Operational Consequences of Alternative Airport Demand Management Policies

Case of LaGuardia Airport, New York

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The current demand management policy at LaGuardia Airport (LGA) New York, must be changed in 2007 under the provision of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century of April 2000 (AIR-21). As a preliminary step for developing a new policy, this study considered how past policies, along with other factors, have affected operational performance at LGA. The interaction between LGA and the rest of the aviation system was also investigated by estimating simultaneous equations of average delay for LGA and the National Airspace System (NAS) by using two-stage least squares. The results demonstrate that the arrival delay impact of AIR-21 on LGA was in the form of Increased Ground Delay Program holding and that although delay increased markedly under AIR-21, there were also observable improvements in the ability of LGA to handle traffic. Furthermore, on the basis of the simultaneous equations analysis, it was found that 1 min of arrival delay at LGA causes about 2 min of delay elsewhere in the NAS, suggesting that demand management at LGA is a national rather than a local issue.

New York's LaGuardia Airport (LGA) is currently the object of intense scrutiny by aviation policy makers. For many years, LGA was recognized as an airport that could not accommodate unconstrained demand. As a result, there have been a succession of demand management regimes, beginning with the high-density rule, followed by the virtual elimination of restrictions under the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century of April 2000 (AIR-21) and the imposition of the so-called Slottery after that. Congress mandated that the current demand management policy at LGA end in 2007, spurring a new round of analysis and policy making geared toward developing a new policy by that time.

As the studies and deliberations continue, it is useful to look back at how past policies have affected operational performance at LGA. Of particular interest is the effect of AIR-21, which was widely perceived to have been disastrous and created a conviction that some form of demand management is absolutely necessary for LGA. Operational trends after AIR-21 are also of interest because they help determine how current policies are working and may work in the future in containing delay.

This study analyzes recent operational experience at LGA and explores how operational results have changed under the various demand management regimes. First the policy history is summarized and the different regimes that have been in place since 1968 are described. Next the operational performance of LGA under the different regimes is compared. An analysis of the performance trends is presented in more detail, with a simultaneous, multivariate model of delay at LGA and in the rest of the National Airspace System (NAS). This model allows differences in delay at LGA under the different regimes to be decomposed by causal factors and the spillover effects of LGA delay on the rest of the NAS (and vice versa) to be assessed.

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EVOLUTION OF DEMAND MANAGEMENT POLICIES

In much of the developed world, demand management through slot restrictions is a common practice. In Europe, for example, slots are allocated on the basis of European Economic Community Council Regulation No. 95/93 and rules coordinated by the International Air Transport Association (IATA) (*1*). The applied policies are mainly "grandfather rights" and "use-it-or-lose-it" rules. Nonattributed, newly created, withdrawn, or given-up slots are pooled and redistributed with priority given to new entrants (*2*). Airlines are allowed to exchange slots without financial transfers. Demand management has been used at some European airports, such as London Heathrow and Paris Charles de Gaulle, since the early 1970s. There is ongoing debate on the revision of the IATA-based slot allocation procedures in favor of market-based approaches. Leading in that area, the U.K. government sponsored a series of studies on demand management that envisage a future "concession system with a time limitation combined with secondary trading and auctioning slots from the pool" (*1*).

The U.S. situation is much different. At virtually all U.S. airports, runway access is on a first-come, first-served basis. Airport access in these cases is only restricted by the availability of terminal facilities. Slot controls have been used at five U.S. airports. In 1968, the high-density rule (HDR) was promulgated to reduce delays at Chicago O'Hare in Illinois and Washington National Airport and three New York airports—Kennedy, Newark, and LaGuardia (the rule was terminated in the 1970s at Newark Airport). The rule was supposed to expire at the end of 1969 but was extended several times, indefinitely in 1973. At LaGuardia Airport, HDR limited the hourly slots (landing or takeoff rights) to 68 between 6:00 a.m. and midnight. Six slots were reserved for general aviation, military, and charter flights, leaving 62 slots per hour for commercial airline flights (*3*). Initially, slots were distributed by a scheduling committee composed of representatives from different airlines. After deregulation, the scheduling committee process was replaced by the use-it-or-lose-it and buy-sell rules issued by FAA in 1985. Although in principle these rules created a market for slots, airlines proved reluctant to sell them, particularly to new competitors (*4*).

In the early 1990s, FAA granted 42 slot exemptions for air service to LaGuardia authorized by the Federal Aviation Authorization Act. Unlike regular slots, these could not be sold and were authorized for specific types of flights: new international flights, new entrant airlines, and essential air services. The exemptions and the restrictions on their use reflected compromises between competing forces, including those concerned that slot restrictions stifled competition and airport neighbors who wished to maintain controls because of noise impacts (*4*). The granting of slot exemptions posed another obstacle to the slot market, since potential buyers conjectured that through exemptions they could obtain access to LGA without paying for slots.

More recently, AIR-21 was enacted, which requires that slot controls be eliminated after January 1, 2007. It also encouraged service to connect the HDR airports and small hub or nonhub airports. AIR-21 granted immediate exemptions to the slot restrictions for flights by regional jets with fewer than 72 seats and providing nonstop service to small-hub or nonhub airports while permitting new entrant carriers and limited incumbent carriers to apply for additional exemptions (*4*). By fall 2000, more than 300 exemption requests per day had been approved for LGA, with a similar number still pending. Delay at LGA dramatically increased. Many observers believe that after AIR-21 these delays had a severe impact on operations throughout the NAS (*5–7*). One analysis by the MITRE Corporation showed that on one particular day, "some 376 flights traveling to 73 airports experienced flights delays because their aircraft had passed through LaGuardia at least once that day" (*8*).

