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Airline Networks: An Econometric Framework to Analyze Domestic U.S. Air Travel

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ABSTRACT

In this paper, we examine the U.S. domestic airline network. Using an exhaustive definition of the airline network and a cross-section pooled time series dataset for 35 consecutive quarters covering 1995:Q1 to 2003:Q3, we analyzed domestic scheduled air transportation. Results suggest the existence of increased vertical disintegration of market segments following the events of September 11, 2001 (9/11). The effects of 9/11 have affected all network classes, with the largest impact on the point-to-point variants. The expansion of Southwest Airlines affected all variants of the network positively, with a proportionately larger impact on the point-to-point over the hub-and-spoke variants. The results of this study are expected to help inform both operational decisionmaking and policymaking. Results may also be useful to manufacturers in projecting the size and mix of the aircraft fleet that are expected to be compatible with the evolving network.

INTRODUCTION

Events beginning with the recession in spring 2001 and the terrorist attacks on September 11, 2001 (9/11), have destabilized the U.S. aviation industry. The accumulated net income from the second half of the 1990s (\$22.8 billion from 1995

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to 2000) was wiped out completely by the \$24.8 billion in losses incurred during the subsequent 11 quarters (2001:Q2 to 2003:Q4) (ATA 2004; *Airline Monitor* 2004), despite a U.S. government-provided cash grant of \$5 billion and a loan program totaling \$10 billion soon after the events of 9/11. Due to a significant hike in the price of jet fuel (more than 40¢ per gallon) that began at the end of 2002 and has continued well into 2004, the industry is expected to lose \$2 billion to \$3 billion in 2004. Without a jet fuel price increase, the industry would most likely have returned a small profit in 2004 due to improved traffic conditions and a slightly better fare environment.

The events of 2001¹ led to a massive restructuring of the airline industry that addressed weak basic business practices. The most significant changes were in capacity reductions in the number of available seat-miles and the number of flights (figure 1). These necessary adjustments reflect a drop in demand, a decline in business travel, and the availability of internet booking. In addition, a realigned fare structure narrowed the gap between premium and walkup fares and leisure fares. Finally, renegotiations of labor and other contracts, and simplification of the network structure, have also played key roles in the restructuring of the industry.

The overall downward capacity adjustments affected industry participants differently, with network carriers affected more than low-cost carriers (LCCs).² LCCs and regional carriers (carriers special-

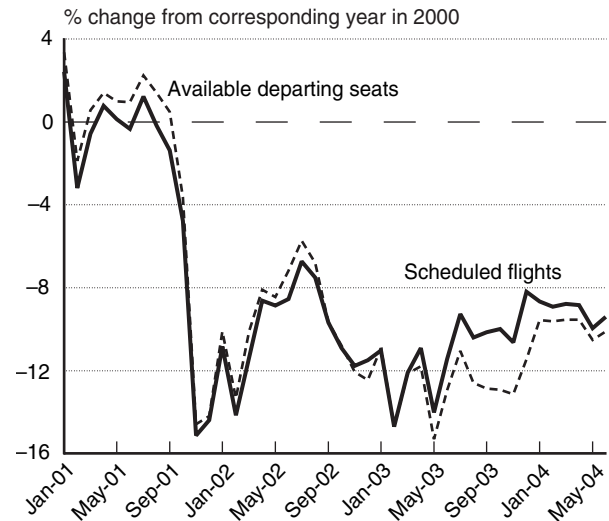
¹ These events include the economic recession starting in spring 2001, the increasing use of internet technology in airline booking, and the tragic events of 9/11. While the first two are associated with cyclical and secular parts of the time series, the events of 9/11 are not.

² Here we define network carriers as American, Continental, Delta, Northwest, United, and US Airways. They generally run their operations through a system of hub-and-spoke airports. Some LCCs, Air Tran in particular and JetBlue to some extent, are also following the hub-and-spoke network model. In 2003, network carriers accounted for about 73% of total revenue passenger-miles (RPM) and provided 72% of available seat-miles (ASM) (*Airline Monitor* 2004), two standard measures of airline output.

We define the LCCs (in order of importance with respect to shares in ASM and RPM) as Southwest, America West, ATA, JetBlue, Air Tran, and Frontier. It is important to recognize that LCC markets are continuously evolving, both in terms of their market shares and the number of participants.

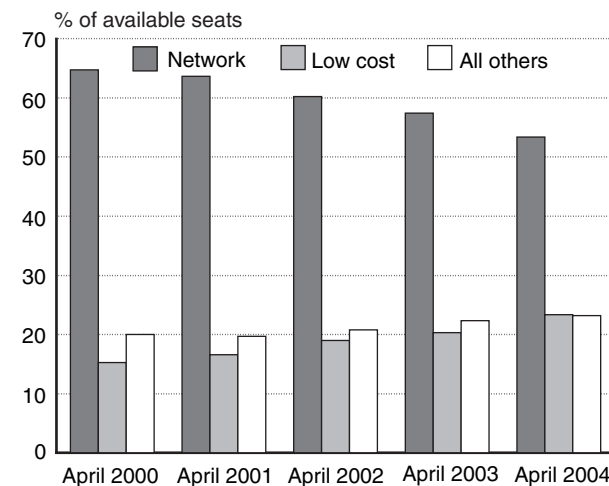
izing in regional jets—RJ carriers)³ appear to have increased their capacity as the network carriers' capacity shrank. While there was an overall fall in demand immediately after 9/11, LCCs and RJ carriers fared better than the network carriers (figure 2).

FIGURE 1 U.S. Airline Industry Capacity Adjustments Since 2000



Source: M.R. Dayton, "Trends and Demand in Aviation Markets," presentation at the ATCA/FAA/Nav Canada Technical Symposium, Office of Inspector General, U.S. Department of Transportation, 2004.

FIGURE 2 Airline Market Share by Type of Carrier



Note: *All others* is primarily regional jet carriers but may include a small percentage of scheduled charter carriers.

Source: M.R. Dayton, "Trends and Demand in Aviation Markets," presentation at the ATCA/FAA/Nav Canada Technical Symposium, Office of Inspector General, U.S. Department of Transportation, 2004.

³ These carriers use small jets and generally supply service for other airlines. Some examples of these carriers are Air Wisconsin partnering with Air Tran, American Eagle partnering with American and Delta, and Cape Air partnering with Continental.

Southwest Airlines was the nation's largest LCC in 2003, with almost half the total LCC market (48% of available seat-miles (ASM) and 45% of revenue passenger-miles (RPM), representing supply and demand, respectively) (*Airline Monitor 2004*). This airline now ranks second, after Delta Airlines, in terms of U.S. domestic passenger enplanements, accounting for about 10% of overall domestic ASM and RPM.⁴ Throughout the last decade, Southwest Airlines expanded its level of activity, although activity accelerated somewhat after 9/11. By aggressively gaining market share, they became a major force in U.S. air travel. Given what appears to be an increasingly distributed network structure (Berry 2004) with less emphasis on hubs and connections,⁵ Southwest appears to have adopted a point-to-point or distributed network variant.

