure 9. The objective function maximizes total profit for the airport's schedule. Notation is as follows:

Z_j = Profit from schedule j
y_j = Decision variable (0,1) on whether schedule j is selected
a_{ij} = Decision variable (0,1) on arrival for time i and schedule j
d_{ij} = Decision variable (0,1) on departure for time i and schedule j
I_j = average number of international or cargo arrivals (a) or departures (d) for time i
T = Set of 15 minute time windows in the day
Σ = Set of schedules submitted to master problem from sub problems
Σ(m) = Set of schedules for market m
M = Set of possible markets for schedule

Constraints 1 and 2 ensure that there are no more flights in a single 15-minute bin than the arrival and departure capacity available to handle these flights, respectively. Capacity is defined to be airport capacity minus the portion of that capacity used by other flights. Other flights refer to the capacity reserved for the international and freight flights, since the model optimizes only domestic air travel. Constraint 3 guarantees that at most only one schedule per market pair is chosen.

$$\max \sum_{j \in S} Z_j y_j$$

subject to

$$\sum_{j \in S} a_{ij} y_j \le C_i - I_i^a \quad \forall i \in \mathcal{T} \qquad (1)$$

$$\sum_{j \in S} d_{ij} y_j \le C_i - I_i^d \quad \forall i \in \mathcal{T} \qquad (2)$$

$$\sum_{j \in S(m)} y_j \le 1 \quad \forall m \in \mathcal{M} \qquad (3)$$

$$y \in B^{|S|}$$

Figure 9 ASOM Master Problem

3.3.2 ASOM Sub-Problem

The sub problem is presented in the Figure 10. The objective function maximizes total profit for the markets schedule from the airport. Notation is as follows:

R_{iq} = Linear segment revenue for time i and segment q
λ_{iq} = Decision variable (0,1) for time i and segment q
C^k_{ij} = Direct operating cost for one flight of fleet type k for flight arc (i,j)
x^k_{ij} = Decision variable (0,1) for one flight of fleet type k for flight arc (i,j)
l = average load factor
S^k = Seats for aircraft of fleet type k
A_{iq} = Linear segment passenger demand for time i and segment q
A_{pr} = Linear segment passenger demand for period r and segment p
R_{pr} = Linear segment revenue for period r and segment p
β_{pr} = Decision variable (0,1) for period r and segment p
T = Set of 15 minute time windows in the day
Π = Set of periods in the day
K = Set of aircraft fleet classes

$$\max\ z = \sum_{i\in\mathcal{T}} \sum_{q\in\mathcal{Q}(i)} R_{iq}\lambda_{iq} - \sum_{(j,i)\in\mathcal{A}^F} \sum_{k\in\mathcal{K}} C^k_{ji} x^k_{ji}$$

$$\text{subject to} \sum_{(j,i)\in\mathcal{A}} x^k_{ji} - \sum_{(i,j)\in\mathcal{A}} x^k_{ij} = 0, \quad \forall i \in \mathcal{T}, k \in \mathcal{K} \tag{4}$$

$$l \sum_{k\in\mathcal{K}} \sum_{(j,i)\in\mathcal{A}^F} S^k x^k_{ji} - \sum_{q\in\mathcal{Q}(i)} A_{iq}\lambda_{iq} = 0 \quad \forall i \in \mathcal{T} \tag{5}$$

$$\sum_{i\in\mathcal{E}(p)} \sum_{q\in\mathcal{Q}(i)} A_{iq}\lambda_{iq} - \sum_{r\in\mathcal{Q}(p)} A_{pr}\beta_{pr} = 0 \quad \forall p \in \mathcal{P} \tag{6}$$

$$\sum_{i\in\mathcal{E}(p)} \sum_{q\in\mathcal{Q}(i)} R_{iq}\lambda_{iq} - \sum_{r\in\mathcal{Q}(p)} R_{pr}\beta_{pr} \leq 0 \quad \forall p \in \mathcal{P} \tag{7}$$

$$\sum_i x^k_{ij} + \sum_i x^k_{ji} \leq max\_freq + 1 \tag{8}$$

$$\sum_{k\in\mathcal{K}} \sum_{(j,i)\in\mathcal{A}^F} S^k x^k_{ji} - IntDem \geq 0 \tag{9}$$

$$\sum_i x^k_{ij} \leq 1 \quad \forall i \in \mathcal{T} \tag{10}$$

$$\sum_i x^k_{ji} \leq 1 \quad \forall i \in \mathcal{T} \tag{11}$$

$$\sum_{q\in\mathcal{Q}(i)} \lambda_{iq} = 1 \quad \forall i \in \mathcal{T} \tag{12}$$

$$\sum_{r\in\mathcal{Q}(p)} \beta_{pr} = 1 \quad \forall p \in \mathcal{P} \tag{13}$$

$$x \in B_+^{|\mathcal{A}^F|\times|\mathcal{K}|}, \lambda_i \in R_+^{|\mathcal{Q}(i)|}, \beta_p \in R_+^{|\mathcal{Q}(p)|}$$

Figure 10 ASOM sub-problem

The sub problem consists of an objective function and 13 constraints.

Constraint 4 creates flow balance constraints that assure that, for each fleet type, there is an equal number of incoming and outgoing aircraft of that type. It also assures that an aircraft must arrive before it can depart and it must remain of the same type.

Constraint 5 assures that there is sufficient supply for the demand, that the aircraft size can accommodate the demand, and that the aircraft does not fly less than 80% full.

Constraint 6 requires that the demand per period be satisfied.

Constraint 7 assures that the airline does not fly any flights that are unprofitable. This does the same for revenue. This is to ensure that even though there is no flight at some time window despite there being demand for it, the demand is still satisfied in the consecutive time window and passengers are not removed from that time period.

Constraint set 8 requires the number of flights into a market is approximately equal to the number of flights out of a market (can differ by no more than one).

Constraint 9 ensures that international passenger demand that is connecting from domestic markets is satisfied. Therefore, we will not eliminate a profitable market which connects domestic passengers to international flights.

Constraints 10 and 11 ensure that there is only one flight between the market pair in the same time window.

Constraint 12 and 13 ensures that only one segment of the piecewise linear approximation for the revenue curve is chosen for each time window and period respectively. The piecewise linear approximation works here because the optimization model is maximizing profit and the revenue versus demand curve approximations are convex.

3.3.3 ASOM Post-Processing

There are two text files created by the model for each run. A sample log file, shown in Figure 11, illustrates the number of markets or sub problems initiated for the model. This file also identifies the number of these initial markets that are profitable. This file shows the number of iterations back and forth between Main and Sub-problems. Lastly, the expected profit from the final airport's schedule is shown.

init_problems():91 markets. (initial markets)

add ABE_0_1 ,z = 14580.140000000003 cost = 13142.0, frequency = 2.0(2), throughput= 300.0, gap=0.0, reduced cost =14580.139000000003

……….

add TYS_0_64 ,z = 1186.4142857142815 cost = 14124.0, frequency = 2.0(2), throughput= 150.0, gap=0.0, reduced cost =1186.4132857142815

Generate columns – 64 Profitable Markets

add ABE_1_65 ,z = 14580.139999999994 cost = 13142.0, frequency = 2.0(2), throughput= 300.0, gap=0.0, reduced cost =14530.138999999994

……….

add TYS_1_128 ,z = 1186.4142857142838 cost = 14124.0, frequency = 2.0(2), throughput= 150.0, gap=0.0, reduced cost =1136.4132857142838

generate_columns() ended with 128columns in master_vars

generate_columns() ended with 64 columns generated at the current node.

Generate columns

add ABE_2_129 ,z = 14580.139999999996 cost = 13142.0, frequency = 2.0(2), throughput= 300.0, gap=0.0, reduced cost =2910.1389999999956

……..

add STL_6_311 ,z = 8221.784615384611 cost = 99270.0, frequency = 10.0(10), throughput= 750.0, gap=0.0, reduced cost =428.78361538461104

add TPA_6_312 ,z = 312182.0929837098 cost = -5.3657078780133816E-12, frequency = 10.0(10), throughput= 2750.0, gap=0.0, reduced cost =312132.09198370983

generate_columns() ended with 312columns in master_vars

Total profit: 6743454.0

Figure 11 ASOM Log File

The second output file is the schedule file, Figure 12. This file shows all of the individual flights on the airport's final schedule. For each flight or row of data the market served, the size of aircraft, the departure time, the arrival time and the frequency is shown.

Market	Size	Dep Time	Arr Time	Freq
ABE	6	76	178	1.0
ABE	6	176	86	1.0
ACK	2	39	143	1.0
ACK	2	123	35	1.0
……				
TYS	3	73	180	1.0
TYS	3	152	67	1.0

Market	Fleet si	i	j	freq	local ti	seats	year	qtr	airport	cap	fp	dist	ASM
ABE	6	76	178	1	76	150	2009	3	EWR	9	8	67	10050
ABE	6	176	86	1	86	150	2009	3	EWR	9	8	67	10050
ACK	2	39	143	1	39	50	2009	3	EWR	9	8	218	10900
ACK	2	123	35	1	35	50	2009	3	EWR	9	8	218	10900
ALB	3	26	130	1	26	75	2009	3	EWR	9	8	143	10725

Comment	profit & fleet #2
airport	EWR
year	2009
cap	12
fp	8

	Values			
Row Labels	Sum of ASM	Sum of seats	Sum of freq	Average Size
ATL	6518750	8750	42	
Grand Total	99574150	94350	628	150.24

Figure 12 ASOM schedule file

The aircraft sizes are grouped into classes in 25 seat intervals, so to determine the class you multiply the size by 25 seats, for example the first row identifies a size 6*25 = 150 seat aircraft.

The departure and arrival times are shown in 15 min intervals starting with 1 or 12:15am. The arrival or departure time which is less than 96 (there are 96 15-minute intervals in a 24-hour day) determines whether this is an arrival or departure from our airport modeled. To determine the arrival or departure time at the other airport subtract 96 from its number. For example the first row shows a departure from our airport to ABE at 76 (1900 hrs or 7:00pm) and this flight arrives at ABE at 178-96 = 82 (2030hrs or 8:30pm ABE local time). All times reported in the schedule are local times.

This schedule data from ASOM can be copied into a spreadsheet program to generate charts and tables and compare different scenarios based on different input parameters.

3.3.4 ASOM Limitations and Consistency Check

The ASOM models exhibits the following limitations:

1. The ASOM model considers airline scheduling decision strictly based on operational profitability rather than any decisions that are made for strategic positioning. It does not model airline competition, except as it uses pricing curves that are based on competitive behavior.
2. The ASOM models chooses only profitable markets to serve and does not consider staying in unprofitable markets during down economic times in order to retain market share. Thus, the model is likely to move out of markets more quickly than might actually occur during recessionary periods.
3. The ASOM models a single airline serving these profitable markets, which finds the optimal schedule minus airline competition. For the analysis of EWR and SFO (hubs for large carriers), this assumption may be closer to actual behavior than at airports such as LGA where there is significant competition at the airport.
4. The ASOM models balanced arrivals and departures and does not model the advantages of banking (i.e. having many incoming flights during one period that would allow passengers to connect to other flights during the next few periods).
5. The model also tries to satisfy the demand based on historic data. Thus, it does not allow demand from the morning to spill into the afternoon.
6. Currently the ASOM models airline adjustments from increases in hedged fuel prices by uniformly increasing all airfares. This methodology does not account for possible changes in passenger demand due to economic outcomes from fuel price changes. Additionally this methodology does not account for any price passenger elasticity changes due to economic outcomes from fuel price changes.