The airport operator, Port Authority of New York and New Jersey, considered the LGA situation to be untenable and on September 19, 2000, announced that it was imposing a moratorium on additional flights there. Following this lead, FAA announced a plan to rescind the AIR-21 slot exemptions that it had already granted and redistribute some those exemptions by a lottery. FAA described this as only a temporary solution that would terminate on September 15, 2001. FAA capped the number of operations per hour for commercial flights at 75. In this way, more than 100 flights permitted under AIR-21 were eliminated, and the remaining exemptions allocated by a lottery on December 4, 2000. The same slot limits and methods for allocating slots continue in place today, but the AIR-21 mandate to remove slot controls at LGA by January 1, 2007, also remains.

OPERATIONAL PERFORMANCE AT LGA

This assessment of LGA operational performance is for January 2000 to June 2004, which was divided into several periods corresponding to demand management policies and other events, most notably the terrorist attacks on September 11, 2001 (9/11), that affected demand at LGA. Starting in 2002, the periods correspond to calendar years. Figure 1 identifies the periods and plots weekday average scheduled

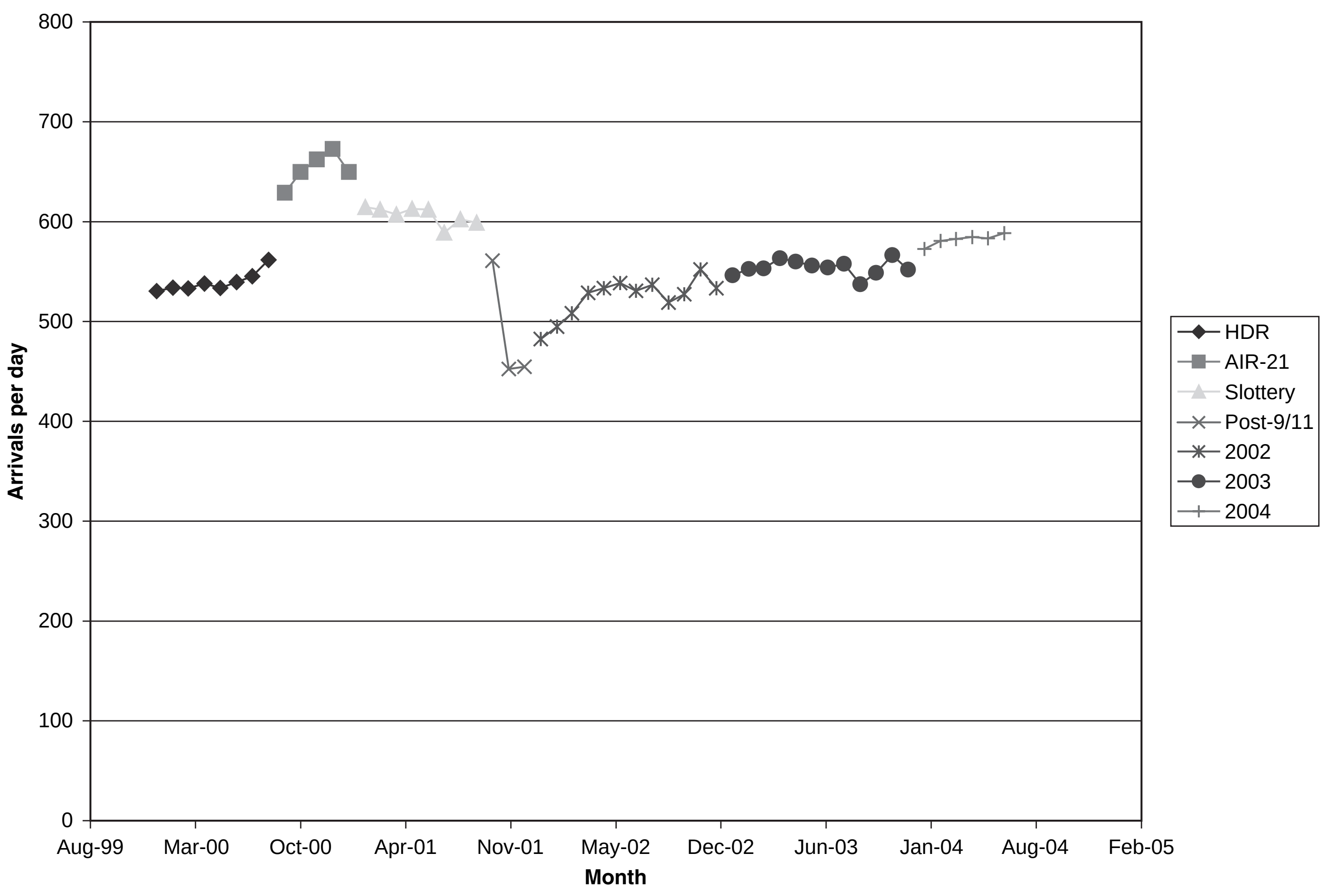

FIGURE 1 Average weekday scheduled arrivals at LGA by month.

flight demand for the associated months. Altogether, there is a total of seven periods:

- The HDR period, from January through August 2000; although AIR-21 took effect in May 2000, one can see from Figure 1 that it was not until September that scheduled flights increased significantly;
- AIR-21 period, from September 2000 through January 2001;
- Slottery period, from February 2001 through September 10, 2001;
- Post-9/11 period, through the end of 2001;
- Year 2002;
- Year 2003; and
- The first half of 2004.

The data used in this analysis are from the Aviation System Performance Metrics (ASPM) database, maintained by FAA's Aviation Policy and Plans Office. Quarter hourly data on delay, cancellations, throughput, demand, and called arrival rates were used. The most important statistic for the current purposes is the average arrival delay per flight (Table 1). Arrival delay is measured against the scheduled arrival time and counts early arrivals as having zero (as opposed to negative) delay. The observed arrival delays under visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) have similar trends. These delays increased by about 11 min after AIR-21, reaching 26 min under VMC and 37 min under IMC. With the introduction of the Slottery, the delays dropped approximately to HDR levels. They fell even more precipitously with the reduction in traffic after 9/11 and have been climbing slowly but quite consistently as traffic has recovered in the years since.