Southwest Airlines has shown that offering lower fares induces increased overall air travel demand (Bennet and Craun 1993; Morrison 2001), which we will call the *Southwest effect* in this paper. In addition to its primary focus on serving larger metropolitan areas through secondary airports, Southwest also flies from airports designated as large hubs based on their traffic levels (e.g., Baltimore-Washington (BWI), Phoenix

(PHX), Las Vegas (LAS), and Midway (MDW)).⁶ Therefore, an expanding Southwest may also have a positive impact on hub-to-hub travel and on spokes that connect to these hub airports through inducing demand in those networks. This process may be further enhanced if other LCCs entering the market follow Southwest's network structure.

Continuous restructuring of the industry, characterized by capacity realignment, changing market shares, and an evolving network, has affected the fleet mix as well. Regional or feeder carriers increasingly take up the markets from which network carriers have retreated. Essentially, network carriers increasingly outsource some of their markets to regional carriers. This vertical disintegration of markets once held by network carriers (i.e., market fragmentation), leads to a greater number of scheduled flights flown by regional jets. Consequently, the number of segments and aircraft operations may go up significantly even though the market, as a whole, may be smaller than before. Figure 3 presents this process of substitution from markets served by network carriers (using larger jets) to markets served by regional carriers (flying regional jets), or fragmentation of markets.

These changes have had a profound impact on the industry as a whole. Ed Greenslet, a long-time aviation industry analyst, summed this up recently (*Aviation Week & Space Technology 2002*, p. 52): "...the domestic airline landscape is changing before our eyes, and the consequences for the tradi-

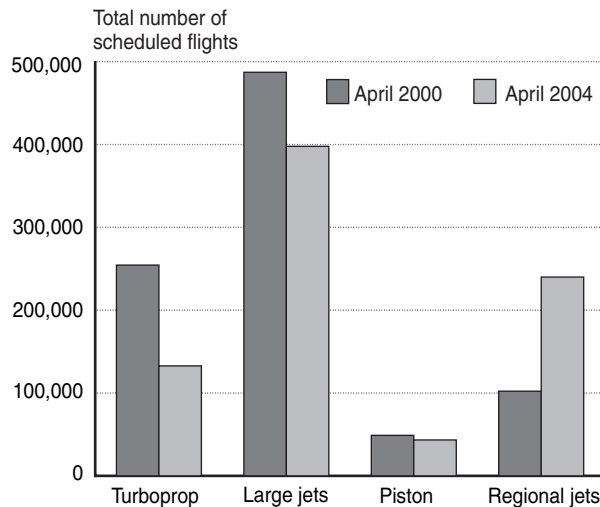
⁴ Southwest ranks third with respect to total passenger enplanements, following American Airlines and Delta Airlines. However, it ranks second when evaluated in terms of domestic enplanements. In 2003, Delta Airlines handled 78 million enplanements compared with Southwest's 74 million. American Airlines carried the most (both domestic and international), about 83 million enplanements with a higher share of international enplanements than Delta. Southwest does not fly any international routes currently.

⁵ The term *distributed network* is used here to represent situations where airlines distribute their operations among more modestly sized airports for traffic traveling between two ends of the network, e.g., among Midway, Nashville, and St. Louis airports for east-west traffic in Southwest's network. This is in sharp contrast to using one or two airports heavily as their main hubs (e.g., Chicago and Denver for American and United) to serve a similar purpose. The term is also used to represent situations where schedules are distributed more uniformly throughout the day as opposed to schedules that have sharp peaks and offpeaks as is often the case in hub-and-spoke airports. Distributed networks (i.e., networks with distributed traffic and distributed schedules) have been found to complement point-to-point networks more than hub-and-spoke networks (Berry et al. 2004). In this sense, distributed networks align more with point-to-point networks.

⁶ Airport hubs in this paper use the U.S. Department of Transportation, Federal Aviation Administration definition. There are four categories, based on the percentage of total national enplanements (i.e., physical counts): large hubs ($\geq 1\%$ of total enplanements), medium hubs (0.25%–0.999% of total enplanements), small hubs (0.05%–0.249% of total enplanements), and nonhubs ($< 0.05\%$ of total enplanements). These are physical hubs.

There is a second "operational" definition that categorizes airports as a hub if inbound flights are scheduled to arrive from multiple origins within a short period of time, thus creating a "bank" of passengers. The coordinated arrival and departure banks together form a wave of activities and lead to peaks in airlines schedules. At present, some physical hubs are also operational hubs. However, an airport can be an operational hub without being a large physical hub (e.g., small airports primarily serving connecting passengers), while a physical hub may exist without being an operational hub (e.g., large airports primarily serving origin and destination passengers).

FIGURE 3 Number of Scheduled Flights by Type of Aircraft: April 2000 and April 2004



Notes: Turboprops include aircraft such as the ATR-42/72, Aerospatiale, Beechcraft 1900, Dornier 328 Turbo, and JETST-31 BAE. Pistons are typically fixed wing Cessnas and Pipers, e.g., the CES-150-185, AERO-200, and PA 12-32.

Source: M.R. Dayton, "Trends and Demand in Aviation Markets," presentation at the ATCA/FAA/Nav Canada Technical Symposium, Office of Inspector General, U.S. Department of Transportation, 2004.

tional airlines are only beginning to be felt. That's because the route networks of low-cost, low-fare airlines have grown large enough to make alternative service available in almost all of the large business markets." The bankruptcy declaration of United Airlines (Dec. 6, 2002), following US Airways' earlier bankruptcy (Aug. 11, 2002), appears to bring that speculation one step closer to reality.

If market shares of airlines are changing and affecting network structure, this is an important phenomenon to be addressed by both analysts and policymakers. The expected transition is certain to have an impact on almost all areas of the National Airspace System and will affect operations as well.

Understanding the emerging network is key to foreseeing what is driving future operational issues as well. A changing network will also have a significant impact on airframe manufacturers. For example, Airbus has aggressively marketed the very large A380 model aircraft over the last few years. As of the third quarter of 2004, Airbus had 139 firm orders for the aircraft. In order for production to be economically viable, Airbus requires about 250 orders. Boeing, on the other hand, recently abandoned the Sonic Cruiser program in favor of the more traditional fuel-efficient 7E7 jets. As of April

2004, Boeing had received its first order for 50 7E7s from Japan's All Nippon Airways. The size and speed of these two aircraft and the types of markets for which they are suited indicate that they are expected to serve clearly different niches within the network: the A380 appears to continue with the assumption that the long-haul hub-to-hub network (e.g., international long-haul routes) will anchor air transportation and be enhanced by feeder routes (i.e., hub-and-spokes), while the 7E7 is designed primarily to serve more point-to-point traffic.

In light of these phenomena, this paper is an attempt to understand the evolutionary nature of the U.S. airline network. In particular, we address and quantify three empirical issues:

- how the changing role of Southwest Airlines affected the network structure,
- how the increasing use of regional jets affected the network structure, and
- how the events of 9/11 were a catalyst for changes in the network structure.

Addressing these issues may provide some important insights that could lead to improved policy-making in a changing environment. It may also allow us to forecast the structure of the network. The paper is organized as follows: the next section presents our definition of an airline network; we then discuss the empirical framework and the data; next, we present our methodology and empirical results; and we conclude with policy suggestions and areas for further research.