In the presence of these limitations a tiered level of consistency checks on the ASOM can be performed to obtain a level of confidence in the results of the model.

Tier 1: The first consistency check compares ASOM results to the historic behavior of the airlines serving these five congested airports (LGA, EWR, JFK, SFO, PHL) for three different economic scenarios: 3QTR07 with $2 fuel prices and 105 GDP index; 3QTR08 with $3.5 fuel prices and 105 GDP index; and 3QTR09 with $2 fuel prices and 103 GDP index. This analysis determines the percent of observations within 15% of the historic data, since the ASOM schedule is expected to be more efficient.

Tier 2: The second consistency check compares annual changes in ASOM results to the annual changes in historic behavior of the airlines serving these five congested airports (LGA, EWR, JFK, SFO, PHL) for two annual changes (3QTR07 to 3QTR08, and 3QTR08 to 3QTR09). This analysis determines the percent of annual trends within 10% of the historic trends.

Tier 3: A third consistency check compares the opposite market schedules generated from the ASOM. For example the ASOM schedule for LGA will contain the LGA-PHL market and the ASOM schedule for PHL will contain the PHL-LGA market. These opposite markets will be compared for consistency.

Tier 4: Lastly the statistical relationships found in the historic data and ASOM analysis between the exogenous factors and the economic access, geographic access and airline profitability factors will be compared. Basically it's important to see if the ASOM models similar trends and behaviors as seen in the historical data. But even comparing historical trends is difficult since the confounding factors from the historical trends cannot be removed.

The results of the 4 tier analysis are provided in Appendix A.

3.4 Method for Statistical Analysis of ASOM outputs

The ASOM outputs analyzed include: (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. The controls or exogenous factors for the model are fuel prices, airport capacity limits and historical gross domestic product.

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. For a two-tailed test of the correlation:
$H0: r = 0$ versus $H1: r \neq 0$ where r is the correlation between a pair of variables.
(3) Next a step-wise regression was performed to identify the factors that most impact the independent variable. Thus, stepwise regression adds variables sequentially, choosing the most significant variable first and continues until the adding of another variable degrades the relative R2 coefficient (i.e. the R2 adjusted for the number of independent terms in the regression equation.

(4) Then these separate individual regression model results were aggregated to develop a picture of the statistically significant relationships between the exogenous factors, the airline scheduling and pricing behavior, and the impacts of these behaviors on airport congestion and airline profitability.

3.5 Scope and Design of Experiment

Two experiments were conducted with the ASOM to determine the impact of airport capacity limits and the impact of change in fuel prices. The ASOM first examined what happens when airport capacity limits are changed with fixed passenger demand (representing gross domestic product) and fuel prices. Next the ASOM examines what happens when fuel prices are changed with fixed passenger demand (representing gross domestic product) and capacity limits.

3.5.1 Experiment #1

Experiment #1, summarized in the factorial design in Table 6, examined airline schedule behavior by tracking (a) aircraft size, (b) flights per day, and (c) daily markets served. It also tracks (d) profitability of the airlines servicing the airports.

Experiment #1 examines airline behavior for three airport capacity levels (high, normal, and low) for five congested airports (LGA, SFO, EWR, JFK, PHL) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices; (2) 3QTR08 with $3.50 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on airline behavior in response to capacity changes for different economic scenarios.

		3QTR 2007					3QTR 2008					3QTR 2009				
Airports		LGA	SFO	EWR	JFK	PHL	LGA	SFO	EWR	JFK	PHL	LGA	SFO	EWR	JFK	PHL
Hedged Fuel Prices ($/Gallon)		$2.08					$3.53					$1.92				
Gross Domestic Product (GDP Quantity Index, 2005=100)		104.9					105.3					102.8				
Capacity Limits (Operations/ hour)	Low	64	64	72	72	72	64	64	72	72	72	64	64	72	72	72
	Normal	72	72	80	80	80	72	72	80	80	80	72	72	80	80	80
	High	80	80	96	96	96	80	80	96	96	96	80	80	96	96	96

Table 6 "Design of Experiment" for ASOM experiment #1. This experiment represents 45 of 45 possible treatments.

3.5.2 Experiment #2

The second ASOM experiment, summarized in the factorial design in Table 7, examined airline schedule behavior by tracking (a) aircraft size, (b) flights per day, and (c) daily markets served. It also tracks (d) profitability of the airlines servicing the airports.

Experiment #2 examines airline behavior for three airport capacity levels (high, normal, and low) and four fuel price levels ($2, $3.5, $5, $8) for one congested airport (EWR) for two different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index, and (2) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on airline behavior in response to capacity changes and fuel price changes for different economic scenarios.

		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 7 "Design of Experiment" for hedged fuel price and capacity limit experiment. Experiment #2 represents 18 of 18 possible treatments.

Limitation of Design of Experiments

Note: These experiments include analysis of hedged fuel prices of $5/gallon and $8/gallon. Historically, fuel prices have not exceeded $3.70/gallon (this highest price happened in July of 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 would undergo significant changes that have not been experienced (or modeled).

4 Results

This section describes the results of the analyses of the Experiments conducted using the ASOM. Section 4.1 examines the results of Experiment #1: the impact of Airport Capacity Limits. Section 4.2 examines the results of Experiment #2: the impact of Fuel Prices Changes and Capacity Limits. Section 4.3 describes the relationship between parameters from a regression analysis. The results of the validation tests on the ASOM model are included in Appendix A.

The results of the ASOM experiments indicate the following effects:

Geographic Access:

i. Markets served per day reduce slightly as capacity limits are reduced, gross domestic product is reduced, or hedged fuel prices are increased

ii. Flights per day are reduced as capacity limits are reduced, gross domestic product is reduced, or fuel prices are increased

Air Transportation Efficiency:

iii. Aircraft size increases slightly as hedged fuel prices are increased or as gross domestic product increases

Airline Profitability:

iv. Airline Profits increase as hedged fuel prices, gross domestic product, aircraft size, or flights per day increase

4.1 Experiment #1 Results: ASOM Capacity Variation Results 3QTR (2007-2009) (LGA, EWR, JFK, SFO, PHL)

In this experiment the ASOM examines airline behavior for different airport capacity levels (high, normal, and low) for five different congested airports (LGA, EWR, JFK, SFO, and LGA) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index; (2) 3QTR08 with $3.5 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on airline behavior in response to capacity changes for different economic scenarios.

4.1.1 Geographic Access

This section describes the results for profitable markets, scheduled flights per day and aircraft size

4.1.1.1 Profitable Markets - The results of ASOM analysis of the profitable markets (NY, SF, and Philadelphia) is shown in Table 8. This table shows the Baseline Direct service Markets for “Normal” Capacity Limits (in Black). The remaining cells in the table show the change in Direct service Markets from this baseline. The results show that adjusting airport capacity limits up and down has little effect on profitable markets served. The analysis shows that most profitable markets can still be served for the five congested airports examined, even when airport capacity is reduced to 10% below current operations. When capacity at these airports is increased, as anticipated with NextGen, ASOM fits a few more current profitable markets into the schedule.

	Caps	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fuel price)	L	-	-1	-2	-4	-4
	N	59	52	79	49	80
	H	+2	+1	-	-	+2
3QTR 2008 ($3.53 fuel price)	L	-1	-	-1	-3	-2
	N	59	39	64	49	74
	H	-	-	+3	+2	-
3QTR 2009 ($1.92 fuel price)	L	-	-5	-1	-2	-2
	N	60	44	73	54	83
	H	-	+2	+2	-	+2

Table 8 Sensitivity of Direct service Markets to Capacity Limits.

When Airport Capacity Limits are reduced through fixed passenger demand (represented by gross domestic product) and fuel prices, the number of profitable markets served does not change.

The results of a linear regression for markets served by the five airports, over 3 years, and for 3 airport capacity limits provides insights into the correlations between the variables and the significant factors that influence airline decisions on markets served (Table 9).

		Fuel Prices	GDP	Caps
Markets	Pearson correlation	-0.199	-0.101	0.329
	P-Value	**0.189**	**0.51**	**0.027**

Table 9 Correlation of significant factors that influence airline decisions on markets served.

The closer the Pearson correlation coefficient is to +1 or -1 the greater the positive or negative correlation (or relationship) is between the factors.

A P-value of .05 or less means that there is 95% confidence in the statistical correlation.
The analysis shows correlation between markets Served and airport capacity limits.

The stepwise regression analysis identified the profitable Markets to be a function of airport capacity limits. This relationship was found to be positive. The correlation accounted for 8.8% (i.e. R-squared) of the observed variation in profitable markets served. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression equation for profitable markets served by the airlines is as follows:

Markets = 26.2 + 0.441 Caps

4.1.1.2 Scheduled Flights per Day

The results of ASOM analysis of the scheduled flights per day at the Metroplex (NY, SF, and Philadelphia) is shown in Table 10. The table shows the Baseline Scheduled flights per day for "Normal" Capacity Limits (in Black). The remaining cells in the table show the change in Scheduled flights per day from this baseline. These results show that adjusting airport capacity limits up and down has little effect on scheduled flights per day. The analysis shows that most of the flights per day for normal capacity limits are still scheduled, even when airport capacity is reduced to 10% below current levels. When capacity is increased, as anticipated with NextGen, ASOM fits a few more scheduled flights per day into the schedule.

	Caps	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fuel price)	**L**	-50	-28	-50	-64	-38
	N	834	634	750	630	876
	H	+28	+12	+44	+26	+68
3QTR 2008 ($3.53 fuel price)	**L**	-18	-12	-38	-28	-32
	N	718	596	644	558	798
	H	+8	-	+24	+34	+44
3QTR 2009 ($1.92 fuel price)	**L**	-46	-68	-34	-58	-50
	N	810	710	704	670	888
	H	+22	+32	+16	+32	+72

Table 10 Sensitivity of Scheduled flights per day to Capacity Limits.

When airport capacity limits are reduced with passenger demand (representing gross domestic product) and fuel prices fixed airlines will reduce the total number of flights. This is expected since the number of operations allowed per hour is reduced. These trends are consistent for all five airports for a booming economy in the third quarter 2007, a slowed economy in the third quarter 2008, and during the recession in the third quarter 2009. And profitable schedules were found for all three quarters for all five airports examined, even in the third quarter 2009 when most airlines were reporting significant losses.

Figure 13 shows how the average daily flights for 3QTR (2007-2008) for all five airports (LGA, EWR, JFK, SFO, PHL) change as airport capacity limits are increased or reduced in comparison to the historic schedule. This analysis shows the proportion of historic non-profitable flights that were not scheduled by the ASOM. This figure also shows how the ASOM scheduled flights per day were reduced as the airport capacity limits were reduced.

