Emergence of Secondary Airports and Dynamics of Regional Airport Systems in the United States

by

Philippe A. Bonnefoy

B. Ing.
Ecole Polytechnique de Montréal, Canada, 2002

SUBMITTED TO THE DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN AERONAUTICS AND ASTRONAUTICS
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2005

2nd copy

Signature of Author: ______________________
Philippe A. Bonnefoy
Department of Aeronautics and Astronautics
May 2005

Certified by: ______________________
Prof. R. John Hansman
Professor of Aeronautics and Astronautics
Thesis Supervisor

Accepted by: ______________________
Prof. Jaime Peraire
Professor of Aeronautics and Astronautics
Chair, Committee on Graduate Students

EMERGENCE OF SECONDARY AIRPORTS AND DYNAMICS OF REGIONAL AIRPORT SYSTEMS IN THE UNITED STATES

by
Philippe A. Bonnefoy

Submitted to the Department of Aeronautics & Astronautics
on May 20th 2005 in partial fulfillment of the
requirements for the Degree of
Master of Science in Aeronautics & Astronautics

Abstract

With the growing demand for air transportation and limited capacity at major airports, there is a need to increase the capacity of airport systems at the metropolitan area level. The increased use of secondary airports has been and is expected to be one of the key mechanisms by which future demand is met in congested metropolitan areas.

This thesis provides an analysis of the factors influencing the emergence of secondary airports and the dynamics of multi-airport systems. The congestion of the core airport, the distribution of population at the regional level, the existence and the proximity of a secondary basin of population close to secondary airports were identified as major factors. Ground access and airport infrastructure, the low level of connecting passengers at the core airport were also identified as a contributing factors. The entry of an air carrier –generally a low-cost carrier- was determined to be an essential stimulus in the emergence phenomenon impacting fares and airport competition levels resulting in market stimulation. But the emergence of secondary airports imposes new constraints that need to be taken into account in the national air transportation system improvements. By providing an identification of the factors that influence the emergence of secondary airports and an understanding of the dynamics of regional airport systems this research provides useful support for the planning and the future development of multi-airport systems.

Thesis Supervisor: ______________________________

Prof. R John Hansman
Professor of Aeronautics and Astronautics

Acknowledgements

First, I would like to express my gratitude to my advisor Professor R. John Hansman for his help, insight and advice throughout these exciting and enriching two years at MIT.

This work was supported by NASA Langley under grant NAG-1-2038 and the Natural Sciences and Engineering Research Council of Canada. Thank you to Robert Yackovetsky from NASA Langley for his feedback and support.

I would like to thank Professor Amadeo Odoni and Professor Richard De Neufville from MIT for their valuable advice, in addition to the NASA/FAA Joint University Program members from Princeton University and Ohio University for their much appreciated feedback.

Thanks to my colleagues in the International Center for Air Transportation at MIT; Richard Cleaz, Emmanuel Carrier, Jonathan Histon, Helen Jiang, Aleksandra Mozdzanowska, Laura Major, Tom and Hayley Reynolds and Roland Weibel. Special thanks to Alex and Roland for all the fascinating and enriching discussions and debates we had.

I would also like to acknowledge Dr. Daniel Leblanc, former Professor of Mathematics and Industrial Engineering at Ecole Polytechnique de Montréal, Canada, for his guidance and advice.

Finally, I would like to express my deepest gratitude to my family for their continuing encouragement, help and support.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AAR	Average Arrival Rate
ADR	Average Departure Rate
BTS	Bureau of Transportation Statistics (United States)
DOT	Department Of Transportation (United States)
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
GDP	Gross Domestic Product
HHI	Herfindahl-Hirschman Index
HR	Hourly Rate
ILS	Instrument Landing System
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LCC	Low-Cost Carrier
MAS	Multi-Airport System
NAS	National Airspace System
NPIAS	National Plan for Integrated Airport System
OD	Origin Destination
OEP	Operational Evolution Plan
RAS	Regional Airport System
SD	System Dynamics
TAF	Terminal Area Forecasts
TRACON	Terminal Radar Approach Control
TS	Traffic Share
UAV	Unmanned Aerial Vehicle
VFR	Visual Flight Rules
VLJ	Very Light Jet
VMC	Visual Meteorological Conditions
WAAS	Wide Area Augmentation System