NETWORK DEFINITION

The airline network is a dynamic environment that has numerous variants. As the business models of participating airlines change, so will the airline network. The market environment facing the network carriers, those with substantial hub-to-hub and hub-to-spoke operations in selected airports, has become increasingly competitive. A complex web linking declining average yield⁷ with a narrowing margin

⁷ Average annual yield (i.e., itinerary fare/passenger-miles flown) has declined by 2% annually over the last two decades following deregulation in 1978. Over the next two decades, analysts predict this rate of decline will slow down to 0.9% a year (SED-F 2003; USDOT FAA 2003).

between premium and walkup versus competitive fares is forcing network carriers to undertake painful cost-cutting measures.

Acknowledging this dynamism and recognizing the present structure of the airline network, we defined the network based on its physical characteristics. Using the U.S. Department of Transportation (USDOT), Federal Aviation Administration (FAA) definition (see footnote 6), our network consists of 35 hub airports—a combination of 31 large hubs and 4 medium hubs. Although we used the physical definition for a hub, many of these airports are also operational hubs for both network carriers and LCCs. The hubs are listed in appendix A.⁸ These airports together accounted for 73% of total scheduled enplanements and 69% of total scheduled aircraft operations in 2002. Although most of these airports qualify for the FAA definition of large hubs (> 1% of national enplanements), four other airports, Cleveland Hopkins (OH), Washington Reagan (DC), Memphis (TN), and Portland (OR), were included to maintain consistency with the FAA's Operational Evolution Plan (OEP) airports. Finally, appendix A provides information on which airlines are the primary and secondary air carriers at these airports.⁹

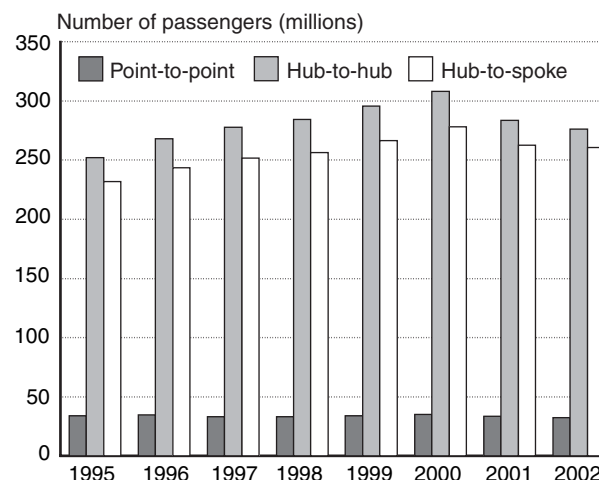
We defined the three variants of the airline network as follows:

- **Point-to-point (PP) variant** covers air travel that takes place between non-OEP airports (e.g., Teterboro (NJ) Airport to Hagerstown (MD) Regional Airport). Any travel outside OEP airports as listed in appendix A represents the point-to-point variant of the network.
- **Hub-to-hub (HH) variant** covers air travel that takes place between two major hubs (i.e., travel between OEP airports; e.g., Atlanta Hartsfield to Boston Logan).

⁸ These 35 airports are also known as Operational Evolution Plan (OEP) airports. The OEP is a major FAA initiative to meet emerging air transportation needs for the next 10 years. For more details, see <http://www.faa.gov/programs/oep/index.htm>.

⁹ The line between primary and secondary carriers is somewhat arbitrary. We provide information (reported by the *Official Airline Guide*) on air carriers that are conducting hub operations in these airports, irrespective of the magnitude.

FIGURE 4 Annual Passenger Enplanements at Airports, by Type of Network Variant



- **Hub-to-spoke (outbound) and spoke-to-hub (inbound) (HS)** covers air travel for which either the origin or the destination (but not both) is a major hub (i.e., travel between non-OEP airports and OEP airports; e.g., Atlanta Hartsfield to Teterboro).

In order to measure variants of network activities, we used two variables, the number of passenger enplanements and the number of actual aircraft departures performed. As figure 4 shows, the number of passenger enplanements in the PP variant was dwarfed by the number of enplanements under both the HH and HS variants. While the HH and HS variants together accounted for around 93% to 95% of the total enplanements, the PP share of the overall network has been in the range of 5% to 7%.

Because Southwest Airlines concentrates its operations in PP markets, it has a higher percentage of the PP variant of the airline network (ranging between 62% and 70% of total enplanements) than the HH (about 4% to 5.5%) and HS (10% to 17%) variants.

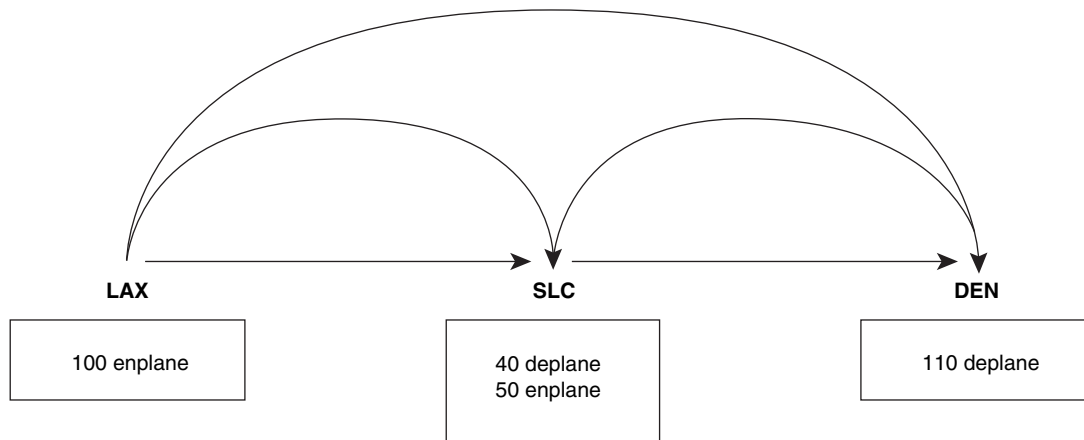
THE FRAMEWORK: RESEARCH QUESTIONS, DATA, AND METHODOLOGY

Research Questions

Here, we formulate three empirical issues for testing:

1. How has the expansion of Southwest Airlines affected different variants of the networks?
2. How has the changing share of regional jets affected parts of the network differently?
3. How have the events of 9/11 affected the overall network and different parts of the network?

FIGURE 5 Illustration of T100 data



Key: DEN = Denver International Airport; LAX = Los Angeles International Airport; SLC = Salt Lake City International Airport.

Notes: **Nonstop segments** are represented by straight arrows, i.e., number of passengers transported between points (between takeoff and landings).

LAX to SLC: 100 passengers transported

SLC to DEN: 110 passengers transported

Onflight markets are represented by curved lines, i.e., where passengers are enplaned and deplaned on a flight.

LAX to SLC: 40 passengers

LAX to DEN: 60 passengers

SLC to DEN: 50 passengers

For a one-stop flight, the number of passengers would be the same as under segment and market.