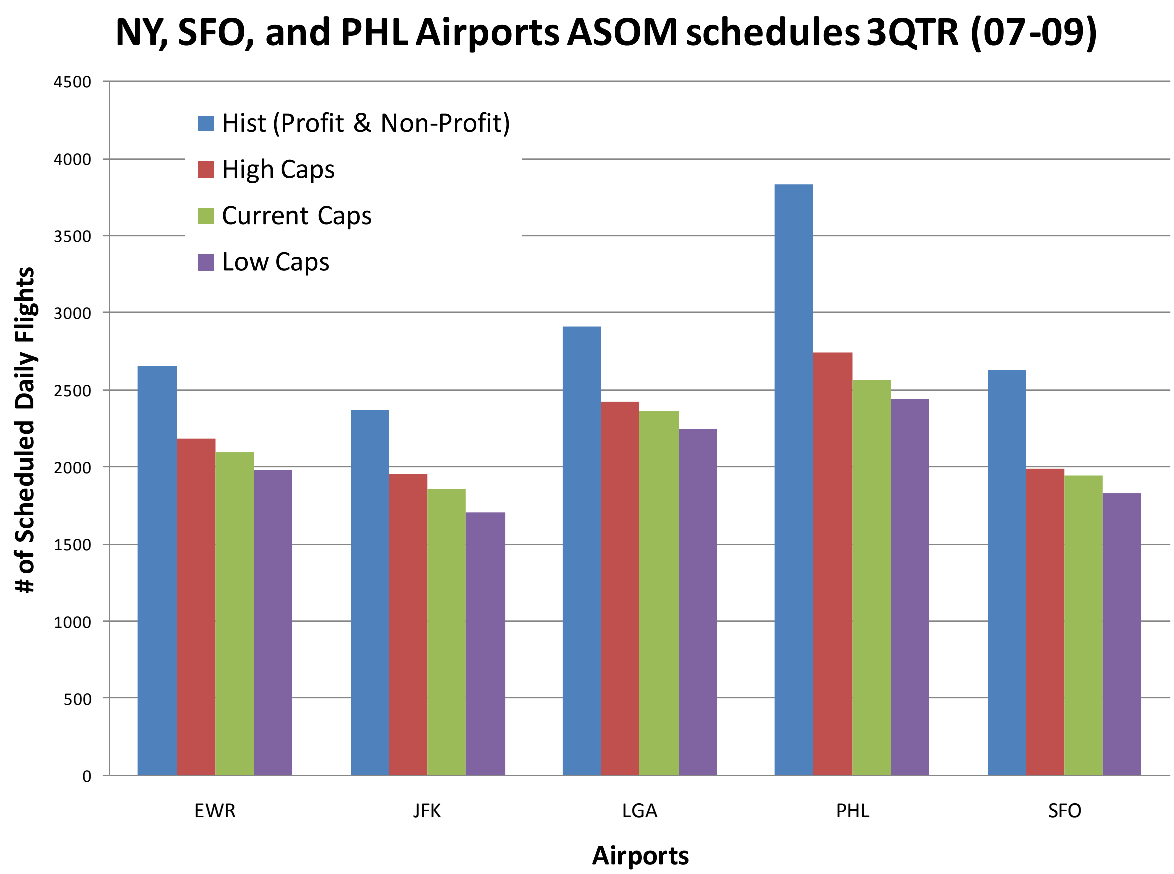

Figure 13 ASOM Flight Schedules slightly reduce as Airport Capacity Limits are reduced

The results of a linear regression for scheduled flights per day by the airports at each of the five airports, over three years and for three airport capacity limits provides insights into the correlations between the variables and the significant factors that influence airline decisions on scheduled flights per day (Table 11).

		Fuel Prices	GDP	Caps
Flights per Day	Pearson correlation	-0.375	-0.266	0.266
	P-Value	**0.011**	**0.077**	**0.078**

Table 11 Table shows statistically significant correlation (95% confidence) between scheduled flights per day and hedged fuel prices.

The analysis shows correlation between scheduled flights per day and fuel price.

The stepwise regression analysis identified the scheduled flights per day to be a function of airport capacity limits and fuel price. This relationship was found to be positive for airport capacity limits and negative for fuel price. The correlation accounted for 17.4% (i.e. R-squared) of the observed variation in scheduled flights per day. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression equation for scheduled flights per day to all markets served by the airlines is as follows:

Flights per Day = 639 + 2.78 Caps - 55.3 fuel price

4.1.2 Airline Profits

The results of ASOM analysis of the airline profits (NY, SF, and Philadelphia) are shown in Table 12. This table shows the Baseline Airline Profits per day for "Normal" Capacity Limits (in Black).   The remaining cells in the table show the change in Airline Profits per day from this baseline. The results show that adjusting airport capacity limits up and down has little to no effect on airline profits. When more capacity is available, as anticipated with NextGen, ASOM shows airlines would add marginally profitable flights to their schedule.

	Caps	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fuel price)	L	-$.106	-$.108	-$.110	-$.923	-$.115
	N	$4.087	$5.624	$5.884	$4.748	$3.477
	H	+$.032	+$.056	+$.107	+$.122	+$.133
3QTR 2008 ($3.53 fuel price)	L	-$.027	-$.037	-$.224	-$.059	-$.057
	N	$3.205	$3.746	$5.347	$4.089	$2.679
	H	+$.014	+$.018	+$.063	+$.048	+$.086
3QTR 2009 ($1.92 fuel price)	L	-$.078	-$.019	-$.269	-$.514	-$.113
	N	$3.938	$3.358	$4.783	$4.667	$3.406
	H	+$.030	+$.012	+$.059	+$.099	+$.156

Table 12 Sensitivity of Airline Profits to Capacity Limits.

When airport capacity limits are reduced with fixed passenger demand (representing gross domestic product) and fuel prices, airlines will adjust operations to maintain profits (dropping the least profitable flights). These trends are consistent for 87% (13/15) of cases examined across five airports for a booming economy in the third quarter 2007, a slowed economy in the third quarter 2008, and during the recession in the third quarter 2009. And profitable schedules were found for all three quarters for all five airports examined, even in the third quarter 2009 when most airlines were reporting significant losses. When examining JFK for third quarter 2007, a 25% reduction in capacity limits reduces the airlines profit by 21%. One explanation is that JFK's schedule for third quarter 2007 was significantly peaked. As the peaks were removed the profit was also removed.

The results of a linear regression for airline profits at each of the five airports, over three years and for three airport capacity limits provides insights into the correlations between the variables and the significant factors that influence airline profit (Table 13).

		Fuel Prices	GDP	Caps	Markets	Flights per Day	Aircraft Size
Profit	Pearson correlation	-0.254	0.068	0.184	0.012	-0.339	0.654
	P-Value	**0.093**	**0.658**	**0.225**	**0.939**	**0.023**	**0**

Table 13 Table shows statistically significant correlation (95% confidence) between airline profits and scheduled flights per day and aircraft size.

The analysis shows correlation between airline profit to scheduled flights per day and aircraft size.

However, the stepwise regression found airline profit correlated with fuel price, gross domestic product, markets served and aircraft size. This relationship was found to be positive for gross domestic product, markets served and aircraft size and negative for fuel price. The correlation accounted for 62.0% (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 equation for airline daily profits for service in and out of the airport is as follows:

Daily Airline Profit = - 21.8 - 0.658 fuel price + 0.229 GDP + 0.0156 Markets + 0.0271 Guage

4.1.3 Air Transportation Efficiency.

4.1.3.1 Aircraft Size - The results of ASOM analysis of the average aircraft gauge (NY, SF, and Philadelphia) is shown in Table 14. This table shows the Baseline average Aircraft Gauge for "Normal" Capacity Limits (in Black). The remaining cells in the table show the change in average Aircraft Gauge from this baseline. The results show that adjusting airport capacity limits up and down has little effect on aircraft gauge. When more capacity is available, as anticipated with Nextgen, ASOM shows airlines would down-gauge and thus not realize the full benefits from Nextgen.

	Caps	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fuel price)	**L**	+1	+4	+5	+3	-1
	N	78	113	139	127	79
	H	-1	-1	-5	-3	-2
3QTR 2009 ($3.53 fuel price)	**L**	-	-1	+4	+2	-
	N	69	132	142	125	78
	H	-1	-1	-2	-2	-2
3QTR 2009 ($1.92 fuel price)	**L**	+1	+4	-	-5	+2
	N	81	115	110	102	71
	H	-2	-	-4	-	-1

Table 14 Sensitivity of average Aircraft Gauge to Capacity Limits.

When airport capacity limits are reduced with passenger demand (representing gross domestic product) and fuel prices fixed, we find that airlines will slightly up-gauge. This is expected since the number of operations allowed per hour is reduced and the same demand must be serviced. These trends are consistent for 93% (14/15) of cases examined across five airports for a booming economy in the third quarter 2007, a slowed economy in the third quarter 2008, and during the recession in the third quarter 2009. Also, profitable schedules were found for all three quarters for all five airports examined, even in the third quarter 2009 when most airlines were reporting significant losses. For JFK third quarter 2009, the optimal schedule down-gauges as capacity is reduced, but under alternate demand circumstance (.e.g. 3 Qtr 2007 and 3 QTR 2008) the optimal schedule up up-gauged. This could reflect the fact that historically when JFK's capacity limits were reduced the airlines de-peaked the schedule and maintained the number of flights.

Figure 14 shows the how the average daily flights for 3QTR (2007-2008) for all five airports (LGA, EWR, JFK, SFO, PHL) change as airport capacity limits are increased or reduced. This figure also shows how the ASOM does not significantly change the size of the aircraft as a function of airport capacity limits.