Chapter 1

Introduction

1.1 Motivation

1.1.1 The U.S. National Airport System

In January 2004, the U.S. national airport system was composed of 19,576 airports of which 5280 were open to the public [1]. As shown on Figure 1, higher concentrations of airports are found in the Eastern part of the United States and in the state of California. This concentration of airports is generally correlated with the distribution of population as shown on Figure 1.

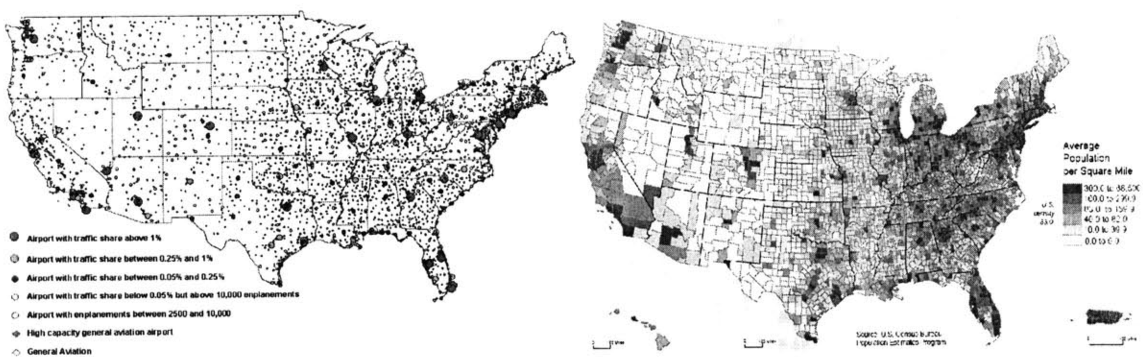


Figure 1: Distribution of airports [3] (by type and size) and population [4] in the U.S.

Due to the lack of land availability in metropolitan areas and other factors such as pressure and opposition from local residents to build new airports -for both land right-of-use and environmental concerns- in addition to lack of funds, the current set of airports is not likely to significantly expand over the upcoming decades. Using Bureau of Transportation Statistics data [2], the study of the evolution of the number of certificated[1] and public airports showed that from 1980 to 1999, the average net loss of certificated

---

[1] Federal Regulation 49 CFR Part 139 prescribes the rules governing the certifications and operation of land airports which serve any scheduled or unscheduled passenger operation of an air carrier that is conducted with an aircraft having a seating capacity of more than 30 passengers. Any airport serving schedules or unscheduled air carrier operations must have a current airport operating certification. Source: Federal Aviation Regulations Part 139 Airport Certification, URL:[http://www.faa.gov/arp/ace/part139.cfm].

airports reached 4 airports per year, accounting for an annual rate of -0.6%. In the case of public airports, after a significant growth in the early 1980s, the national set of public airports was diminishing by an average of 36 airports per year. These constraints imply that the current set of airports will have to accommodate any growth of demand for air transportation and traffic.

1.1.2 Evolution and distribution of traffic

Air traffic has been growing significantly over the last decades. As shown on Figure 2, total enplanements increased by a factor of 2.4 from 294 million enplanements in 1978 to 706 million in 2000 corresponding to an average growth rate of 4% per annum. The 11% decrease in passenger traffic between 2000 and 2002 resulted from the economic recession that started early 2001 and was later strongly reinforced by the Sept 11 events. Since 2002 passenger traffic has been steadily increasing and is forecasted to exceed the 2000 levels in 2005. Total commercial operations followed the same patterns as total enplanements over the last three decades.