Another metric that reflects airport operational performance is the cancellation rate, which is the cancelled arrival counts divided by the scheduled arrivals. From Table 1, it can be seen that cancellation rates under VMC for AIR-21 are three times those for HDR. The increase under IMC is slighter. The cancellation rate remained high even after the implementation of the Slottery. The rates plummeted after 9/11 and then steadily increased during the following years, reaching AIR-21 levels under VMC conditions during the first half of 2004.

Table 1 includes the saturation rate, which is the proportion of quarter hours when arrival demand was greater than the airport arrival acceptance rate (AAR). Also presented are the average arrival count and average arrival demand under saturation. Aside from 2004, the AIR-21 period has the highest saturation rates under both VMC and IMC conditions. The saturation rates decreased after the implementation of the Slottery and dropped sharply after 9/11. They come back to the almost same level as those in the HDR period in 2002 and closely matched the rates in the Slottery period in 2003. In the first half of 2004, the saturation rates were exceedingly high. This finding may be related to changes in how the AARs are set, which will be considered later.

For those quarter hours in which there is saturation, the average arrival count and demand are presented in Table 1. The average arrival count under saturated conditions is a measure of airport capacity based on actual counts rather than called rates (acceptance rates of arrivals or departures determined by air traffic controllers). The average arrival counts in the different periods are close together. The excessive demand pressure created by the AIR-21 exemptions appears to have increased saturation counts slightly, an effect that persisted in the later periods except for the months just after 9/11. The low VMC arrival count after 9/11 probably reflects reduced demand.

The arrival demand metric presented in Table 1 reflects the number of aircraft expected that want to land at LGA in a given time period based on their flight plan at the time of departure. A flight is counted as demand in a given quarter hour if its planned wheels-on time is before or during that period and it has not landed or if it lands during that period. Average arrival demand under saturation is a measure of the severity of congestion—the length of the virtual queue—during saturated periods. This congestion increased dramatically after AIR-21, especially under VMC, reflecting the effect of the expanded schedule. The Slottery pushed this metric back to nearly pre-AIR-21 levels under VMC but not under IMC. The subsequent trends reflect the pattern of post-9/11 retrenchment and subsequent recovery seen in the other metrics.

TRENDS IN RATES AND CAPACITIES

Several of the metrics reported in Table 1 are based on the concept of a saturated period, which is defined here as one in which demand exceeds the reported AAR. Table 1 shows that the average AARs have varied over time, increasing slightly after AIR-21 and fluctuating thereafter. Although the called rate is supposed to reflect controllers' estimates of airport arrival capacity in a given quarter hour, it may also be affected by other factors. For example, in recent years FAA has used the ratio of arrival count to AAR to calculate the airport efficiency metric. The use of this metric may encourage lower rates to be called in order to make the airport look more efficient.

TABLE 1 Airport Operational Performance at LGA

	Average Arrival Delay		Cancellation Rate		Saturation Rate		Arrival Count*		Arrival Demand*		AAR	
	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC
HDR	14.00	28.66	0.02	0.08	0.30	0.25	8.31	7.39	10.99	12.59	8.80	8.29
AIR-21	26.20	37.30	0.06	0.11	0.36	0.29	8.67	7.87	15.42	15.18	8.81	8.68
Slottery	14.45	30.20	0.05	0.13	0.35	0.27	8.77	8.06	11.68	16.69	8.97	8.63
Post 9/11	5.80	10.14	0.02	0.02	0.23	0.19	7.43	7.27	8.19	9.68	8.60	8.93
Year 2002	9.55	21.12	0.02	0.05	0.28	0.27	8.10	7.68	9.96	14.02	8.93	8.74
Year 2003	10.55	18.61	0.03	0.08	0.33	0.29	8.44	7.91	11.05	13.65	8.81	8.58
Year 2004	11.62	24.73	0.06	0.08	0.40	0.40	8.56	8.26	11.18	15.16	8.19	8.00

*For those quarter hours with arrival demand larger than acceptance rate

This situation suggests that the AAR may not be a reliable measure of the capacity at LGA.

To obtain an alternative estimate, quarter-hourly ASPM data were used to find the capacity by using Tobit regression. The data used are from January 2000 to June 2004 and included quarter-hour arrival counts, arrival demand, runway configuration, and visibility condition (IMC or VMC). In the quarter hours when arrival demand is greater than capacity, the arrival count reveals the capacity. For the time periods when the arrival demand is less than the capacity, the observed count is a reflection of demand rather than capacity.

Let C_i^* represent the capacity; C_i, the observed arrival count; and A_i, the arrival demand for quarter hour *i*. The mathematical formulation is

$$C_i = C_i^* \quad \text{for } A_i \geq C_i^*$$

$$C_i = A_i \quad \text{for } A_i \geq C_i^* \qquad (1)$$

A simple expression is assumed for capacity at LGA such that $C_i^* = a_{\text{con}(i)} + \epsilon_i$, where $a_{\text{con}(i)}$ is the average capacity of LGA under condition *i* (where condition refers to both runway use and visibility) and ϵ_i is a random error term, which is assumed to be normal. This model is called a Tobit model, and unbiased and consistent estimates for the average capacities can be obtained by using data for demand and count for time periods in which a given condition prevails.