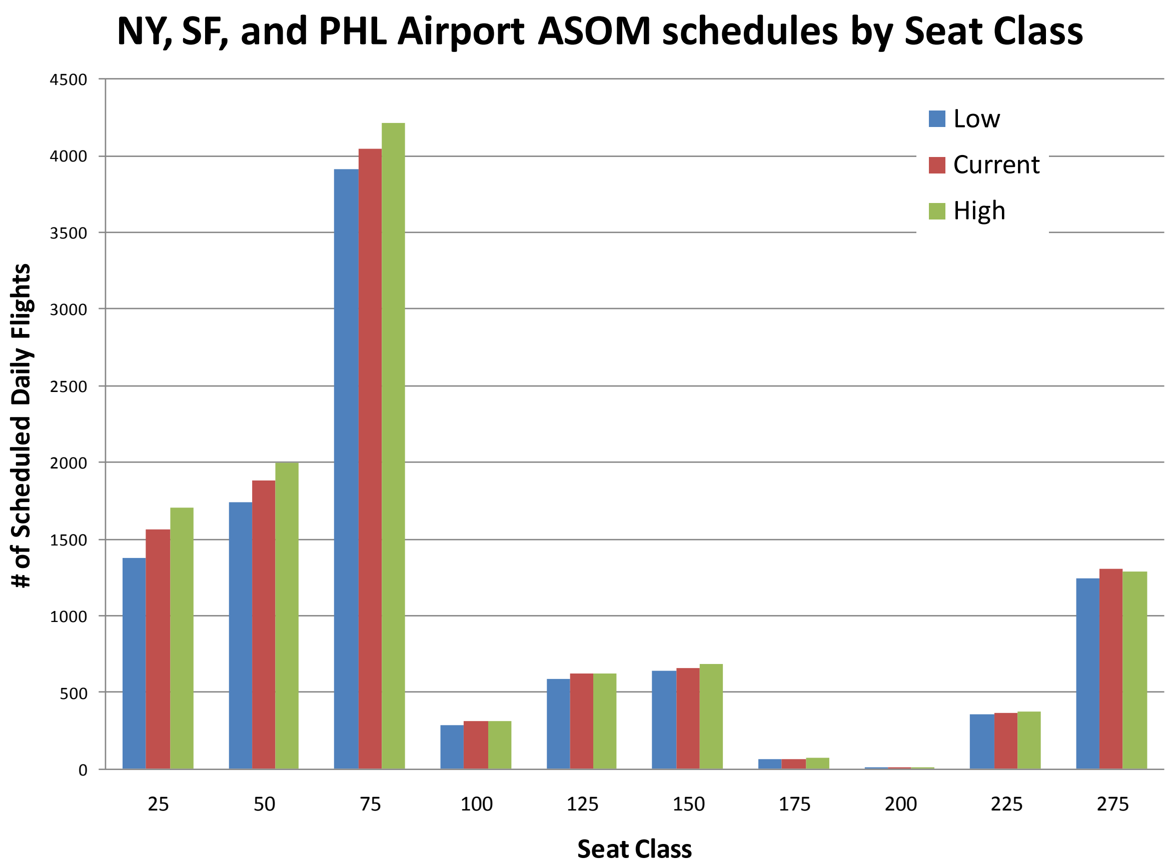

Figure 14 ASOM average Aircraft Gauge insensitive to Capacity Limits

The results of a linear regression for aircraft size for the airports at each of the five airports, over three years and for three airport capacity limits provides insights into the correlations between the variables and the significant factors that influence airline decisions on aircraft size (Table 15).

		Fuel Prices	GDP	Caps
Aircraft Size	Pearson correlation	0.159	0.236	0.051
	P-Value	**0.298**	**0.119**	**0.741**

Table 15 Table shows no statistically significant correlation (95% confidence) between average Aircraft Gauge and exogenous factors.

The analysis shows no correlation between aircraft gauge and fuel price, gross national product, or capacity limits.

The stepwise regression analysis identified no functional relationship between aircraft gauge and fuel price, gross national product, or capacity limits.

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 class aircraft have historically poor performance (cost per seat-hr). The newest part of the airline industry fleet is regional jets that are more fuel efficient that the larger aircraft in the overall fleet. As fuel prices increase, there is more incentive for the ASOM to move to smaller aircraft. Figure 15 illustrates this point, showing how 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, and greater flight frequency. This result has significant implications for future airspace use.

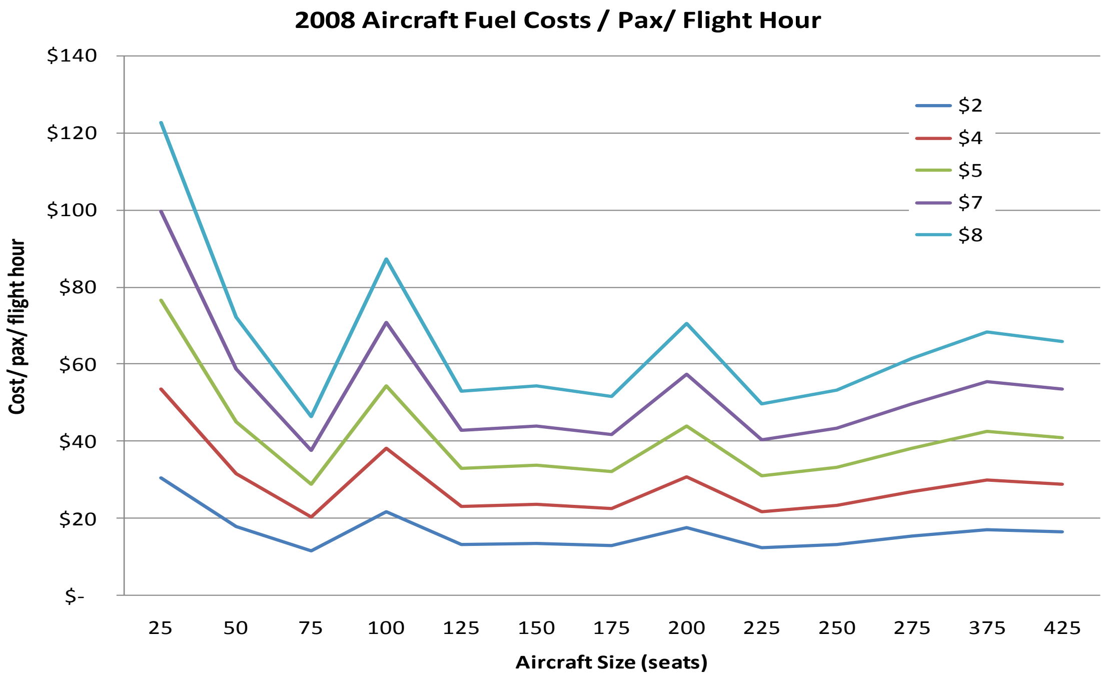

Figure 15 Poor aircraft performance ($/seat-hr) in 100- and 200-seat aircraft classes

4.2 Experiment #2: ASOM Capacity and Fuel Price Variation Results

In this experiment the ASOM examines airline behavior for different airport capacity levels (high, normal, and low) and for different fuel price levels ($2, $3.5, $5) for one congested airport (EWR) for two different economic scenarios (3QTR07 with $2 fuel prices and 105 GDP index, and 3QTR09 with $2 fuel prices and 103 GDP index). The results provide insights on airline behavior in response to capacity changes and fuel price changes for different economic scenarios.

4.2.1 Geographic Access

This section describes the results for profitable markets, scheduled flights per day and aircraft size

4.2.1.1 Profitable Markets - The results of ASOM analysis of the profitable markets for EWR are shown in Table 16. This table shows the Baseline (underlined) Direct service Markets for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at $2.08/gallon and $1.92/gallon. The remaining cells in the table show the change in Direct service Markets from this baseline. When hedged fuel prices approach $5 the target airport starts to lose Direct service Markets (yellow). The results show that

EWR Markets	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	L	-2	-1	-8
	N	79	-1	-9
	H	-	-	-5
3QTR 2009 ($1.92 fuel price)	L	+1	-1	-5
	N	74	+1	-1
	H	-	+1	-

adjusting airport capacity limits up and down has little effect on profitable markets served. However, significant increases in fuel prices reduced the number of markets served. In the table the underlined quantity represents the baseline ASOM results for markets served for normal capacity limits and fuel prices in line with historic prices for the quarter examined. When more capacity is available, as anticipated with NextGen, ASOM fits a few more current profitable markets into the schedule.

Table 16 Sensitivity of EWR Direct service Markets to Hedged Fuel Price and Capacity Limits.

The results of a linear regression for markets served by EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence airline decisions on markets served (Table 17).

		Fuel Prices	GDP	Caps
Markets	Pearson correlation	-0.505	0.515	0.376
	P-Value	**0.033**	**0.029**	**0.124**

Table 17 Table shows statistically significant correlation (95% confidence) between direct service markets and hedged fuel prices and Gross Domestic Product.

The analysis shows correlation between markets Served to fuel prices and Gross Domestic Product.

The stepwise regression analysis identified the profitable markets to be a function of capacity limits, fuel prices and GDP. This relationship was found to be positive for capacity limits and GDP, and negative for fuel prices. The correlation accounted for 83.4% (i.e. R-squared) of the observed variation in profitable markets served. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression equation for profitable markets served by the airlines is as follows:

Markets = - 98.4 + 0.122 Caps + 1.61 GDP - 1.36 Fuel Price

***4.2.1.2 Scheduled Flights per Day* -** The results of ASOM analysis of the scheduled flights per day for EWR are shown in Table 18. This table shows the Baseline (underlined) scheduled flights per day for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at $2.08/gallon and $1.92/gallon. The remaining cells in the table show the change in scheduled flights per day from this baseline. When hedged fuel prices approach $5 the scheduled flights per day significantly reduce (yellow). The results show that adjusting airport capacity limits up and down has little effect on scheduled flights per day, but significant increases in fuel prices reduce the number of scheduled flights per day. In the table the underlined quantity represents the baseline ASOM results for scheduled flights per day for normal capacity limits and fuel prices in line with historic prices for the quarter examined. When more capacity is available, as anticipated with Nextgen, ASOM fits a few more flights into the schedule.

EWR Flights	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	L	-50	-52	-106
	N	750	-12	-86
	H	+44	+6	-62
3QTR 2009 ($1.92 fuel price)	L	-34	-56	-92
	N	672	-16	-54
	H	+16	+14	-30

Table 18 Sensitivity of EWR scheduled flights per day to Hedged Fuel Price and Capacity Limits.

These fuel price trends are consistent for all three capacities for a booming economy in the third quarter 2007 and during the recession in the third quarter 2009. Profitable schedules were found for both quarters examined, even in the third quarter 2009 when most airlines were reporting significant losses.

The results of a linear regression for scheduled flights for EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence airline decisions on markets served (Table 19).

		Fuel Prices	GDP	Caps
Flights per Day	Pearson correlation	-0.607	0.435	0.558
	P-Value	**0.008**	**0.071**	**0.016**

Table 19 Table shows statistically significant correlation (95% confidence) between scheduled flights per day and Hedged Fuel Prices and airport capacity limits.

The analysis shows correlation between markets served to fuel prices and capacity limits.

The stepwise regression analysis identified the scheduled flights per day to be a function of capacity limits, fuel prices and GDP. This relationship was found to be positive for capacity limits and GDP, and negative for fuel prices. The correlation accounted for 88.2% (i.e. R-squared) of the observed variation in profitable markets served. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression equation for daily scheduled flights is as follows:

Flights = - 1392 + 2.48 Caps + 18.9 GDP - 22.3 Fuel Price

4.2.2 Airline Profits

The results of ASOM analysis of airline profit for EWR are shown in Table 20. This table shows the Baseline (underlined) Airline Profit for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at $2.08/gallon and $1.92/gallon. The remaining cells in the table show the change in Airline Profit from this baseline. When hedged fuel prices exceed $3.50 the airline profit significantly increases (yellow). The results show that adjusting airport capacity limits up and down has little effect on airline profit, but significant increases in fuel prices increase airline profit. In the table the underlined quantity represents the baseline ASOM results for airline profit for normal capacity limits and fuel prices in line with historic prices for the quarter examined.

EWR Profit	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	L	-.110	+.934	+1.257
	N	$5.884	+1.030	+1.317
	H	+.107	+1.110	+1.379
3QTR 2009 ($1.92 fuel price)	L	-0.269	0.537	0.569
	N	6.511	+0.864	+1.071
	H	+0.059	+0.908	+1.096

Table 20 Sensitivity of EWR Airline Profit to Hedged Fuel Price and Capacity Limits.

These fuel price trends are consistent for all three capacities for a booming economy in the third quarter 2007 and during the recession in the third quarter 2009. Profitable schedules were found for both quarters examined, even in the third quarter 2009 when most airlines were reporting significant losses.