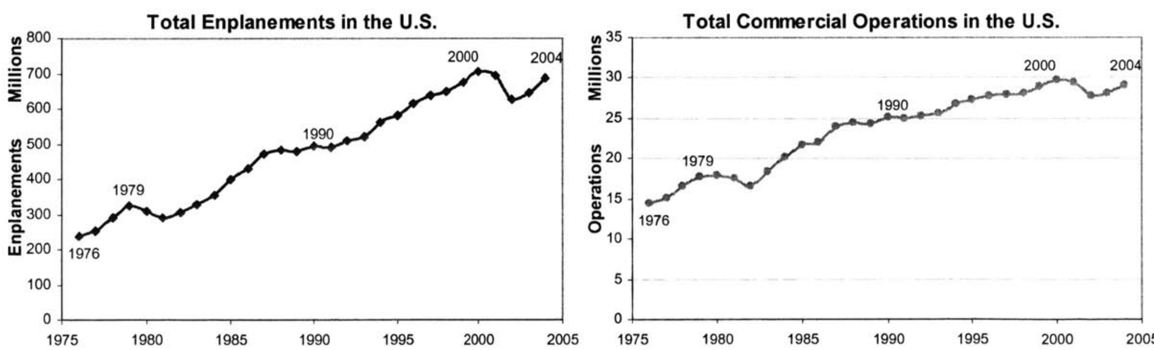


Figure 2: Evolution of U.S. total enplanements and operations since 1976

Figure 3 shows the relation between total enplanements and U.S. Gross Domestic Product (GDP) from 1976 to 2001. Except for recession years, a strong positive correlation between GDP and enplanements was found. Due to positive feedback mechanisms between the economy and the demand for air transportation [7], it is assumed that if Gross Domestic Product (GDP) increases in the upcoming years, passenger traffic should increase.

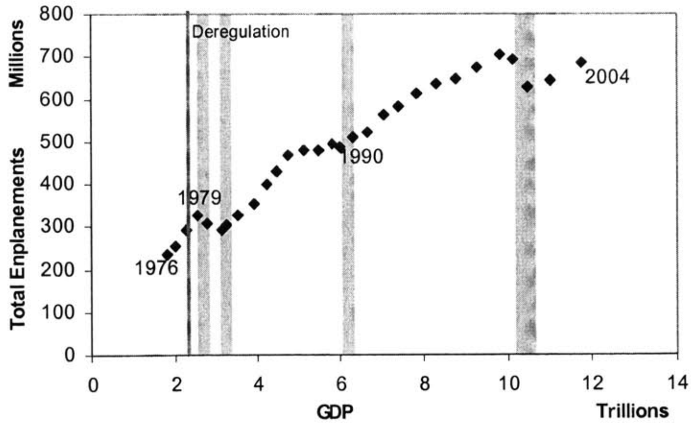


Figure 3: Relation between GDP [5] and total enplanements from 1976 to 2001

However, passenger traffic is not uniformly distributed over the national airport system. Using historical records of enplanements from the FAA Terminal Area Forecasts database [17] airport traffic shares were computed for each of the 2715 available airports. Traffic share was defined as the passenger enplanements at the airport divided by the sum of enplanements over the entire set of airports. Even though there are more than 2715 public airports in the United States, the remaining airports are small general aviation airports that generally do not handle any commercial traffic. Therefore the sum of passenger traffic over the available set of airports corresponds to the commercial traffic at the national level.