Source: U.S. Department of Transportation, Office of the Secretary, *O&D Survey Reporting Regulations for Large Air Carriers: Code of Federal Regulations Part 241, Section 19-7* (Washington, DC: 1992).

Answering these questions may provide some important insights into the process by which the network is undergoing changes. Furthermore, understanding these changes may also allow us to forecast the structure of the network into the future.

Data

Data for this exercise come from the Bureau of Transportation Statistics (BTS), DOT T100 schedule. T100 is the transportation schedule for Form 41 data that every major airline is required to submit to BTS each quarter. T100 is divided into two parts: T100 market segment data (T100M), which cover on-flight origin and destination (O&D) or direct markets; and the T100 segment data (T100S), which contains data for market segments. In particular, T100S is the Data Bank 28DS of Form 41 that provides segment traffic (i.e., the number of passenger enplanements, freight ton-miles, and departures scheduled and performed) by scheduled air carriers for freight and mail by service class and type of aircraft equipment, capacity (i.e., available freight ton-miles and available passenger seat-miles), and performance indicators (i.e., ramp-to-ramp elapsed

time and airborne elapsed time) by month and year. The data are reported by major air carriers operating between airports located within the boundaries of the United States and its territories (see CFR 2001 for more details). The data cover January 1995 to September 2003.¹⁰ For our empirical analysis, we used T100 domestic segment quarterly data for the period covering 1995:Q1 to 2003:Q3 (data for 35 continuous quarters).

Figure 5 shows the nonstop segment data (T100S) for a hypothetical flight from Los Angeles (LAX) to Salt Lake City (SLC) and then to Denver (DEN). The data for the LAX-SLC segment thus includes not only the O&D traffic within that segment (i.e., people originating in LAX and destined for SLC), but also the passengers who are originating at LAX, stopping at SLC, and then flying on to Denver. The T100M market data, on the other hand, for LAX-SLC includes only those people originating in LAX and destined for SLC. Unfortu-

¹⁰ See <http://www.transtats.bts.gov> and click on the aviation data link for T100 domestic data segments in the Form 41 traffic file.

nately, however, T100M is limited to fewer variables: number of passengers by O&D, freight, mail, carriers, distance, month, and year.

Each segment reported in T100S is unique, distinctively defined by air carrier and the type of equipment flown. Therefore, the LAX-SLC flights shown in figure 5 will be reported twice, for example, if a carrier flew the segment using two equipment types, holding all other factors constant. The total number of segments can be aggregated over the same O&Ds to provide a logical basis for defining the network. For example, there were 70,127 distinct segments in 2003:Q3. These unique segments reduced to 11,179 O&D segments when summarized by the same O&D, thus providing the basis for our estimation. Summed over 1,695,848 distinct segments for 1995:Q1 to 2003:Q3, we had 228,129 observations. These observations were used to estimate our econometric model.

Methodology and Results

Estimation

For both total passenger enplanements and aircraft departures performed, we specified econometric models in natural logs¹¹ by variants of the network as follows:

$$\ln(Pax_{ij;k}) = F [\text{seasonal dummy, share of Southwest Airlines in total passenger, share of regional jets in total passenger, dummy representing } 9/11, \ln(\text{one-quarter lag of passenger})] \quad (1)$$

$$\ln(A/C\ Dep_{ij;k}) = F [\text{seasonal dummy, share of Southwest Airlines in total departures, share of regional jets in total departures, dummy representing } 9/11, \ln(\text{one-quarter lag of departures})] \quad (2)$$

where

- \ln = natural log,
- i = origin,
- j = destination,
- k = type of network.

¹¹ We used natural logs, as opposed to levels, for two reasons. First, transforming the endogenous variables into their natural logs eliminated heteroskedasticity from the dataset. Second, estimated coefficients of log-transformed models have clearer intuitive appeal than using level variables.

The three variants of the network, $k = 0, 1, 2$, are defined as point-to-point (PP; $k = 0$), hub-to-hub (HH; $k = 1$), and hub-to-spoke, including both hub-to-spoke and spoke-to-hub traffic (HS; $k = 2$). The two endogenous variables, $\ln(Pax_{ij;k})$ and $\ln(A/C\ Dep_{ij;k})$ are the natural logs of the number of total passenger enplanements and total aircraft departures performed, respectively, aggregated within the i - j O&D market for the k -th variant of the network.

It is important to understand that both passenger enplanements and aircraft departures performed are generally determined by economic factors (e.g., fares and income), demographic factors (e.g., population and age distribution in O&D markets), and the quality of services (e.g., schedule choices and types of aircraft) (Bhadra 2003). Notice also that whether hubs connect directly to other airports (HS) or via other hubs (HH) depends on market features such as the size and composition of the market, fares, connection possibilities, and so forth (see Shy (2001, 215–231) for an analytical discussion of airline networks; and Bhadra and Hechtman (2004) for an empirical analysis). In our present dataset, however, not all such information is available.¹² Nonetheless, the independent variables specified above may capture the trends in passenger enplanements and performed departures quite substantially and well enough, as discussed earlier.

In particular, we postulate that seasons affect both passenger enplanements and departures performed, and those variations may differ depending on the type of network. Empirically speaking, air travel goes through cyclical variations, peaking during spring and summer (i.e., April-September; season dummy = 1) and hitting its trough during fall and winter (i.e., October-March; season dummy = 0). Thus, we designed a seasonal dummy variable to capture this cycle.

¹² The list of variables available in T100S and T100M has been given above. Many factors, fares in particular, are reported in what is commonly known as the Origin and Destination Survey or the DB1B. That database, while containing useful information such as fares and quarterly passengers in an O&D market, does not include information on aircraft equipment types and other performance indicators (for more details on types of data and variables, see http://www.transtats.bts.gov/Databases.asp?Mode_ID=1&Mode_Desc=Aviation&Subject_ID2=0).

Following our earlier discussion, we formulated a variable that accounts for Southwest Airlines' share of total passenger enplanements and aircraft departures performed.¹³ This share variable (i.e., the percentage share of Southwest Airlines in total enplanements) has been designed to capture the impact of the airline on different variants of the network (i.e., $k = 0, 1, 2$) defined over i - j segments. Similarly, the share of regional jets¹⁴ has been formulated to capture their impact on totals. A dummy variable representing the beginning of the effect following 9/11 (i.e., 2001:Q3) was formulated to examine the effects of 9/11 on two endogenous variables defined for the network type.¹⁵ In other words, this dummy variable assumes a value of 0 for the period 1995:Q1 to 2001:Q2 and a value of 1 for the period 2001:Q3 to 2003:Q3. Finally, an autoregressive term, the log of both enplanements and aircraft departures performed lagged one quarter, was used to capture the time series component of this time series pooled cross-section sample. It is important to note here that we postulate that both enplanements and aircraft departures performed are driven by the same set of explanatory variables and are determined simultaneously as a system.

Given the interdependency among enplanements and departures performed, it is likely that the error structures of the equations may be linked to each other. Although each equation in the system above appears to be independent and unrelated, they might be linked to each other through errors. Thus,

¹³ We define the share of passengers as: $(\text{Southwest's passengers}/\text{total passengers}) * 100$. Thus, this and other share variables are expressed in 100th of units and not in a fraction, 0 to 1.