The results of a linear regression for airline profit for EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence airline decisions on markets served (Table 21).

		Fuel Prices	GDP	Caps	Markets	Flights per Day	Aircraft Size
Profit	Pearson correlation	0.568	0.789	0.128	0.219	0.113	0.942
	P-Value	**0.014**	**0**	**0.613**	**0.382**	**0.654**	**0**

Table 21 Table shows statistically significant correlation (95% confidence) between airline profit and hedged fuel prices, GDP, and aircraft gauge.

The analysis shows correlation between airline profit to fuel prices, GDP, and aircraft gauge.

The 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 equation for daily airline profit is as follows:

$$\text{Profit} = -2.09 + 0.0167\ \text{Caps} + 0.0489\ \text{Gauge}$$

4.2.3 Air Transportation Efficiency.

4.2.3.1 Aircraft Size - The results of ASOM analysis of the average aircraft size scheduled for EWR are shown in Table 22. This table shows the Baseline (underlined) Aircraft Gauge for "Normal" Capacity Limits, and passenger demand. The remaining cells in the table show the change in aircraft gauge from this baseline. The results show that adjusting airport capacity limits up and down has little effect on aircraft gauge, but significant increases in fuel prices increased 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.

EWR Gauge	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	**L**	+5	+14	+21
	N	<u>139</u>	+13	+20
	H	-5	+9	+20
3QTR 2009 ($1.92 fuel price)	**L**	-	+15	+26
	N	<u>110</u>	+17	+30
	H	-4	+15	+30

Table 22 Sensitivity of EWR Aircraft Gauge to Hedged Fuel Price and Capacity Limits.

These fuel price trends are consistent for all three capacities for a growing economy in the third quarter 2007 and during the recession in the third quarter 2009. Profitable schedules were found for both quarters examined, even in the third quarter 2009 when most airlines were reporting significant losses.

Figure 16 shows the how the ASOM schedule of daily flights by aircraft class for EWR 3QTR 2007 changes 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.

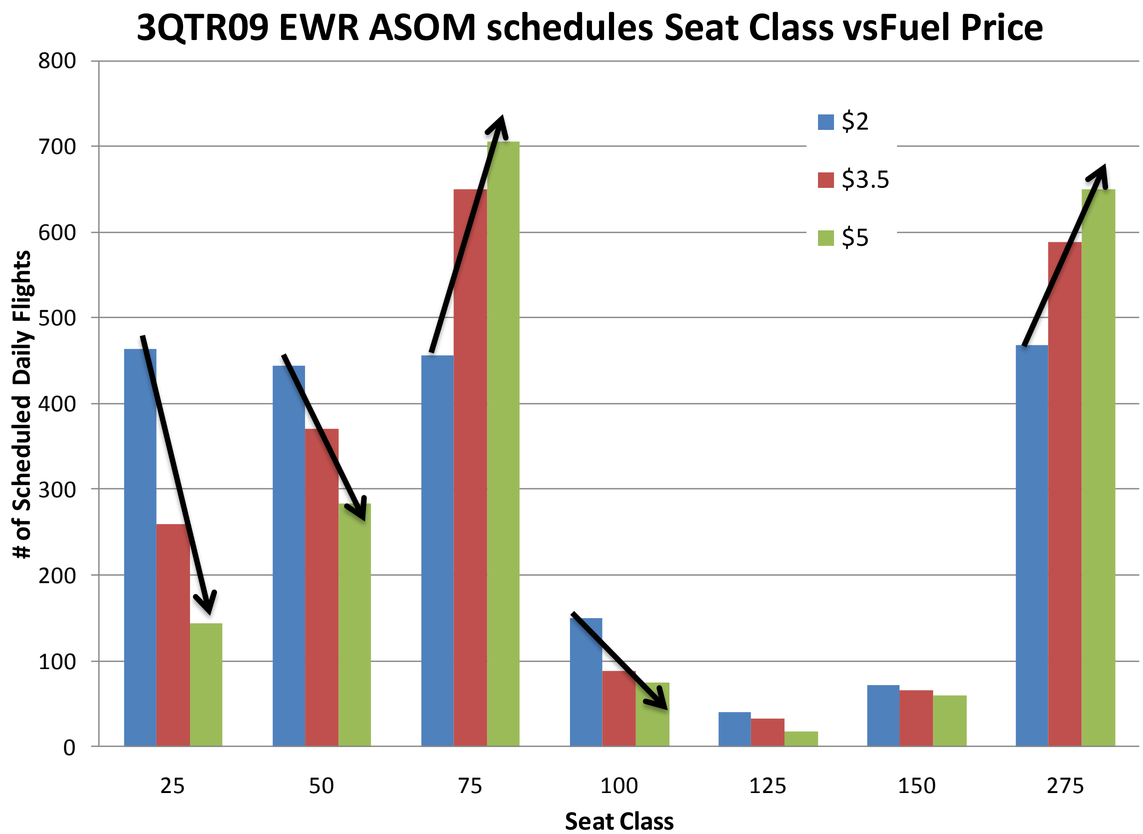

Figure 16 ASOM increases 75 and 275 seat aircraft in EWR's schedule as fuel prices increase

The results of a linear regression for aircraft gauge at EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence airline decisions on aircraft gauge (Table 23).

		Fuel Prices	GDP	Caps
Aircraft Size	Pearson correlation	0.637	0.764	-0.07
	P-Value	**0.004**	**0**	**0.781**

Table 23 Table shows statistically significant correlation (95% confidence) between aircraft gauge and hedged fuel prices and GDP.

The analysis shows correlation between aircraft gauge to fuel prices and GDP.

The stepwise regression analysis identified aircraft gauge to be a function of fuel prices, gross domestic product, and airport capacity limits. This relationship was found to be positive for gross domestic product and fuel prices, and negative for airport capacity limits. The correlation accounted for 96.9% (i.e. R-squared) of the observed variation in aircraft gauge. The remaining effects are inter-airline competition, changes in airline business models, and airline restructuring when emerging from bankruptcy. The regression equation for average aircraft gauge is as follows:

Gauge = - 1112 - 0.118 Caps + 11.8 GDP + 8.43 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. Figure 17 illustrates this point, where 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.

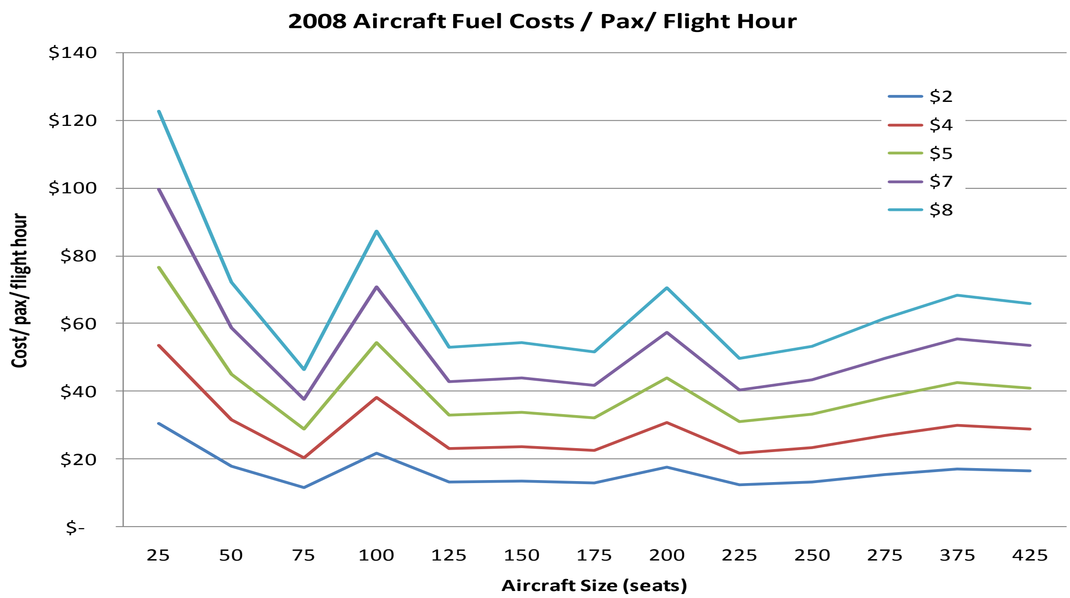

Figure 17 Poor Aircraft Performance ($/Seat-Hr) in 100 & 200 Seat Classes

4.2.3.2 Total arrival and departure seats - The results of ASOM analysis of the total arrival and departure seats for EWR are shown in Table 24. This table shows the Baseline (underlined) total arrival and departure seats for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at $2.08/gallon and $1.92/gallon. The remaining cells in the table show the change in arrival and departure seats from the baseline. 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 increases 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.

EWR Seats	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	L	-3350	3100	-1050
	N	104000	8300	1400
	H	2350	7600	5300
3QTR 2009 ($1.92 fuel price)	L	-3900	3650	5750
	N	77500	9650	13350
	H	-1100	12350	16550

Table 24 Sensitivity of EWR total arrival and departure seats to Hedged Fuel Price and Capacity Limits.

The results of a linear regression for total arrival and departure seats at EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence total arrival and departure seats (Table 25).

		Fuel Prices	GDP	Caps	Markets	Flights per Day	Aircraft Size
Seats per Day	Pearson correlation	0.28	0.903	0.194	0.542	0.424	0.874
	P-Value	**0.261**	**0**	**0.44**	**0.02**	**0.079**	**0**

Table 25 Table shows statistically significant correlation (95% confidence) between total arrival and departure seats to gross domestic product, number of direct service markets, and average aircraft gauge.

The analysis shows correlation between total arrival and departure seats to gross domestic product, markets served, and aircraft size.

The 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 equation for total daily arrival and departure seats is as follows:

Seats = - 99427 + 128 Flights + 160 Markets + 684 Gauge

4.2.3.3 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 26. This table shows the Baseline (underlined) available seat miles for "Normal" Capacity Limits (i.e. 80 operations/hour), and passenger demand at $2.08/gallon and $1.92/gallon. The remaining cells in the table show the change in available seat miles from this baseline. 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.

EWR ASM (millions)	Caps	$2	$3.5	$5
3QTR 2007 ($2.08 fuel price)	L	-4.9	-1.2	-7.3
	N	<u>**119.1**</u>	5.6	-5.3
	H	1.2	3.7	2.7
3QTR 2009 ($1.92 fuel price)	L	-7.7	-1.9	-0.3
	N	<u>**85.4**</u>	10.0	11.7
	H	-0.9	11.7	13.7

Table 26 Sensitivity of EWR available seat miles to Hedged Fuel Price and Capacity Limits.

The results of a <u>linear regression for total available seat miles</u> at EWR over two years, for three airport capacity limits and for four different fuel prices provides insights into the correlations between the variables and the significant factors that influence total available seat miles (Table 27).

		Fuel Prices	GDP	Caps	Markets	Flights per Day	Aircraft Size	Seats
ASMs	Pearson correlation	0.145	0.925	0.219	0.627	0.526	0.807	0.987
	P-Value	**0.565**	**0**	**0.382**	**0.005**	**0.025**	**0**	**0**

Table 27 Table shows statistically significant correlation (95% confidence) between available seat miles to GDP, number of direct service markets, scheduled flights per day, average aircraft gauge, and total arrival and departure seats.