This estimation was carried out for each of the seven periods identified earlier. The estimates are shown in Table 2. In 2004, the most recent period, capacity under VMC varies between 8.7 and 10.5 (per quarter hour) and under IMC between 7.7 and 9.2. The more common runway configurations have VMC capacities over 10 and IMC capacities between 8 and 9. However, there are several configurations in which IMC capacity drops below 8. These are generally cases in which, as a result of crosswinds, a single runway must be used. Table 2 suggests that VMC capacities declined somewhat under AIR-21 for the most common configurations. For example, in the HDR period the VMC capacity for runway configuration 22|13 was 10.7, whereas during the AIR-21 period it was 9.7. More generally, results suggest an inverse relationship between VMC capacity and the amount of traffic in the system. This finding may be related to congestion in the airspace in the eastern United States that, under high traffic conditions, impairs the delivery of flights to the LGA terminal area at the planned times used to construct the demand variable. Fleet mix changes engendered by AIR-21 may also play a role. Whatever the cause, the effect seems to exist only under VMC conditions.

MULTIVARIATE MODELS OF LGA AND NAS DELAY

Simultaneous models of delay at LGA and in the rest of the NAS were used to decompose average daily delay at LGA into components related to different delay causes and to assess the spillover effects of LGA delay. The assessment of spillover effects through simultaneous estimation provides an alternative to previous studies of delay spillover (*9, 10*), which rely on simulations. In addition to having a stronger empirical base, the econometric approach reflects the overall experience during a large sample of days instead the handful of days typically considered in a simulation.

For LGA, the explanatory variables include congestion and weather conditions at LGA itself, delay at other airports, convective weather, and other factors. The model of NAS delay includes as explanatory variables delay at LGA, congestion and weather conditions at airports other than LGA, convective weather, and other factors. The models form a simultaneous system because LGA delay is explained partly by NAS delay, and NAS delay is explained partly by LGA delay. To estimate the models, the fact that each model contains variables that are not included in the other model was exploited. In econometric terms, the equation system is overidentified. This method allows the use of two-stage least squares [as described, for example, by Pindyck and Rubinfeld (*11*)] for estimation.

TABLE 2 Estimation Results for Tobit Arrival Capacity Model for LGA

			Period						
CONF*	MC**	PCT***	HDR	AIR-21	Slottery	Post 9/11	2002	2003	2004
22|13	VMC	18.7	10.7	9.7	10.5	11.0	10.9	10.7	10.5
22|31	VMC	19.7	9.5	9.5	10.2	10.5	10.3	10.2	10.2
31|4	VMC	16.6	11.0	9.7	10.2	10.8	10.8	10.4	10.5
4|13	VMC	9.3	11.5	9.9	10.5	11.9	10.9	10.9	10.4
31|31	VMC	7.5	8.3	8.6	8.1	8.0	8.1	8.2	8.8
Other	VMC	9.5	9.0	9.1	7.8	8.9	9.0	9.9	8.7
22|13	IMC	4.9	8.9	8.4	8.5	9.1	9.1	9.0	8.8
22|31	IMC	1.0	7.9	9.3	9.3	9.4	9.3	8.9	8.9
31|4	IMC	0.7	8.3	8.8	8.9	9.0	8.5	9.4	8.8
4|13	IMC	8.0	8.5	8.3	8.3	9.2	8.5	8.9	8.8
31|31	IMC	0.2	5.2	8.9	10.2	na	5.8	8.1	9.2
Others	IMC	3.8	6.8	7.9	5.8	3.3	6.7	6.6	7.7

*CONF: runway configuration
**MC: meteorological condition
***PCT: percentage of configuration used from January 2000 to June 2004

Model Variables

Arrival Delay

One cause of arrival delay at a given airport is congestion at other airports. At the individual flight level, delays propagate forward to create additional delays downstream. Aggregated to the daily level, higher congestion at other airports is expected to result in higher average arrival delay at LGA, and vice versa. In the models described here, arrival delay against schedule was used as the delay metric. This usage is reasonable because at the daily level, arrival and departure delays are highly correlated. Thus for the LGA average arrival model, daily average arrival delay at other airports was used on the right-hand side. The average is based on all flights arriving at the 31 benchmark airports other than LGA. Similarly the NAS average delay model contains the LGA average delay on the right-hand side. To accomplish the simultaneous estimation, predictions of the two delay variables were actually used on the right-hand sides, based on the fully exogenous variables in the two models.

Deterministic Queuing Delay

Deterministic queuing delay indicates the operational demand and supply relationship at the airport. For a given day, scheduled arrival demand at LGA based on the *Official Airline Guide,* cancellations, and the estimated capacity from the previous section in this paper on trends in rates and capacities was used to construct the daily deterministic queuing delay variable (Figure 2). The cumulative flight demand at quarter hour i is the sum of scheduled arrival demand minus all cancellations until time i. The arrival count in each quarter hour is restricted by either arrival demand or capacities, which ensures that the curve of cumulative arrival counts is always below the demand curve. The area between these two curves is the total delay. The daily average queuing delay at LGA was calculated by dividing this total delay by the total number of LGA arrivals in that day. For NAS queuing delay, the same method was used aggregated to obtain an average for arrivals at the 31 benchmark airports other than LGA.

Adverse Weather

Adverse weather was introduced in two ways. First, convective weather was modeled by using a daily summary of en route weather information based on the hourly data obtained from the Surface Summary of Day database maintained by the National Oceanographic and Atmospheric Administration. That database contains various weather observations for 1,500 U.S. weather stations. Each observation contains a binary variable indicating whether the station had recorded thunderstorms during that day. The whole country was divided into regions of 10 degrees latitude by 10 degrees longitude (Figure 3) and the proportion of weather stations in each region reporting thunderstorms was computed. Convective weather makes certain portions of the en route airspace unflyable, forcing reroutes, ground holds, and other restrictions. It also disrupts operations in terminal areas.