¹⁴ Here we define RJs as the following: Canadair RJ-100/R, Canadair RJ145-200, Embraer EMB-135, Embraer EMB-145, Embraer EMB-140, Avroliner RJ85, BAE-146-3, and Do328JET. There may be other RJs outside of this definition.

¹⁵ Other factors, e.g., slowdown of the economy, internet booking, etc., were also taking place around this time (see footnote 1). However, the purpose of including a dummy variable for 2001:Q3 and later is to capture the sudden unsystematic effect that took place in this quarter and its impact. In other words, this dummy variable should be interpreted as representing the impact of 2001:Q3 as a catalyst for all that changed in the time series before and after this event.

this type of system is also called "disturbance-related" or "error-related" regression equations.

Under this circumstance, econometricians often recommend the use of the seemingly unrelated regression (SUR) technique for estimation (Pindyck and Rubinfeld 1991, p. 308). SUR is used when a system consists of two or more equations where errors may be correlated across equations. SUR is considered to be appropriate when all the right-hand side regressors are assumed to be truly exogenous and the errors satisfy the following conditions:

1. $\varepsilon_{ij;k}$ (i.e., error terms) have zero means and finite variances,
2. the variances of errors may differ, and,
3. there is a presumed correlation between $\varepsilon_{ij;1}$ and $\varepsilon_{ij;2}$.

Given that 1–3 are likely to be true for the dataset we used, we adopted the SUR methodology for estimation (SAS 1993).

Results

Table 1 presents the results of the estimation of the two equations specified linearly. Quite a few interesting features underlying the data and findings deserve special attention.

First, it is important to note that we make a distinction between the number of observations (N) used and the number read (i.e., the last two columns in table 1). The difference between N read and N used arises because of the unavailability of data, accounted for primarily by the lack of lagged variation in the one-quarter lag of passenger enplanements and departures performed on a particular segment. In other words, quarter t did not have a corresponding quarter $t-1$ observation. Reviewing these numbers across rows, it is evident that the PP network has relatively less continuity over time than the other two types of networks. In particular, almost half of the segments (46%) that were observed at quarter t for the PP network did not have lagged entries for quarter $t-1$. Hence only 39,880 observations were used from a total of 73,438 observations.

In comparison, the HS network, including both HH and HS routes, seems to have more continuity over time, and hence observations used are far closer to the available total number of observations. Given that we used 35 continuous quarters in our

**TABLE 1 System of Scheduled Aviation Activities in the United States:
Number of Passengers and Aircraft Departures (in natural logs)**

Network variants (1)	System equations (2)	Intercept (3)	Seasonal dummy (4)	Share of Southwest Airlines (5)	Share of RJ carriers (6)	9/11 dummy (7)	Ln (one quarter lag) (8)	Adj. R ² (9)	N(used) (10)	N(read) (11)
PP	$\ln(Pax_{ij})$	0.5039*	0.0958*	0.0032*	-0.0011*	-0.1083*	0.9107*	0.8903	39,880	73,438
	$\ln(A/C Dep_{ij})$	0.1928*	0.0367*	0.0017*	-0.0006*	0.0465*	0.9215*	0.8865		
HH	$\ln(Pax_{ij})$	-0.8040*	0.1205*	0.0009*	-0.0004*	-0.0161*	0.9203*	0.9039	34,192	35,827
	$\ln(A/C Dep_{ij})$	0.4363*	0.0407*	0.0011*	0.0013*	-0.0110*	0.9263*	0.9155		
HS	$\ln(Pax_{ij})$	-0.7568*	0.0863*	0.0012*	0.0006*	-0.0309*	0.9128*	0.8485	97,171	118,864
	$\ln(A/C Dep_{ij})$	0.4290*	0.0006	0.0007*	0.0012*	-0.0028	0.9151*	0.8591		

Key: * = 99% level of significance.

Note: First row in each network variant represents scheduled passengers and the second row represents the number of aircraft departures.

analysis, the number of observations under the HH network variant represents, on average, 1,000 segments per quarter. Segments under the HS variant, on the other hand, are almost three times the size of the HH variant per quarter. The PP segments fall in between those of HH and HS.

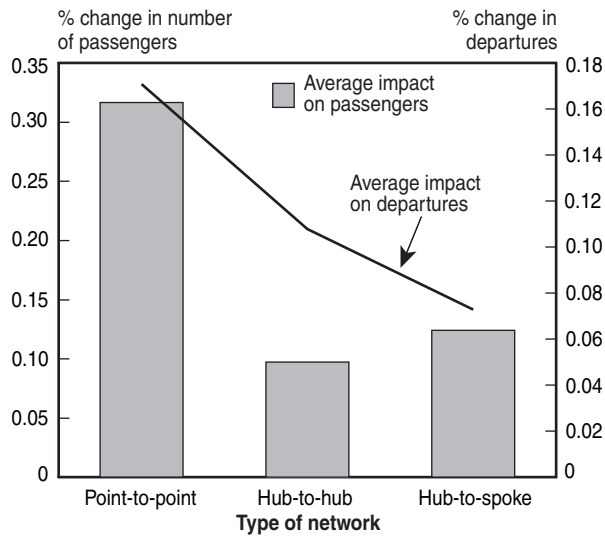
Second, the estimated system model appears to have a very good fit. In particular, all the explanatory variables describe the two endogenous variables very well, resulting in a high adj. R². Almost 90% of the variation in the dependent variables, across the different networks, is explained. Third, almost all the variables, with the exception of the seasonal and the 9/11 dummy variables in the case of the HS network, are statistically significant at the 99% level. Furthermore, the estimated parameters of the simultaneous system appear to confirm the expected signs for the empirical hypotheses for most variables.

In particular, the seasonal dummy variable confirms the hypothesis that in spring and summer both passenger enplanements and aircraft departures performed go up, increasing the most for the HH network, followed by the PP and HS variants. On average, the spring and summer quarters add about 12% to passenger enplanements and 4% to departures performed on the HH network variant, while adding 10% more passenger enplanements and 4% more departures to the PP network variant. The HS variant gains about 9% more passenger enplanements during the peak travel season, while departures in this network do not show significant

seasonal changes, thus suggesting excess capacity. Examination of passenger data for 2000 for major carriers (i.e., those who use the HH and HS network variants primarily) indicates that, on average, passenger enplanements increased by 6.3 million per quarter during the spring and summer, or about 12% more than the overall quarterly average (ATA 2004).

As anticipated, Southwest Airlines impacts all variants of the network positively and in varying degrees. This further confirms the already empirically established *Southwest effect*. Figure 6 summarizes the findings from table 1. Notice that the effects of Southwest Airlines (column 5 in table 1) are captured by two variables in equations 1 and 2: Southwest Airlines' share of total passenger enplanements and departures performed for equations 1 and 2, respectively. Estimated parameters, multiplied by 100 (to account for the share expression in units of 100), thus represent the effect of a one percentage point increase in Southwest Airlines' market share on the percentage change in passenger enplanements and departures performed (i.e., natural logs of these two variables). Thus, a one percentage point increase in Southwest Airlines' market share in total segment passenger enplanements will add 0.32% more passengers each quarter (i.e., in the short run, holding all other factors constant) to the overall PP network. Similarly, a one percentage point Southwest expansion adds 0.09% and 0.012% more passengers overall for the HH and HS

FIGURE 6 Impact of a One Percentage Point Change in Southwest Airlines' Market Share on Different Variants of the Network



variants, respectively, for each representative quarter in the short run.