The analysis shows correlation between total available seat miles to GDP, markets served, scheduled flights per day, aircraft size, and total arrival and departure seats.

The 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 equation for ASMs is:

ASM = - 10803115 - 1818714 Fuel Price + 1273 Seats

5 Conclusions

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 proportional relationships defined by the linear regressions below:

   Markets = - 98.4 + 0.122 Caps + 1.61 GDP - 1.36 Fuel Price
   R-Sq(adj) = 60.4%

   Flights = - 1392 + 2.48 Caps + 18.9 GDP - 22.3 Fuel Price
   R-Sq(adj) = 85.5%

   Gauge = - 1112 - 0.118 Caps + 11.8 GDP + 8.43 Fuel Price
   R-Sq(adj) = 96.9%

   Seats = - 99427 + 128 Flights + 160 Markets + 684 Gauge
   R-Sq(adj) = 99.8%

   ASM = - 10803115 - 1818714 Fuel Price + 1273 Seats
   R-Sq(adj) = 99.1%

   Profit = - 2.09 + 0.0167 Caps + 0.0489 Gauge
   R-Sq(adj) = 91.6%

Figure 18 identifies the relationships between factors. The multipliers establish the magnitude of the relationships between parameters. For example, a $1 increase in hedged fuel prices lead to a 22.3 reduction in scheduled flights per day to all markets. A negative relationship indicates that a positive increase in the source, leads to a decrease in the result. The bold lines show the direct and indirect contributions for airline profit.

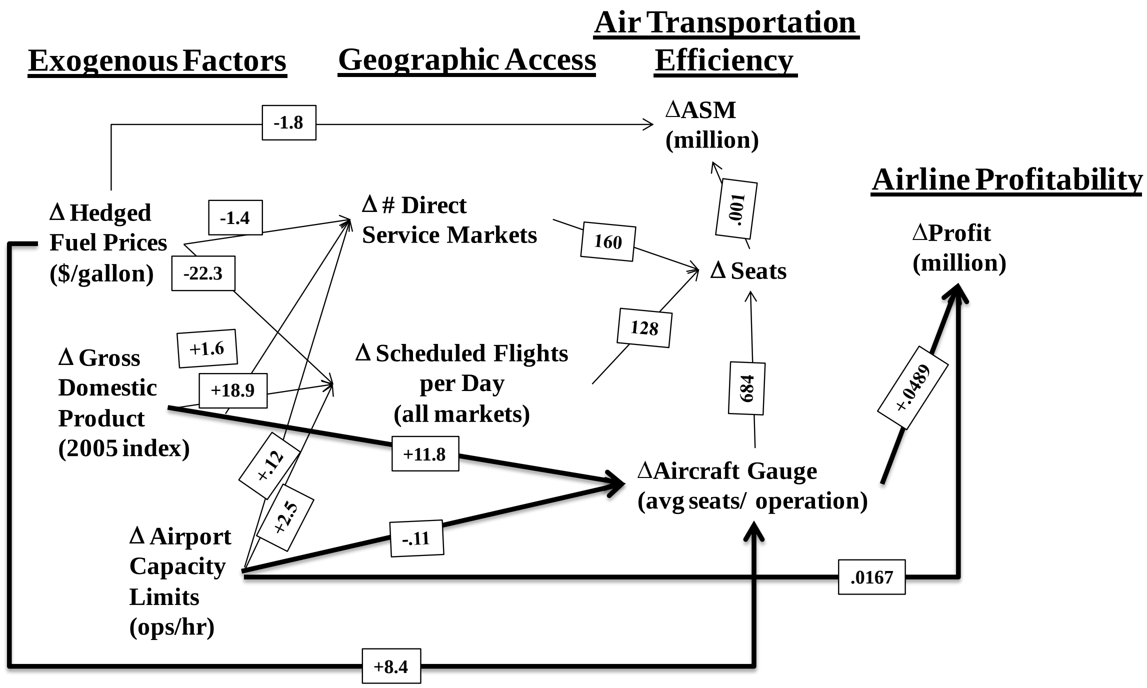

Figure 18 Summary of multipliers between the exogenous, economic access, geographic access, and airline profitability factors

2. <u>The Air Transportation System is Stable</u>: 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 hedged fuel price, as capacity limits are imposed (e.g. -4 operations per hour), markets are reduced (-.5) and scheduled flights per day to all markets decrease (-10), daily profit decreases (-$67K). In this scenario average aircraft size increases (.44 seats per operation).

   - For a fixed passenger demand and fixed capacity limits at the airports, as hedged fuel prices increase (e.g. +$1 per gallon), markets are reduced (-1.4), scheduled flights per day to all markets decrease (-22.3), daily profit increases (+$411K). In this scenario average aircraft size increases (+8.4 seats per operation). This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.

3. <u>Airport Capacity Limits Do Not Have Large Scale Negative Effects</u>: Regulatory authority to manipulate the market through the introduction of airport capacity (and airport capacity limits) has no large scale 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.

These results are summarized in the Table 28.

Objections	Observations		
	Reduction in 4 ops/ hr (Capacity Limits) leads to …	$1 increase in Hedged Fuel Prices per Gallon leads to ...	1% drop in Gross Domestic Product (ref. 2005 GDP) leads to …
Geographic Access - elimination of service (e.g. smaller markets)	-0.5 market & -10 Flights/ day	-1.4 markets & -22 Flights/ day	-1.6 markets & -19 Flights/ day
Economic Access - increased airfares	N/A	$16 increase in airfare	N/A
Airline Finances - reduced profits	Loss of $67K per day	Increase of $411K per day through Aircraft Gauge Changes	Decrease of $577K per day through Aircraft Gauge Changes
Air Transportation Efficiency - increased congestion	Reduced Congestion	Reduced Congestion & +6.4 seats/ scheduled aircraft	Reduced Congestion & +12.5 seats/ scheduled aircraft

Table 28 Impacts of Airport Capacity Limits, Hedged Fuel Prices, and Gross Domestic Product on Geographic Access, Economic Access, Airline Finances, and Air Transportation Efficiency.

4. <u>Hedged fuel prices and economic health drive air transportation performance</u>: 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 GDP) and airline operating costs (determined by fuel prices) have significant impacts.

   For example, for a fixed passenger demand and hedged fuel price, as capacity limits are imposed (e.g. -4 operations per hour), markets are reduced (-.5) and scheduled flights per day to all markets decrease (-10), daily profit decreases (-$67K). In this scenario average aircraft size increases (.44 seats per operation).

   Table 47 above demonstrates how an increase in hedged fuel price or a change in GDP results in loss of markets and flights, and small loss in profit. These factors both have the effect of increasing the average number of seats per aircraft.

5. <u>Combination of increased passenger demand and increased operating costs directly causes increase in aircraft size</u>. It is financially viable for airlines to up-gauge in order to service the passenger demand.

   <u>The airlines' ability to up-gauge does not occur in the real-world due to: (1) distortions in the labor cost structure for pilots as a result of the pilot union scope clause labor agreements, and (2) (due to #1) aircraft manufacturers have failed to design and produce aircraft appropriate to match the passenger market demand.</u>

5.1 Recommendations

1. Examine the possibility of relaxing Pilot Union Scope Clauses to incentivize aircraft manufacturers to produce, and airlines to acquire and deploy the correct sized aircraft (88 - 112 seats) to match the passenger O/D market demand.

2. Introduce capacity limits at congested airports. This has the effect of significantly reducing congestions and delays (across the NAS), without financial penalties to airlines or loss of geographic and economic access. Introduce service standards at all of the 35 largest airports so that there is a metric in place that will warn airspace management personnel that a congestion problem is likely to occur unless capacity limits are imposed.

3. Research and develop aircraft technologies (e.g. engines) to provide improved performance for the 88 - 112 seat class of aircraft. This improves airlines profits, and has the added benefit of reducing emissions.

5.2 ASOM Experiments 1 & 2 Summary

Table 29 summarizes the historical and ASOM statistical analysis of geographic access. Clearly the ASOM experiment #2 provided a more balanced experiment to understand the impacts from the exogenous factors and also provided the best function model fits or adjusted R^2.

Relationships		Historical	Exp #1	Exp #2
Markets	Hedged Fuel Prices			-1.4
	GDP	+1.44		+1.6
	Caps		+.44	+.12
	Adj R2	25.2%	8.8%	60.4%
Flights per Day	Hedged Fuel Prices		-55	-22.3
	GDP	+1.83		+18.9
	Caps		+2.8	+2.5
	Adj R2	15.6%	17.4%	85.5%

Table 29 Geographic Access Functional Models Summary

Table 30 summarizes the historical and ASOM statistical analysis of air transportation efficiency.

Relationships		Historical	Exp #1	Exp #2
Gauge	Hedged Fuel Prices			+8.4
	GDP			+11.8
	Caps			-.11
	Adj R2			96.9%
Seats	Markets			+160
	Flights per day			+128
	Gauge			+684
	Adj R2			99.8%
ASMs (millions)	Hedged Fuel Prices			-1.8
	Seats			+.001
	Adj R2			99.1%

Table 30 Air Transportation Efficiency Functional Models Summary

Table 31 summarizes the Historical and ASOM statistical analysis of airline profitability access. Clearly the ASOM experiment #2 provided a more balance experiment to understand the impacts from the exogenous factors and also provided the best function model fits or adjusted R^2.

Relationships		Historical	Exp #1	Exp #2
Profitability / Profit	Hedged Fuel Prices	-.280	-.658	
	GDP		+.229	
	Caps			+.0167
	Markets		+.016	
	Flights per Day			
	Gauge		+.027	+.0489
	Adj R2	79.6%	62.0%	91.6%

Table 31 Airline Profitability Functional Models Summary

5.2.1 Geographic Access.

The ASOM generates optimally profitable airline schedules; therefore the outputs can be directly examined for geographic access. The number of markets served directly by an airport is primarily affected by the demand for air transportation. The number of flights per day to a market is also primarily determined by passenger demand.

Capacity limits at airports did result in a small reduction in markets served and flights per day. Airline network restructuring, airline financial restructuring, and inter-airline competition also affected markets served and flights per day.

1. The fluctuations 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 1.9 decrease in the number of markets with direct service; for every $1 increase in hedged fuel prices, there is a decrease of 17.8 scheduled flights per day; and for every $1 increase in hedged fuel prices, there is a 6.4 seat increase in the average aircraft size flown.

2. The growth/decay in demand for air transportation (as measured by the GDP) is a determinant of the number of markets served. A linear regression showed that: for every incremental increase in the GDP index, there is a 1.8 increase in the number of markets with direct service; for every incremental increase in the GDP index, there is an increase of 17.3 scheduled flights per day; and for every incremental increase in the GDP index, there is a 12.5 seat increase in the average aircraft size flown. As the economy slowed, the number of markets with direct service decreased.

3. The introduction of capacity limits (as measured by limits on number of operations per hour) is a determinant of the number of markets served. A linear regression showed that for every additional operation per hour allowed, there is a .1 increase in the number of markets with direct service; for every additional operation per hour allowed, there is an increase of 2.4 scheduled flights per day.