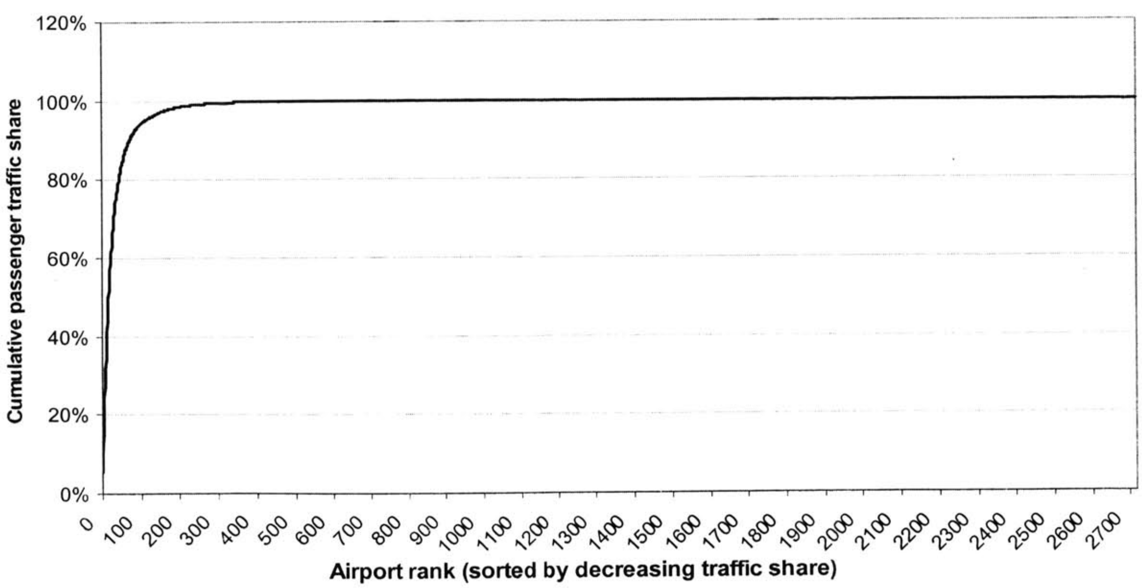


Figure 4: Lorenz curve of airport traffic share in the U.S.

Figure 4 shows the cumulative distribution of traffic share of airports ranked by decreasing importance. It was found that only 31 airports handle 70% of the overall U.S. passenger traffic and 90 % of the traffic is handled by 70 airports. This observation implies a concentration of the traffic over a limited number of airports. Distribution inequality is typically measured using the Gini Index. It is typically utilized to quantify the inequality of income distribution at the national level. More generally, it can be applied to any Lorenz curve (Figure 4) and is computed as follow:

$$Gini\_Index = \left(\frac{\sum_{i=1}^{n} CTS_i}{n/2} - 1 \right) * 100 \tag{1}$$

where CTS_i is the cumulative of the traffic share (from 0 to 1) for airport i and n represents the size of the set of airports. Gini Indexes range from 0 to 100 where 0 means that the traffic is distributed uniformly on the set entire set of airports and 100 implies that it is concentrated at one airport. Using historical records of enplanements for year 2003 from the FAA Terminal Area Forecast database, the Gini Index of passenger traffic was found to be equal to 99. This implies significantly high distribution inequality. This concentration of traffic implies that a small number of airports handle a large fraction of the traffic. It also highlights the fact that a large fraction of the national airport infrastructure is underutilized. In fact, all airports beyond rank 96 (Figure 4) handle less than 0.1% of the national passenger traffic and beyond rank 240 they handle less than 0.01% of the national traffic.

1.1.3 Inadequacy between demand and supply

The concentration of traffic that was observed at the national level implies that a few key airports handle large volumes of traffic. Due to a direct relationship between enplanements and operations through aircraft size and load factor these same airports handle large volumes of operations. However, airports have a finite capacity[1], generally measured in achievable volumes of operations. Based on first principles of queuing theory,

[1] Refer to Appendix B for greater details on various measures of airport capacity.

when an airport is operating close to its capacity, normal operations are disrupted and delays[1] are generated. If demand keeps increasing the system can reach a gridlock.