Compared with other research (Bennett and Craun 1993; Morrison 2001), the estimated values in our model represent a much smaller *Southwest effect*. In past studies, the Southwest effect has been estimated using the impact of the entry of Southwest Airlines on airline fares in different markets, and the impact of falling airfares, in turn, on passenger demand (e.g., Morrison 2001). For example, the effect of Southwest Airlines on fares was estimated to be in the range of 6% to 46% for every one percentage point increase in Southwest's market share, and the effects of those falling fares on passenger demand were estimated to be in the range of 5% to 10% for each percentage point decline in fares (Bennett and Craun 1993). Thus, the total Southwest effect (of a one percentage point increase in market share on the percentage increase in overall market share) has been estimated to be in the range of 30% to 460%. Bhadra (2003) estimated elasticities of demand for the overall U.S. domestic air markets in the range of 0.55 to 1.8, which would yield lower values for the Southwest effect in the range of 3.3% to 82.8%. As is apparent, our estimated effects are smaller still.

There are several reasons for this major difference in results. The earlier studies examined the Southwest Airlines phenomenon when the carrier

was much smaller in size and for a particular year. We, however, studied the effects of the presence of Southwest on all networks and estimated these effects over a time series. The long-term accumulated effects of this expansion, as will become evident later, are not small. As noted earlier (see figure 4), Southwest Airlines' strongest presence is in the PP network. About 70% of all passengers in the PP network (32.34 million in 2002) flew Southwest Airlines (i.e., 22.65 million). In comparison, about 5% and 14% of the passengers in the HH and HS networks, respectively, flew Southwest. Between 1995 and 2002, about 35 million passengers flew in the PP network annually, which had an average annual growth rate of about 0.6%. During this period, however, Southwest Airlines expanded its PP network market share from 62% to 70%, or from 21 million passengers in 1995 to 22.65 million in 2002. Southwest Airlines grew, on average, twice as fast (1.13% per year) as the average annual growth rate of the entire PP network. Similar magnitudes of scale and growth also follow for the HH and HS networks. Clearly, these rates suggest much smaller expansion than seen in earlier studies.¹⁶

Second, the specification of the model may also be responsible for the results. Unlike earlier studies, we specified both passenger enplanements and departures performed as endogenous variables simultaneously determined via a common set of variables. If some of the independent variables assumed to be exogenous are actually endogenous (e.g., RJ carrier shares), this incorrect specification of the true model may seriously underestimate the magnitude of the coefficient on all the other exogenous variables, including the Southwest effect.

Although they appear to be rather small, the magnitude of the estimated parameters translate to considerable changes in the number of enplanements as Southwest Airlines expands its market share. It is obvious that more departures will have to be performed in order to accommodate these additional flows of enplanements due to a substan-

¹⁶ An expansion in the magnitude of 30% to 460% (mentioned earlier) from the base of 1995 would require total passengers for Southwest Airlines under the PP network to be between 27 million and 118 million annually. This is unlikely given that the total size of the network is about 35 million passengers annually.

tial increase in Southwest Airlines' market share. Hence, departures would increase by 0.17% to accommodate greater passenger enplanements (0.32%) under the PP variant of the network; 0.11% to accommodate additional passenger enplanements (0.09%) under the HH variant; and 0.07% to accommodate the 0.12% increase in passenger enplanements under the HS variant of the network (see figure 6).

It is interesting to note that the Southwest expansion adds proportionately more enplanements and departures to the PP variant than to the other two types of networks. Therefore, the expansion of Southwest Airlines will enhance the PP-type network while still positively influencing both the HH and HS networks. This result simultaneously confirms the expanding distributed or PP network of Southwest Airlines and the Southwest effect.

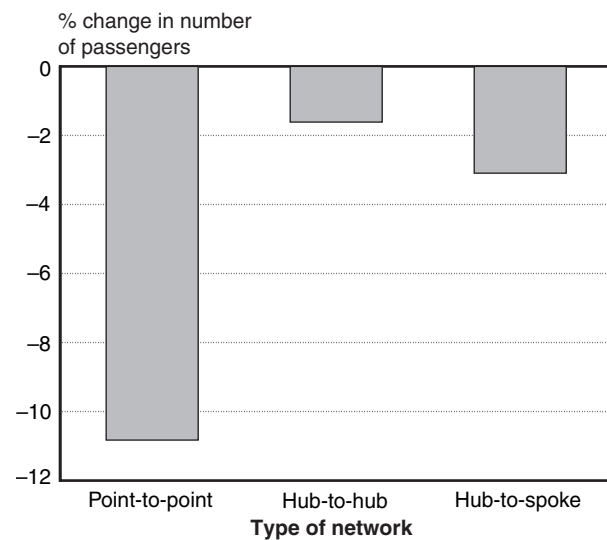
To the extent that the presence of RJs is truly exogenous,¹⁷ RJs' percentage of shares of total enplanements and performed departures have interesting implications. The expansion of RJ carriers is associated with a reduction in traffic in the PP network, and it encourages and even accommodates an increase in the HS feeder operations network (see column 6 in table 1).

For the HH network, RJ expansion is accompanied by fewer passenger enplanements and more departures. Another way to look at this is that increasing the shares of RJs is apparently accompanied by more departures under the HH network to compensate for the smaller number of passengers carried by each aircraft. These findings seem to establish the point that RJs are an important tool for feeding hubs in hub-and-spoke networks.

Because RJs are generally considered to represent an improvement in the quality of service offered on feeder routes (i.e., in the HS network), the expansion of RJs is expected to enhance both the HS network and the HH network fed by HS routes. However, this expansion may negatively affect passenger travel on HH routes, where RJs are more likely to be perceived as a reduction in the quality of service as compared with larger jets (e.g., B737s)

¹⁷ We acknowledge the limitation that in a well-specified model of an airline network, the share of RJs may be endogenous as well.

FIGURE 7 Effect of 9/11 on Different Variants of the Network



that previously served those routes. In the PP network, the negative impact of RJs on enplanements and departures may reflect (as in the HH network) a decline in traffic caused by broader economic factors not included in our model. It may also reflect higher fares required by the greater unit costs of RJs compared with larger B737-type jets. Finally, since Southwest Airlines operates B737s *exclusively*, the presence of RJs on a route is likely to be highly collinear with the *absence* of Southwest Airlines on the route, so that the RJ share may be picking up part of the explanatory power of the Southwest share.