4. Airline network restructuring (e.g. Delta's expansion at JFK), airlines financial restructuring (e.g. USAirways bankruptcy filing impacted PHL), and inter-airline competition also impact the number of markets served.

5.2.2 Economic Access

The ASOM generates optimally profitable airline schedules; therefore the outputs of markets served and airfares are a key input parameter for the model. Regression analysis of airfare versus hedged fuel prices provides the basis for results for economic accessibility. Passenger accessibility to air transportation through airfares at these airports followed established patterns of passenger demand during this period. 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).

1. 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 $330) 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.

2. The change in airfare was driven by changes in hedged fuel prices (which impacts airline operational costs) ($R2$=83.1%). At the five airports studied (LGA, JFK, EWR, PHL, and SFO), every $1 increase in hedged per-gallon fuel prices resulted in an average of $16 increase in airfares, which yielded an average reduction in passenger demand of 1.5%.

5.2.3 Airline Profitability.

The ASOM generates optimally profitable airline schedules; therefore the outputs can be directly examined for airline profitability. Airline profitability for the routes serviced at these five airports is a complex phenomenon driven by demand for air transportation, passenger's responses to price increases, and operating costs. During this period, airline profitability was 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). During the spike in fuel costs, the airlines were faced with significantly greater operating costs and decreased demand due to the economic downturn.

1. Inputs for the ASOM are preprocessed from historical data reflecting airline behaviors and responses to the exogenous factors. Therefore the ASOM input data reflects:

    a. airline profitability decreased as airlines were unable to increase airfares as fast as hedged fuel prices increased.

    b. airlines shed less profitable markets in order to improve profitability. Similarly the ASOM algorithm will eliminate the least profitable markets and flights first, when adjusting the airline schedule within airport capacity.

    c. airlines decreased aircraft size in order to maintain profitability as demand decreased. Similarly the ASOM algorithm will use the most cost efficient aircraft to meet market passenger demand.

2. Changes in airline profits are driven by changes in air transportation efficiency (as measured by gauge in this study) and airport capacity limits (R2=91.6%). For example for passenger demand and operations at EWR, daily airline profits were increased $48.9K for every additional seat per flight operation, and increased $16.7 for every additional flight operation allowed per hour (increase to capacity limits).

5.2.4 Air Transportation Efficiency.

Air transportation efficiency is measured by the throughput of passengers through the network based on aircraft size (i.e. number of seats) per runway/airspace. Air transportation efficiency is also measured by the total arrival and departure seats and by the total available seat miles scheduled in and out of the airport.

1. A linear regression showed that: for every incremental increase in the GDP index, there is an 11.8 seat increase in the average aircraft size flown; for every $1 increase in hedged fuel prices, there is an 8.4 seat increase in the average aircraft size flown; for each additional flight operation allowed per hour (increase to capacity limits), there is a decrease of .11 seats for the aircraft size flown. This statistical relationship explained for 96.9% of the variations in aircraft gauge (R2=96.9%).
2. Economic conditions (as measured by GDP in this study) and operational costs (as measured by hedged fuel prices in this study) effect changes in airline profit by driving changes in aircraft gauge. For example for passenger demand and operations at EWR, average aircraft size was increased by 8.4 seats, which causes daily airline profits to increase $411K for every $1 increase in hedged fuel prices; also, average aircraft size was increased by 11.8 seats, which causes increased $577K for every incremental increase in the GDP index. This result is valid within the hedged fuel price range of $1.50 and $4 per gallon.
3. The change in the total arrival and departure seats was driven by changes in direct service markets, the scheduled flights per day to all markets, and the average aircraft size (seats per operation) (R2=99.8%). Every additional direct market served added 160 seats to the total arrival and departure seats. 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.
4. 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 (R2=99.1%). Every $1 increase in hedged per-gallon fuel prices

resulted in a reduction of 1.8 million ASMs. An incremental increase in the total arrival and departure seats resulted in an increase of 1273 ASMs.

Note: These results are not consistent with the observed historical data. The historical data did not show the up-gauging experienced by the ASOM model. There are several explanations including: airline competition, fleet inflexibility, and airline pilot union scope clauses.

5.3 Recommendations

1. DOT and FAA should evaluate options to relax Pilot Union Scope Clauses that would allow incentives for aircraft manufacturers to produce, and airlines to acquire and deploy, aircraft in the 88 – 112-seat range. Currently, the oldest and least efficient part of the total airline industry fleet is within this category. To economically up-gauge from a regional jet, the airlines need to move from a 60-80 seat plane directly to a 120+ seat plane. Such a jump is often not economically viable.

2. Introduce capacity limits at congested airports. This has the effect of significantly reducing congestions and delays (across the NAS), without financial penalties to airlines or loss of geographic and economic access.

3. Research and develop aircraft technologies (e.g. engines) to provide improved performance for the 88 – 112-seat class. The use of such aircraft will increase the efficiency of the airspace (i.e. more passenger throughput) and will also reduce emissions.

5.4 Future Work

5.4.1 Airline Schedule Optimization Model (ASOM) to Complete the "Design of Experiment".

The historical analysis was dictated by the events that occurred during the period under study and provided an analysis of four of a possible 27 treatments (3 GDP % change possibilities x 3 fuel price % change possibilities x 3 airport capacity limit % change possibilities).

To examine the effect of the remaining treatments, an optimization model was developed. The Airline Schedule Optimization Model (ASOM), calibrated using the historical data, is used in a follow-up study to evaluate the consequences of alternative combinations of economic conditions, changes in operating costs, runway capacity restrictions and airfare changes. The results of the study will complete the design of experiment and forecast what the airlines are likely to do if the economy has a significant upswing or if the government imposes capacity restrictions at other airports.

5.4.2 Absence of Economies-of-Scale through Up-gauging (or "Cash for Clunkers").

During the calibration of the ASOM, it was observed that the optimization model failed to show the airlines increasing aircraft size from 80 to 100 seats. The ability to up-gauge in this range is critical to taking advantage of the concept of using the same runway slots to ferry additional passengers.

This behavior is a result of the absence of economies-of-scales in up-gauging in this range. The significantly higher costs of operation at the 100-seat and 200-seat class of aircraft prevent airlines from up-gauging. In the 100 seat range the only aircraft in revenue-service are the older, DC-9 class that is more expensive to operate. No new, efficient aircraft are available in this range. This phenomenon becomes more pronounced as the price of fuel increases.

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Appendix A: Validation of ASOM Model

A.1 ASOM Consistency with Historic Results for Geographic Access

Table 32 shows the summary results of a consistency check of the baseline ASOM results for markets served, scheduled flights per day and aircraft gauge when compared to the historic behavior of the airlines serving these five congested airports (LGA, EWR, JFK, SFO, PHL) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index; (2) 3QTR08 with $3.5 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The ASOM scheduled on average 2% fewer markets and 12% fewer flights for aircraft 5% smaller.

Consistency in trends and relationships is the best the ASOM will allow, since the ASOM models airline scheduling behavior from an operational versus strategic position and the ASOM does not model airline competition. The ASOM models only profitable markets, thus not strategically taking a short term loss to retain market demand. The ASOM models balanced arrivals and departures, therefore no banking is allowed.

The following sections will show consistency analysis results from comparing baseline ASOM results to historical data, comparing ASOM annual trends versus historic trends, and comparing opposite markets.

	Markets	flight/day	gauge
Mean	**-2%**	**-12%**	**-5%**
Standard Deviation	2%	5%	19%
Range	6%	19%	64%
Minimum	-6%	-21%	-28%
Maximum	0%	-2%	36%
Count	15	15	15

Table 32 ASOM results for consistency check - geographic access

A.1.1 ASOM Consistency with Historic Results for Markets Served

The ASOM baseline results for markets served was compared to historic results for all five congested airports (LGA, SFO, EWR, JFK, PHL) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index; (2) 3QTR08 with $3.5 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on ASOM consistency in predicting airline behavior.

Table 33 shows 93% of ASOM profitable markets served within 4% of historical data. The ASOM results showed on average 2% fewer profitable markets served; results for EWR 3QTR 2008, with peak fuel prices, showed 6% fewer profitable markets than the historical data.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fp)	% Δ from Hist	-3%	0%	-2%	-2%	-2%
3QTR 2008 ($3.53 fp)	% Δ from Hist	0%	-3%	**-6%**	0%	-3%
3QTR 2009 ($1.92 fp)	% Δ from Hist	0%	-2%	-4%	0%	-3%

Table 33 ASOM results for consistency check – markets served

Table 34 shows 100% of ASOM profitable market annual trends within 3% of historical annual trends. Additionally, 100% of these trends were in the same direction.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 07-08	Hist*	-6%	-25%	-12%	2%	-10%
	Model	-3%	-26%	-15%	4%	-10%
3QTR 08-09	Hist*	2%	18%	7%	6%	16%
	Model	2%	18%	9%	6%	15%

Table 34 ASOM annual trends for profitable markets

A.1.2 ASOM Consistency with Historic Results for Scheduled Flights per day

The ASOM baseline results for scheduled flights per day were compared to historic results for all five congested airports (LGA, SFO, EWR, JFK, PHL) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index; (2) 3QTR08 with $3.5 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on ASOM consistency in predicting airline behavior.

Table 35 shows 87% of ASOM scheduled flights per day within 15% of historical data. The ASOM results showed on average 12% fewer scheduled flights per day. The ASOM results for LGA and SFO 3QTR 2008, with peak fuel prices, showed 18% and 21% less scheduled flights per day respectively than the historical data.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fp)	**% Δ from Hist**	-7%	-13%	-8%	-2%	-14%
3QTR 2008 ($3.53 fp)	**% Δ from Hist**	**-18%**	**-21%**	-14%	-15%	-14%
3QTR 2009 ($1.92 fp)	**% Δ from Hist**	-7%	-10%	-11%	-7%	-13%

Table 35 87% of ASOM profitable markets served within 15% of historical data

Table 36 shows 50% of ASOM annual trends for scheduled flights per day are within 10% of historic trends. Additionally, 70% of these trends were in the same direction.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 07-08	**Hist***	-6%	3%	-10%	4%	-10%
	Model	-17%	-8%	-16%	-10%	-11%
3QTR 08-09	**Hist***	-1%	9%	2%	4%	12%
	Model	13%	24%	5%	13%	14%

Table 36 50% of ASOM trends for Scheduled Flights per day are within 10% of Historic trends

Figure 19 shows PHL third quarter 2009 historical operations per hour by time of day versus the ASOM results for capacity limits set at 72, 80 and 96 operations per hour. Modeled operations rarely meet the capacity limits since the model produces a domestic schedule therefore the historic international operations per hour are subtracted from the available capacity (72, 80 or 96) for domestic operations. It is interesting to see where the model peaks its schedule when capacity limits are relaxed to 96 operations per hour versus where the peaks were historically. But as clearly can be shown with this chart, the model is trying to create an optimal schedule that meets demand by time of day, by reducing redundant service and up gauging when economically beneficial.