As a second weather metric, the proportion of the day in which LGA (for the LGA model) or the other benchmark airports (for the NAS model) were under IMC was used. Airports have lower capacity under IMC. Although in theory this effect should be reflected in the AAR and thus the queuing variable, results from the previous section on operational performance at LGA suggest that the called AARs may not fully reflect capacity differences between IMC and VMC.

Total Flight Operations

As an additional variable in the NAS model, the total flight operations to all 32 benchmark airports were included. This variable captures effects of traffic volume not reflected in the other variables.

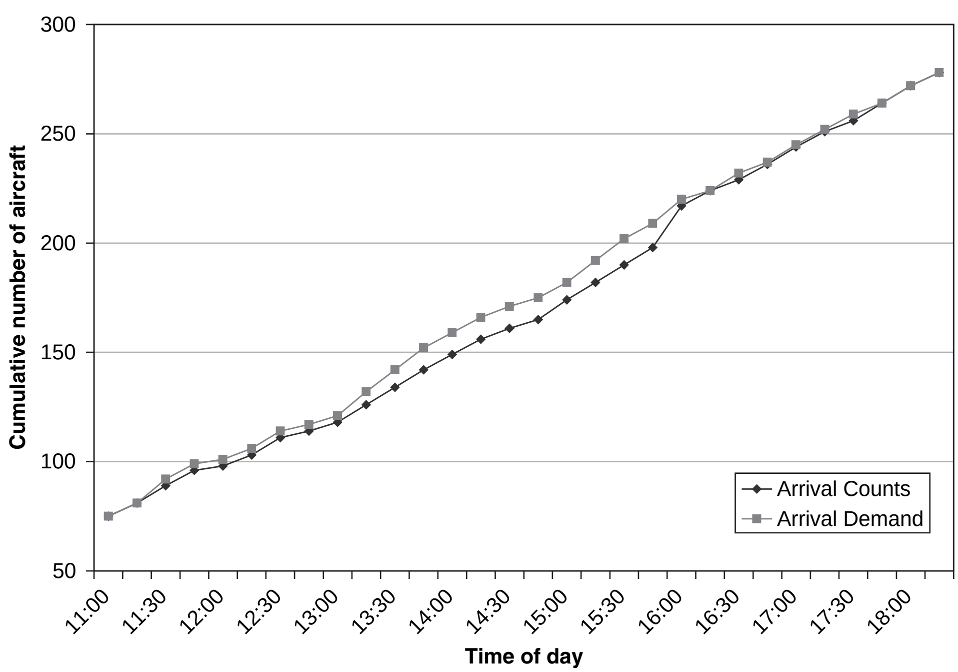

FIGURE 2 Queuing diagram of arrivals at LGA.