The events following 9/11 had a sizeable impact on all types of networks (see column 7, table 1). As figure 7 demonstrates, the PP network suffered the most, losing, on average, 11% of its passengers but performing, interestingly, about 5% more departures per quarter following 9/11. The HS network, on the other hand, lost approximately 3% of its enplanements and 0.28% of its departures per quarter, which can be attributed to factors relating to the events of 9/11. The HH network lost about 1.6% of its passenger enplanements per quarter and 1.1% of its departures performed each quarter. The reductions in passenger enplanements in the PP network, combined with increased aircraft operations, suggest that large network carriers were outsourcing their operations on these routes to smaller regional carriers flying smaller aircraft. This vertical disintegration of markets appears to be stronger in the PP

network post 9/11 than it was on the HH and HS networks, where enplanements and aircraft operations declined together.

Finally, past enplanements and departures performed have proven to be robust explanatory variables for both the endogenous variables in the system. For example, a 1% increase in past quarter passenger enplanements and departures performed would increase both current enplanements and current departures by about 0.9% (see column 8, table 1). This coefficient has further implications. Together with other structural variables, the long-term effects can be separated by the accumulated effects from all short-term variables as follows: $\Sigma b_i / (1 - c)$, where b_i 's are the estimated structural parameters of the two equations, and c is the estimated parameter of the log-lagged value of the endogenous variables. Notice here that while Σb_i captures all the short-term effects, $\Sigma b_i / (1 - c)$ captures the long-term accumulated effects of all the variables on the endogenous variables. Thus, although a one percentage point expansion in Southwest Airlines' market share increases the passenger volume in the PP network by 0.32% in the short run, its long-term accumulated effect on total passenger enplanements is 3.58%, that is $(0.32 / (1 - 0.9107))$. Applying this formulation to the sum of the effects of all variables would yield, for example, a cumulative effect of 2.21% and 2.50% on passenger enplanements and departures performed, respectively, for the PP network. In other words, the impact of all short-term structural parameters (i.e., Σb_i) accumulates at the rate of 0.197% per quarter for passenger enplanements and 0.196% per quarter for departures performed and eventually yields the long-term impacts. Long-term accumulated effects for passenger enplanements and departures performed were calculated, respectively, as 1.98% and 3.70% for the HH network and 2.76% and 2.26% for the HS network. These calculated rates correspond fairly well to those observed from actual data.

These findings may have important uses. First, they may be important for understanding the impact of Southwest Airlines and other LCCs on the airline network. For example, despite the smaller magnitudes and associated issues related to mis-

specification, our findings indicate that the expansion of Southwest Airlines in particular, and perhaps LCCs in general, would increase the flow of traffic in the overall network substantially. While this expansion would have a proportionately greater effect on the PP network, the HH and HS networks would be positively affected as well. Using the estimated coefficients underlying these segments, we can now compute the effect on segment traffic in any market in which Southwest Airlines operates. This means a clear isolation of the Southwest impact on segment passenger traffic and departures by network can be performed.

Second, some of these estimated coefficients can also be used to partially estimate and forecast, keeping other variables constant, the effect on individual markets that can be expected if Southwest Airlines enters those markets, for example, the Philadelphia market beginning in May 2004. The estimated parameters can be used to forecast traffic at the Philadelphia airport with the expansion of Southwest Airlines, and hence may aid airport infrastructure planning not only for Philadelphia but also for those airports linking with it. A similar reasoning applies to the RJ expansion. In addition, partial coefficients with respect to the 9/11 dummy variable can also be used to estimate financial losses in different segments incurred by different airlines.

Finally, the simultaneous system model as a whole can be used to forecast enplanements and departures performed for segment traffic under different types of network structures. The estimated model can provide a foundation for forecasting segment traffic given anticipated and projected values of the explanatory variables for different types of networks, especially with given market share levels for Southwest Airlines and RJ aircraft. Since the segment traffic is the primary measure of traffic flow dealt with by the air traffic control (ATC) system regularly, both at en route centers and at airports, the ability to better project segment traffic in a way that takes explicit account of airline networks may improve the ATC system. Better traffic projections may also help planners better allocate resources to improve the country's critical air transportation infrastructure.

The estimated model has been found to be robust and stable. However, the model is still somewhat limited. It can be argued that some of the explanatory variables, Southwest and RJ expansion in particular, are not truly exogenous. In fact, they result from interactions in the complex market processes and hence cannot be posited truly as independent variables. Furthermore, the dependent variables may depend on market and economic factors (e.g., fares and income), demographic factors, and quality of service. While incorporating these variables may improve the model, the marginal benefit in the overall model fit (e.g., improvement in the adj. R^2) may be somewhat limited. Finally, the model in its present form may be misspecified, as indicated by the comparison of estimated coefficients with that of other studies (e.g., Southwest effects). While we acknowledge these limitations, we believe that the proposed analytical framework and estimated model can provide a strong foundation for both policy analysis and forecasting.

CONCLUSIONS, POLICY OBSERVATIONS, AND FUTURE RESEARCH

In this paper, we examined the U.S. domestic airline network. By defining hub-to-hub, hub-and-spoke, and point-to-point as the three essential network components, we have identified domestic scheduled air transportation under each of these networks. Using cross-section pooled time series data for 35 consecutive quarters for all scheduled carriers in the United States between 1995:Q1 and 2003:Q3, we were able to estimate a simultaneous system comprising passenger enplanements and aircraft departures performed in types of networks and aggregated within O&D markets.

Our findings indicate the existence of increased vertical disintegration of market segments following the events of 9/11. Second, seasonality tends to play an important role in determining segment traffic, peaking during the spring and summer. Third, we found evidence that the expansion of Southwest Airlines affects all networks positively, with a proportionately larger impact on the point-to-point network than on the hub-and-spoke network. Fourth, regional jets have been found to affect the network in mixed ways, with negative impacts on the point-

to-point network and positive impacts on the hub-and-spoke network. Fifth, effects from 9/11 have been generally negative on all three types of networks, with the largest impact falling on point-to-point passenger traffic, followed by passenger traffic on the hub-and-spoke and the hub-to-hub networks. Increased use of departures to accommodate a lower number of passenger enplanements, in the case of the point-to-point network, provides additional indirect evidence of market segmentation. Finally, auto-regressive terms for both enplanements and departures performed have proven to be robust explanatory variables.

These are meaningful results and may provide better insight into the nature of the U.S. airline network and the factors that explain its evolution over time. The overall statistical fit may also justify using the model to forecast the trends in scheduled network activities by segments. Furthermore, estimated coefficients may be used both to guide policy decisions and to facilitate the planning of the air transportation infrastructure. In particular, empirical results tend to demonstrate that the future airline network may be more distributed as Southwest Airlines or similar airlines expand their operations.

Our analysis is the first systematic effort, as far as we are aware, to empirically establish the existence of an emerging distributed network in the U.S. air transportation system. The infrastructure that served the hub-and-spoke operations in the past may be required to change to further accommodate the needs of Southwest Airlines and other LCCs. Additional attention should therefore be given to the segment traffic and the network structure that is emerging as the industry undergoes serious structural changes.¹⁸

The model we propose to capture these emerging trends, however, is somewhat limited due to the lack of other important explanatory variables: fare, income, and population at segment end points, and the quality characteristics influencing these services. Treating Southwest Airlines and RJ expansion as explanatory variables may also limit our understanding of the potentially endogenous character of

¹⁸ The FAA's recent initiative (USDOT FAA 2004) examines this issue by looking further and beyond the infrastructure needs of the 35 traditionally large OEP airports.

these factors and may limit the model's applicability in forecasts. Due to these important omissions, our model may also suffer from misspecification. Improvement of the model could be approached by incorporating explanatory factors and determining which factors are truly endogenous. These are tasks for future research.