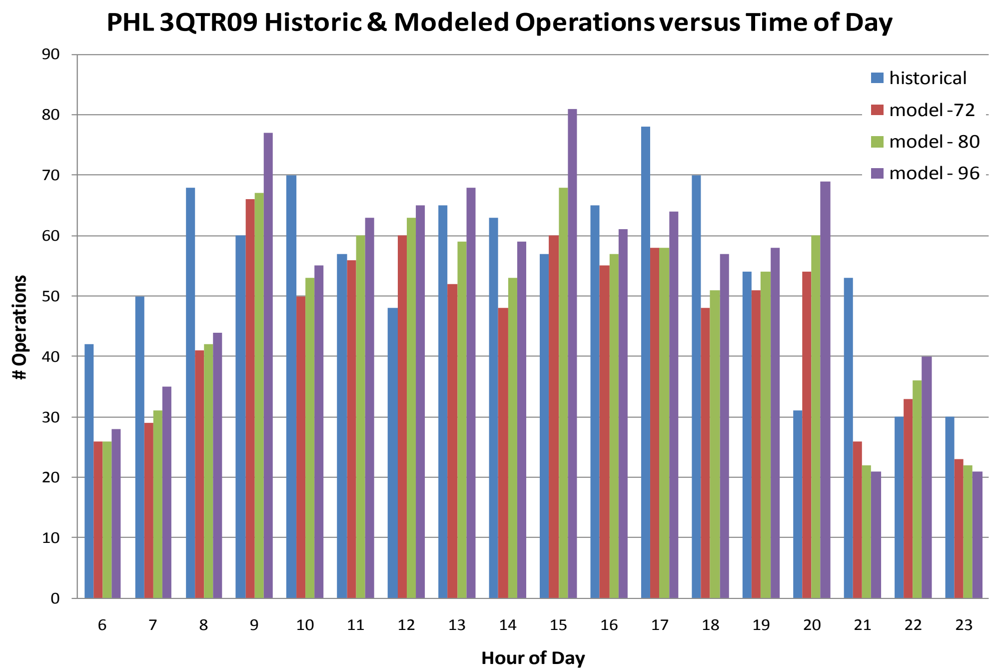

Figure 19 ASOM Distribution of daily flights matches historical distribution

A.1.3 ASOM Consistency with Historic Results for Aircraft Gauge

The ASOM baseline results for aircraft gauge were compared to historic results for all five congested airports (LGA, SFO, EWR, JFK, PHL) for three different economic scenarios: (1) 3QTR07 with $2 fuel prices and 105 GDP index; (2) 3QTR08 with $3.5 fuel prices and 105 GDP index; and (3) 3QTR09 with $2 fuel prices and 103 GDP index. The results provide insights on ASOM consistency in predicting airline behavior.

Table 37 shows 67% of ASOM results showed lower aircraft gauge than historical data. The ASOM results showed on average 5% smaller aircraft gauges than historically flown. The ASOM results for EWR 3QTR 2007 and 2008 showed greater than 30% up-gauging when compared to the historical data.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 2007 ($2.08 fp)	% Δ from Hist	-17%	-7%	30%	7%	-20%
3QTR 2008 ($3.53 fp)	% Δ from Hist	-26%	6%	36%	4%	-20%
3QTR 2009 ($1.92 fp)	% Δ from Hist	-12%	-9%	-1%	-21%	-28%

Table 37 ASOM consistency with historic results for aircraft gauge

Table 38 shows 50% of ASOM annual trends for aircraft gauge are within 10% of historic trends. Additionally, 30% of these trends were in the same direction.

	Cap	LGA	SFO	EWR	JFK	PHL
3QTR 07-08	Hist*	0%	2%	0%	2%	-1%
	Model	-10%	17%	4%	-1%	-1%
3QTR 08-09	Hist*	-1%	2%	8%	9%	2%
	Model	17%	-12%	-21%	-17%	-8%

Table 38 ASOM annual trends for aircraft gauge

A.1.4 ASOM Comparison of Opposite Markets

The ASOM results for opposite markets were compared for six market/ opposite market pairs for 3QTR09 ASOM results. The results provide insights on for predicting airline behavior.

Table 39 shows 50% of ASOM opposite markets match with flights per day. The ASOM results showed that LGA-PHL, EWR-SFO, and JFK-PHL market schedules matched well with their opposite markets. However, the ASOM results showed that EWR-PHL, JFK-SFO, and PHL-SFO market schedules did not match their opposite markets. The ASOM found reciprocal service from PHL to EWR and SFO not to be as profitable as other markets. Also, the ASOM scheduled more than twice the number of seats from SFO to JFK as compared to the opposite market.

Opposite Market Matches			
Airport	**Market**	**Flights**	**Seats**
LGA	PHL	14	350
PHL	LGA	14	350
EWR	SFO	18	2950
SFO	EWR	14	2850
JFK	PHL	2	100
PHL	JFK	4	100

Opposite Market no Match			
Airport	**Market**	**Flights**	**Seats**
EWR	PHL	4	700
PHL	EWR	0	0
JFK	SFO	38	2150
SFO	JFK	46	5550
PHL	SFO	12	1100
SFO	PHL	0	0

Table 39 ASOM Comparison of opposite markets flights per day

A.1.5 Historic versus ASOM Functional Relationships

Table 40 summarizes the historical and ASOM functional relationships found in the analysis. This ASOM analysis of airline behavior has revealed eight new functional relationships, not previously seen in the historic analysis (highlighted in green). This analysis has also reinforced three and contradicted one functional relationship previously seen in the historic analysis (highlighted in yellow). Five functional relationships found in the historic analysis were not evaluated by the ASOM (highlighted in orange). Thus the ASOM has reinforced and expanded upon known functional relationships previously found in historical analysis.

Relationships		Historical	ASOM
Hedged Fuel Prices	Airfare	+	N/A
	Aircraft Size		+
	Flights/ Day		-
	Markets		-
	Profit	-	+
Gross Domestic Product	Airfare	+	N/A
	Aircraft Size		+
	Flights/ Day	+	+
	Markets	+	+
	Profit		+
Capacity Limits	Flights/ Day	+?	+
	Markets		+
Aircraft Size	Profit		+
	Congestion	-	N/A
Flights/ Day	Profit		+
	Congestion	+	N/A
Markets	Congestion	+	N/A

8 New Relationships found in ASOM

4 Relationship founds Historic & ASOM

5 Historic Relationships Not Examined in ASOM

Table 40 The ASOM functional relationship with historical analysis

Figure 20 graphically illustrates the finding shown in table 60. Specifically the ASOM was consistent in finding positive relationships between gross domestic product and airline schedules, and the ASOM was consistent in finding a positive relationship between capacity limits and airline schedules. Only one contradiction was found with the relationship between hedged fuel prices and profit.

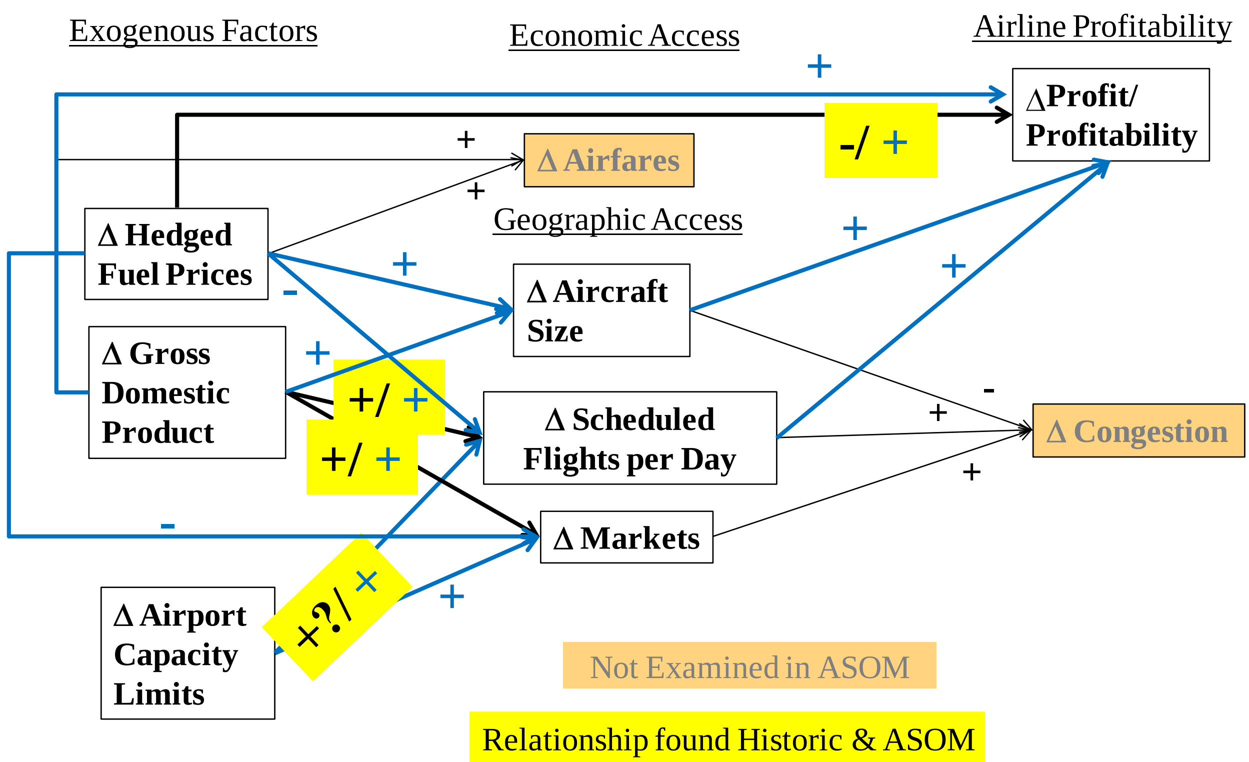

Figure 20 Graphical illustration of ASOM and historic analysis relationships

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 10 - 2010

2. REPORT TYPE
Contractor Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Optimizing Air Transportation Service to Metroplex Airports - Part II: Analysis Using the Airline Schedule Optimization Model (ASOM)

5a. CONTRACT NUMBER
NNX07AT23A

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Donohue, George; Hoffman, Karla; Sherry, Lance; Ferguson, John; Kara, Abdul Qadar

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
411931.02.71.07.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/CR-2010-216861

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 03
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES
Langley Technical Monitor: Rosa M. Oseguera-Lohr

14. ABSTRACT
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; the failure to increase capacity at the same rate as the growth in demand results in unreliable service and systemic delay. This report describes the results of an analysis of airline strategic decision-making that affects geographic access, economic access, and airline finances, extending the analysis of these factors using historic data (from Part 1 of the report). The Airline Schedule Optimization Model (ASOM) was used to evaluate how exogenous factors (passenger demand, airline operating costs, and airport capacity limits) affect 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 airport capacity limits, as well as the effect of increased hedged fuel prices, which serve as a proxy for increased costs per flight that might occur if auctions or congestion pricing are imposed; also incorporated are demand elasticity curves based on historical data that provide information about how passenger demand is affected by airfare changes.

15. SUBJECT TERMS
Air transportation; Airports; Airline operations; Metroplex operations; Airline scheduling; Airline schedule optimization

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
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