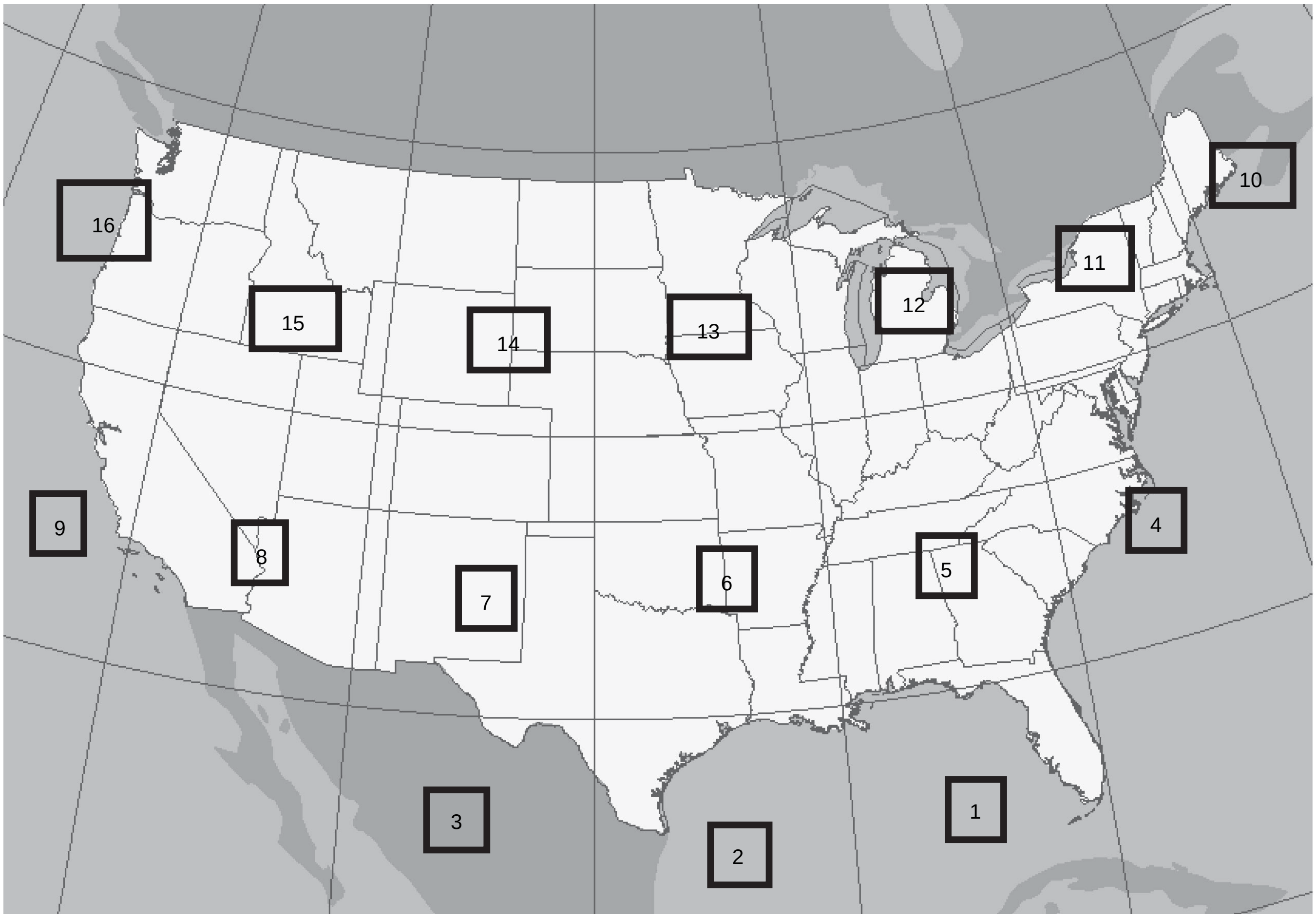

FIGURE 3 Regions for weather index calculation.

Model Specification and Estimation

Two multivariate models of average arrival delay were estimated with the factors discussed in the previous paragraphs. In addition, to compare the effect of different time periods, dummy variables were introduced that are set to 1 if the day is within one of the specified time periods and 0 otherwise. A set of dummy variables was also employed to capture the seasonal effects. Thus, the base specifications of average arrival delay are the following, in which the variables with the caret represent predictions based on exogenous variables in the two models:

Model 1 (daily average arrival delay at LGA):

$$D_L(t) = \alpha_L + \beta_1 \times \hat{D}_S(t) + \beta_2 \times LQ(t) + \beta_3 \times LQ^2(t) + \beta_4 \times I_L(t) + \beta_5 \times I_L(t)^2 + \sum_k \lambda_{kL} W_k(t) + \sum_i \omega_{iL} Q_i(t) + \sum_j \theta_{jL} D_j(t) + v(t)$$

Model 2 (daily average arrival delay at rest of benchmark airports):

$$D_S(t) = \alpha_S + \gamma_1 \times OP(t) + \gamma_2 \times \hat{D}_L(t) + \gamma_3 \times SQ(t) + \sum_k \lambda_{kS} W_k(t) + \sum_i \omega_{iS} Q_i(t) + \sum_j \theta_{jS} D_j(t) + u(t)$$

where

$D_L(t)$ = average observed arrival delay against schedule at LGA on day *t;*
$\hat{D}_S(t)$ = average observed arrival delay at airports other than LGA on day *t;*
$LQ(t)$ = average arrival deterministic queuing delay at LGA on day *t;*
$SQ(t)$ = weighted average arrival deterministic queuing delay of system on day *t;*
$OP(t)$ = total operations (arrivals) of system on day *t;*
$I_L(t)$ = daily IMC_ratio recorded at LGA on day *t;*
$W_k(t)$ = weather index of different regions on day *t;*
$Q_i(t)$ = seasonal dummy variable, set to 1 if daily arrival delay is observed in quarter *i* and 0 otherwise;
$D_j(t)$ = demand management regime dummy variable, set to 1 if daily arrival delay is observed in time period *j* and 0 otherwise;
$v(t)$, $u(t)$ = stochastic error terms; and

α, β, λ, ω, θ, and γ are coefficients.

In a standard regression, it is assumed that the error term is normally, identically, and independently distributed. However, initial estimation experience reveals that the errors are heteroscedastic and autocorrelated. In Model 1, the heteroscedasticity was related to the departure delay at other airports and the queuing delay at LGA; the higher the value of $\hat{D}_S(t)$ or $LQ(t)$, the greater the variances of the error terms. In Model 2, there is no systematic heteroscedasticity but only that related to time series. Thus, a similar approach as that in the section on operational performance at LGA was used, applying, for Model 1, a generalized autoregressive conditional heteroscedastic (GARCH) model:

$$v_t = \epsilon_t - AR1 \times v_{t-1}$$

$$\epsilon_t = \sqrt{h_t} \cdot e_t$$

$$h_t = \text{ARCH0} + \text{ARCH1} \times \epsilon_{t-1}^2 + \text{GARCH1} * h_{t-1} + \left[\text{Het1} \times \hat{D}_S(t) + \text{Het2} \times LQ(t)\right]$$

$$e_t \sim \text{IN}(0,1)$$

where AR1 ARCH0, ARCH1, GARCH1, and Het are coefficients to be estimated. The Model 2 specification is analogous except that the Het1 and Het2 terms are excluded.

These models were estimated using two-stage least squares following the procedure described by Pindyck and Rubinfeld (*11*). Taking autocorrelation and heteroscedasticity into consideration, in each stage, models are estimated by using feasible least squares instead of ordinary least squares.

Estimation Results

Estimation results are shown in Table 3 and 4. From the R^2 results in the last row of Table 3, it is apparent that the LGA model explains about 47% of the variation in average daily arrival delay at LGA. The estimated coefficient for average queuing delay is 1.57. However, the negative coefficient for the quadratic term shows that this effect attenuates with the increase of queuing delay. Nonlocal factors also contribute to delay at LGA. One minute of delay at other airports causes about 1.24 min of increased delay at LGA. Of the convective weather variables, only two were found statistically significant (see Figure 3 for identification of regions). It should be noted