The following sections give an illustration of capacity crises in the U.S. air transportation system. A first illustration is given with the state of the system in 2000 that exhibited record high of traffic and delays. After the traffic decrease experienced in 2001, the pressure on the system was relieved. However, by 2003 the results of a localized capacity crisis were observed at Chicago O'Hare airport. Finally, an assessment of the future capability of the air transportation system to accommodate the growth of demand under the current traffic concentration patterns is presented.

i. Congestion of the U.S. Air Transportation System in 2000

In 2000, the U.S. air transportation system exhibited high level of delays as shown on Figure 5 that illustrate the evolution of total national delays from 1995 to 2004. The typical annual pattern of delays is usually characterized by relatively low level of delays from January to April. The increase of the operations count during the summer forces delays to increase (due to fixed short term capacity of the system). Peaks of delays typically appear in June, July and August. After the summer, delays gradually decrease until December.

---

[1] In the air transportation industry delays are defined as the time between the time published –generally published in the OAGs- and the time actually performed. As airline publish departure and arrival time (at the gate), a flight is usually associated with two measure of delays; a departure delay and an arrival delay. At the aggregate level, delays are a time varying metric which follows – in the first order - the behavior of its cause: the airport utilization ratio. As the level of operations follow daily, weekly and annual patterns, delays follow the same type of patterns.

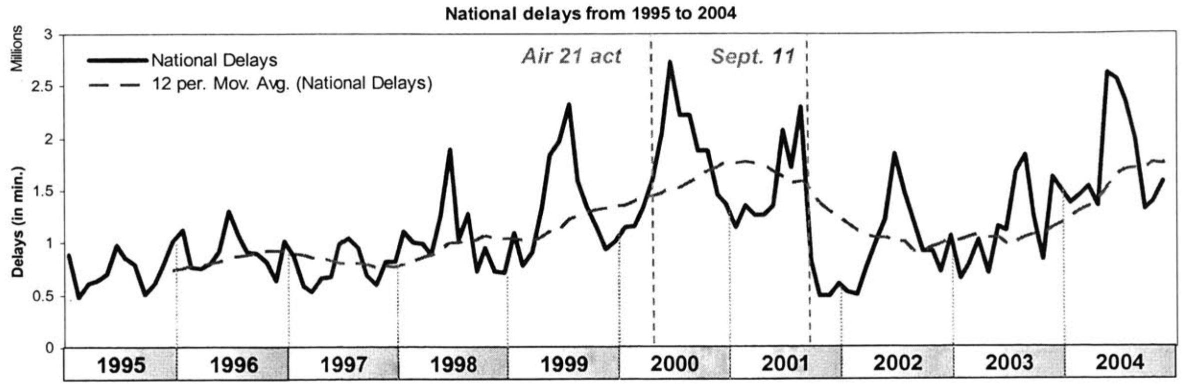


Figure 5: Monthly delays (national level) from 1998 to 2001 [24]

The 12 year moving average highlights clearly the general trend of increasing delays until 2001 (Figure 5). Delays reached a peak of 2.3 million minutes of delays in June 2000. However, unlike previous years, in 2000, delays did not drop significantly at the end of the summer and remained at high levels until November. By the first quarter of 2001, the beginning of an economic recession started to have an impact on traffic. As traffic decreased, delays did not persist. With the major reduction in number of flights after September 2001, pressure was relieved from the system and delays reached a record low in October.

Table 1: Airports with highest delays in 2000

Code	Airport name	Delays per 1000 flights
LGA	LaGuardia	155.9
EWR	Newark	81.2
PHL	Philadelphia	44.5
ATL	Atlanta	30.9
BOS	Boston	47.5
JFK	NY Kennedy	38.8
DTW	Detroit	17.6
ORD	Chicago O'Hare	63.3
DFW	Dallas-Fort Worth	23.8
IAD	Washington Dulles	19.5
MSP	Minneapolis-St. Paul	12.7
STL	Lambert St. Louis	18.2
LAX	Los Angeles	21.9
SFO	San Francisco	56.9
PHX	Phoenix Sky Harbor	22.0
MIA	Miami	11.3
IAH	Houston Bush	28.1
CVG	Cincinnati	15.4