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APPENDIX A Activities at 35 Operational Evolution Plan (OEP) Airports in the United States: 2002

Airport code	Airport	Primary and secondary air carriers	City	State	Hub type	Number of annual scheduled passengers	Percentage of total passengers	Number of annual scheduled A/C ops	Percentage of total A/C ops
ATL	Atlanta Hartsfield Intl	Delta, Airtran	Atlanta	GA	L	36,321,239	5.79	642,727	4.87
ORD	Chicago O'Hare Intl	United, American	Chicago	IL	L	31,026,878	4.94	612,553	4.64
LAX	Los Angeles Intl	United, American, Southwest	Los Angeles	CA	L	26,323,259	4.19	447,170	3.39
DFW	Dallas-Ft Worth Intl	American, Delta	Dallas-Ft Worth	TX	L	24,148,619	3.85	493,772	3.74
PHX	Phoenix Sky Harbor Intl	America West, Southwest	Phoenix	AZ	L	16,930,419	2.70	370,247	2.80
DEN	Denver Intl	United, Frontier	Denver	CO	L	16,544,458	2.64	330,825	2.50
LAS	Las Vegas McCarran Intl	Southwest, America West, United	Las Vegas	NV	L	16,540,417	2.64	317,700	2.41
IAH	George Bush Intercontinental	Continental, American	Houston	TX	L	15,889,349	2.53	299,903	2.27
MSP	Minneapolis-St Paul Intl	Northwest, American	Minneapolis	MN	L	15,553,423	2.48	326,974	2.48
DTW	Detroit Metropolitan Wayne County	Northwest	Detroit	MI	L	15,124,490	2.41	337,816	2.56
JFK	John F Kennedy Intl	American, Jet Blue, Delta, United	New York	NY	L	15,050,456	2.40	245,475	1.86
SFO	San Francisco Intl	United, American	San Francisco	CA	L	14,856,842	2.37	260,501	1.97
EWR	Newark Intl	Continental, American	Newark	NJ	L	14,073,453	2.24	282,849	2.14
MIA	Miami Intl	American, Continental	Miami	FL	L	13,889,275	2.21	304,863	2.31
MCO	Orlando Intl	Delta, Southwest, American	Orlando	FL	L	12,631,347	2.01	201,203	1.52
SEA	Seattle-Tacoma Intl	Alaska, United	Seattle	WA	L	12,570,572	2.00	217,352	1.65
STL	Lambert-St Louis Intl	American, Southwest	St Louis	MO	L	12,412,120	1.98	295,148	2.23
PHL	Philadelphia Intl	US Airways, American	Philadelphia	PA	L	11,631,738	1.85	267,402	2.02
CLT	Charlotte Douglas Intl	US Airways	Charlotte	NC	L	11,589,824	1.85	239,173	1.81
BOS	Boston Logan Intl	American, US Airways, Delta	Boston	MA	L	10,665,476	1.70	207,138	1.57
LGA	La Guardia	US Airways, American, Delta,	New York	NY	L	10,416,041	1.66	207,915	1.57
CVG	Cincinnati-Northern Kentucky Intl	Delta	Covington-Cincinnati, OH	KY	L	9,879,246	1.57	150,943	1.14

continued on next page

APPENDIX A Activities at 35 Operational Evolution Plan (OEP) Airports in the United States: 2002 (Continued)

Airport code	Airport	Primary and secondary air carriers	City	State	Hub type	Number of annual scheduled passengers	Percentage of total passengers	Number of annual scheduled A/C ops	Percentage of total A/C ops
BWI	Baltimore-Washington Intl	Southwest, US Airways	Baltimore	MD	L	9,489,296	1.51	210,349	1.59
HNL	Honolulu Intl	Aloha, Hawaiian, ATA	Honolulu	HI	L	9,266,615	1.48	174,544	1.32
PIT	Pittsburgh Intl	US Airways, Delta	Pittsburgh	PA	L	9,212,335	1.47	188,154	1.42
SLC	Salt Lake City Intl	Delta, Southwest	Salt Lake City	UT	L	8,908,798	1.42	151,121	1.14
FLL	Ft Lauderdale-Hollywood Intl	Continental, Delta, Southwest, American, US Airways, Spirit, Jet Blue	Ft Lauderdale	FL	L	7,983,704	1.27	147,874	1.12
IAD	Washington Dulles Intl	United, Delta, American	Washington	DC	L	7,936,618	1.26	130,351	0.99
MDW	Chicago Midway	American, Southwest	Chicago	IL	L	7,573,932	1.21	161,468	1.22
TPA	Tampa Intl	Southwest, Delta, US Airways, Continental, Air Tran, American	Tampa	FL	L	7,544,284	1.20	145,968	1.11
SAN	San Diego Intl-Lindburgh Field	Southwest, American, United	San Diego	CA	L	7,224,573	1.15	143,298	1.08
PDX	Portland Intl	Alaska, United, Southwest	Portland	OR	M	5,970,960	0.95	122,407	0.93
DCA	Washington Reagan Natl	US Airways, Delta	Washington	DC	M	5,311,436	0.85	121,456	0.92
CLE	Cleveland Hopkins Intl	Continental, American	Cleveland	OH	M	5,007,767	0.80	86,572	0.66
MEM	Memphis Intl	Northwest	Memphis	TN	M	4,784,135	0.76	237,385	1.80
Aggregate of all 35 airports						460,283,394	73.34	9,080,596	68.75
Scheduled air transportation in the nation as a whole						627,600,000	100.00	13,208,600	100.00

Key: A/C = aircraft; L = large hubs; M = medium hubs.

Notes: Only scheduled passenger and A/C operations were considered to make the data compatible with T-100 segment data.

Airport hubs in this paper use the U.S. Department of Transportation, Federal Aviation Administration definition. There are four categories of total enplanements (i.e., physical counts): large (> 1% of total enplanements), medium (0.25%–0.999% of total enplanements), small hubs (0.05%–0.249% of total enplanements), and nonhub (< 0.05% of total enplanements). These are physical hubs.

There is a second definition that categorizes airports as a hub where inbound flights are scheduled to arrive from multiple origins within a short period of time thus creating a bank of

passengers. The coordinated arrival and departure banks together form a wave of activities and lead to peaks in airlines schedules. Some physical hubs are, thus, operational hubs. However, an airport can be an operational hub without being a physical hub (i.e., airports primarily serving connecting passengers), and a physical hub may exist without being an operational hub (i.e., airports primarily serving origin and destination passengers).

Sources: U.S. Department of Transportation (USDOT), Federal Aviation Administration (FAA), *Terminal Area Forecast (TAF)* (Washington, DC: 2003); USDOT, FAA, *Aerospace Forecasts, 2003–2014* (Washington, DC: U.S. Government Printing Office, 2003); and *Official Airline Guide (OAG)*, available from <http://www.oagflights.com>.