TABLE 3 Estimation Results of Arrival Delay at LGA

	Description		Estimate	SE	*p*-Value
Intercept			−1.18	2.11	0.58
$LQ(t)$	Average queuing delay at LGA		1.57	0.21	<.0001
$LQ^2(t)$	Quadratic average queuing delay at LGA		−0.03	0.01	<.0001
$D_S(t)$	Predicted arrival delay for NAS		1.24	0.12	<.0001
$I(t)$	IMC_ratio		17.41	2.64	<.0001
$I(t)2$	Square of IMC_ratio		−7.36	2.91	0.01
$W_1(t)$	Thunderstorm ratio	Region 1	−2.13	1.98	0.28
$W_2(t)$		Region 2	0.37	2.18	0.87
$W_3(t)$		Region 3	2.42	7.67	0.75
$W_4(t)$		Region 4	5.98	3.31	0.07
$W_5(t)$		Region 5	−5.14	2.81	0.07
$W_6(t)$		Region 6	−5.85	2.81	0.04
$W_7(t)$		Region 7	0.50	3.97	0.90
$W_8(t)$		Region 8	8.06	7.10	0.26
$W_9(t)$		Region 9	−10.62	10.10	0.29
$W_{10}(t)$		Region 10	0.58	7.16	0.94
$W_{11}(t)$		Region 11	33.50	4.09	<.0001
$W_{12}(t)$		Region 12	−6.44	3.53	0.07
$W_{13}(t)$		Region 13	2.72	2.23	0.22
$W_{14}(t)$		Region 14	−3.24	4.36	0.46
$W_{15}(t)$		Region 15	−15.76	7.04	0.03
$W_{16}(t)$		Region 16	−5.31	15.01	0.72
$D_2(t)$	Dummy variable for the AIR-21 period		2.20	1.21	0.07
$D_2(t)$	Dummy variable for the Slottery period		−0.44	1.40	0.75
$D_2(t)$	Dummy variable for the post 9/11 period		−4.87	2.15	0.02
$D_2(t)$	Dummy variable for year 2002		−1.17	1.30	0.37
$D_2(t)$	Dummy variable for year 2003		−0.59	1.27	0.64
$D_2(t)$	Dummy variable for half of year 2004		−1.43	1.27	0.26
$Q_1(t)$	Dummy variable for Quarter 1		−2.49	0.80	0.00
$Q_2(t)$	Dummy variable for Quarter 2		−1.67	1.14	0.14
$Q_3(t)$	Dummy variable for Quarter 3		−0.02	1.26	0.99
R-square			0.47		

Thunderstorm ratio: the number of stations reported thunderstorm/total amount of stations

TABLE 4 Estimation Results of Arrival Delay for NAS

	Description		Estimate	SE	*p*-Value
Intercept			7.42	0.83	<.0001
$OP(t)$	Total operations (arrivals) in the system		0.00	0.00	0.66
$D_L(t)$	Predicted average arrival delay at LGA		0.09	0.01	<.0001
$SQ(t)$	Average arrival queuing delay of system		1.19	0.04	<.0001
$W_1(t)$	Thunderstorm ratio	Region 1	2.47	0.64	0.00
$W_2(t)$		Region 2	–0.59	0.56	0.29
$W_3(t)$		Region 3	1.36	2.04	0.50
$W_4(t)$		Region 4	2.96	0.84	0.00
$W_5(t)$		Region 5	4.03	0.71	<.0001
$W_6(t)$		Region 6	4.39	0.62	<.0001
$W_7(t)$		Region 7	0.79	1.28	0.54
$W_8(t)$		Region 8	−1.85	2.10	0.38
$W_9(t)$		Region 9	1.63	2.91	0.58
$W_{10}(t)$		Region 10	–0.62	1.99	0.75
$W_{11}(t)$		Region 11	3.08	1.18	0.01
$W_{12}(t)$		Region 12	9.73	0.88	<.0001
$W_{13}(t)$		Region 13	0.08	0.77	0.92
$W_{14}(t)$		Region 14	–0.19	1.16	0.87
$W_{15}(t)$		Region 15	2.63	1.73	0.13
$W_{16}(t)$		Region 16	−1.75	4.69	0.71
$D_2(t)$	Dummy variable for the AIR-21 period		–0.97	0.61	0.11
$D_2(t)$	Dummy variable for the Slottery period		–0.73	0.45	0.11
$D_2(t)$	Dummy variable for the post 9/11 period		–2.59	0.83	0.00
$D_2(t)$	Dummy variable for year 2002		–2.40	0.47	<.0001
$D_2(t)$	Dummy variable for year 2003		–2.64	0.44	<.0001
$D_2(t)$	Dummy variable for half of year 2004		–0.99	0.44	0.02
$Q_1(t)$	Dummy variable for Quarter 1		0.18	0.46	0.70
$Q_2(t)$	Dummy variable for Quarter 2		–2.81	0.51	<.0001
$Q_3(t)$	Dummy variable for Quarter 3		–3.22	0.56	<.0001
R-square			0.65		

Thunderstorm ratio: the number of stations reported thunderstorm/total amount of stations

that convective weather may also affect LGA delays by causing delays at other airports, factors that are separately accounted for in this model.

Examination of the fixed effects reveals that seasonal differences in delay are fairly small once other factors are accounted for. The only significant seasonal effect is for spring, during which average delays are about 2 min less, all else being equal. The time-period fixed effects, in contrast, are somewhat larger and more significant. They imply that when LGA delays are compared with the HDR period (used as the baseline) and the other factors are controlled for, LGA delays were 2 min higher starting with AIR-21 and then dropped in the Slottery period. The time-period fixed effect reaches its lowest after 9/11 and then comes back gradually through 2004. Air traffic control procedures were changed in the New York airspace in fall 2000 under the FAA's choke point program. These changes included new routes for propeller aircraft and an additional eastern route for New York–bound traffic from the Atlantic Seaboard, New England, and Europe (*12*). However, these improvements still were not able to alleviate the secondary congestion brought by overscheduling in AIR-21.

With the results in Table 4 and the daily data, the average arrival delay at LGA was decomposed by causal factors that were included in the delay model, and results were aggregated to compare the different time periods (see Figure 4). The average delay in a given period is the difference between the positive and negative bars. The bars are decomposed into the different factors included in the LGA delay model. For example, in the HDR period the average arrival delay was 21 min, of which 16 min is associated with delay at other airports, 2.5 min with the average arrival queuing delay, and so on. The most consistent contributor to LGA arrival delay is delay at other airports, which generates from 11 to 18 min. That contribution declined slightly during the Slottery period and sharply after 9/11 but increased steadily in the following time periods. The most variable contributor is the average arrival queuing delay, which increased 5 min from HDR to AIR-21 and causes the same amount of observed delay.

Table 4 shows the results of the NAS delay model, which explains average arrival delay for flights to 31 benchmarks airports other than LGA. This model explains about 70% of the variation in average

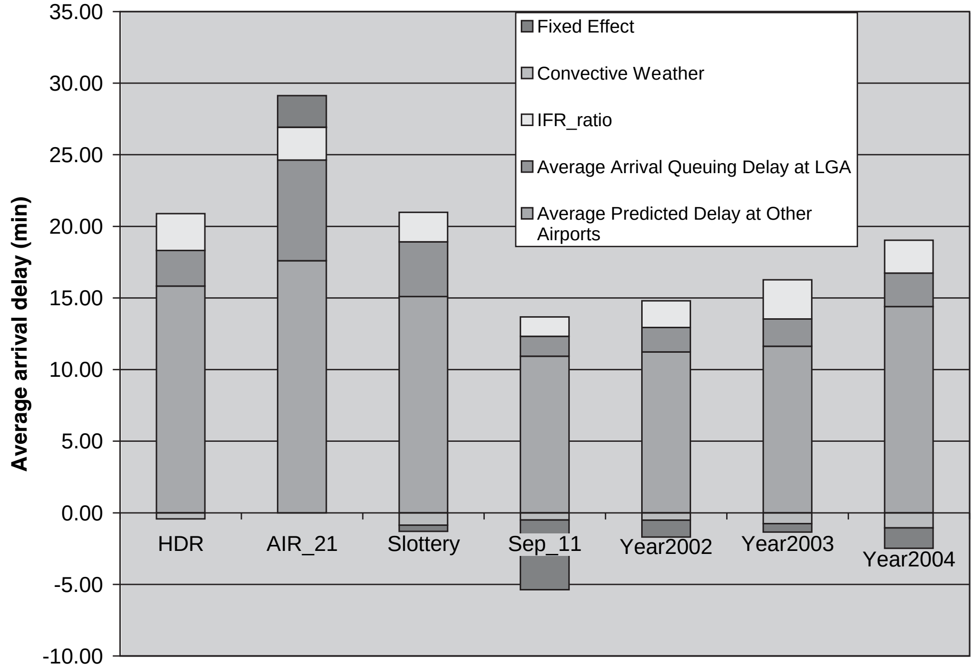

FIGURE 4 Decomposition of LGA average arrival delay by causal factors and by time period (IFR = instrument flight rules).

arrival delay. The prevalence of queuing delay, total operations, and thunderstorm activity in the eastern United States are all significant factors. Of particular interest here is the effect of LGA delay. It can be seen that a 1-min increase in average arrival delay at LGA causes a 0.09-min increase in average arrival delay at the other benchmark airports. To put this in perspective, one may consider that the ratio of non-LGA to LGA arrivals is about 34 to 1; thus the increase in total arrival delay at non-LGA airports from a 1-min increase in total arrival delay at LGA is $34 \cdot 0.09 \approx 3$ min. This finding supports the claims that the congestion at LGA resulting from AIR-21 had substantial spillover effects throughout the NAS. Further analysis is necessary to determine if this spillover was widely dispersed across flights and airports or more concentrated.

CONCLUSIONS

Although congestion management (or demand management) is a common practice at busy airports in much of the world, in the United States it is the exception rather than the rule. The preferred approach has always been to accommodate demand by providing adequate capacity rather than suppressing traffic through economic or administrative measures. The handful of U.S. airports at which some form of demand management is in place must operate in a policy environment that is averse to this practice. This tension was heightened by airline deregulation, which eliminated regulatory barriers to airline entry and exit and discouraged airlines from acting cooperatively to manage congestion and allocate scarce capacity. The inherent conflict between policies aimed at limiting air traffic to manageable levels and those aimed at maintaining a competitive marketplace has been exacerbated by an airport pricing policy based on cost recovery rather than resource allocation. A regulated airport industry was limited in its ability to use market signals to shape the behavior of a deregulated airline industry. Management of the problem was thus left to FAA and Congress, resulting in shifting policies that have had substantial impacts on operational performance.

No airport has been more strongly affected by these tensions than LGA. There the slot exemptions mandated by AIR-21 caused a surge of traffic beginning in summer and culminating in fall 2000. This traffic brought major increases in delays, most of them related to runway queuing delay. The Slottery policy was successful in reversing this degradation, whereas 9/11 reduced traffic to the point where delays related to congestion at LGA virtually disappeared. Flight activity and associated delay have been gradually coming back since; as of 2004, levels are approaching the ones during the pre-9/11 Slottery period.

This analysis suggests that the operational problems caused by AIR-21 extended beyond those directly related to traffic increases. Arrival capacities under several of the more common runway configurations declined under AIR-21. Moreover, even when the most important delay drivers are controlled for, average delays during the AIR-21 period are somewhat higher than those before and after. These results suggest that the excessive demand pressure created by the AIR-21 exemptions actually inhibited the ability of LGA to handle traffic.

These effects notwithstanding, it is important to recognize that much of the delay at LGA is caused by factors other than local congestion. In particular, delay elsewhere in the NAS has been the primary source of delay at LGA throughout the period analyzed. However, delay at LGA has also contributed significantly to delay at other airports. It is this mutual dependency that makes airport congestion management a national rather than a local problem.

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