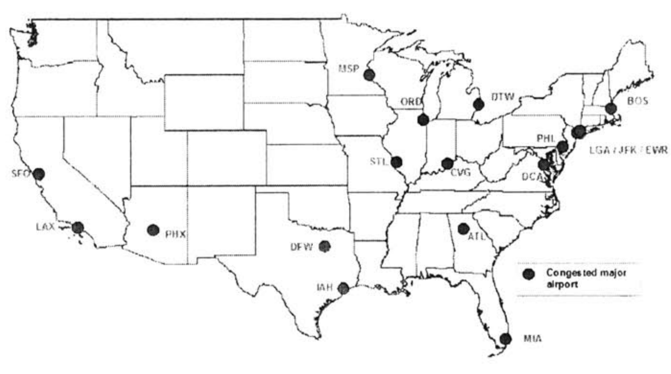


Figure 6: Congested major airports in 2000 [24]

As shown on Figure 6 that represents the 18 U.S. domestic airports that experienced the highest percentage of delayed operations in year 2000, most major airports in the U.S. experienced significant delays. Table 1 also shows the ranking of the airports and the average number of flights delayed for every 1,000 scheduled flights. La Guardia was found to have exhibited by far the highest level of delays with 15,6 % of flights delayed.

An in depth analysis of the delays at La Guardia was performed using FAA monthly delay data [24]. Figure 7 shows the evolution of monthly delays from 1995 to 2004. It was observed that early 2000, delays were at slightly higher levels then they were in 1999, however, this was without comparison with the levels of delays that occurred over the summer. In September 2000, La Guardia airport exhibited a record of 488,000 minutes of cumulative delays. Delays remained high throughout October and November.

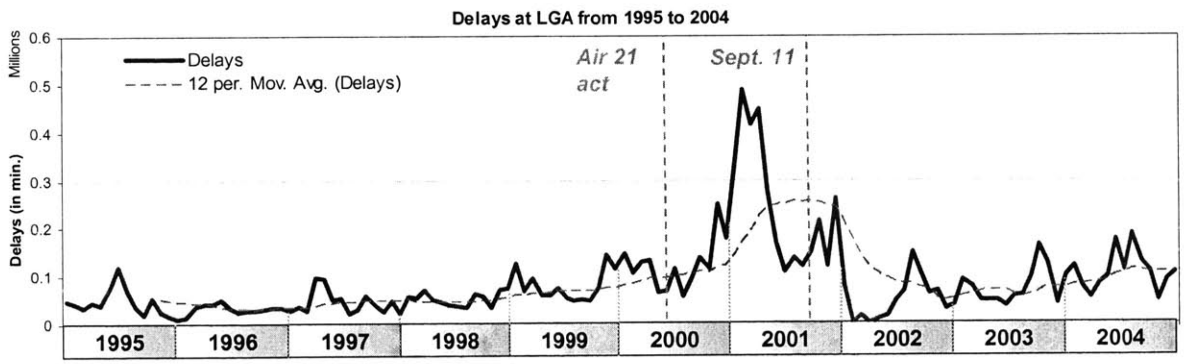


Figure 7: Monthly delays at La Guardia airport from 1998 to 2003 [24]

Figure 8 show the comparison between the total monthly demand, capacity and performed operations at La Guardia airport from January 2000 to December 2000. In the case of the data covering the entire day, as shown in Figure 8, the overall demand exceeded the airport capacity by 45%. Reducing the time window of observation from 07:00 to 21:59 showed that the demand for this period exceeded the capacity by 115%. In term of operations –the fraction of demand that was really performed-, during the 07:00 to 21:59 time period, the utilization ratio for the September to November period reached 0.98. From first principles of queuing theory these ratios are usually unsustainable for a long period of time, implying that delays probably propagated after 21:59.

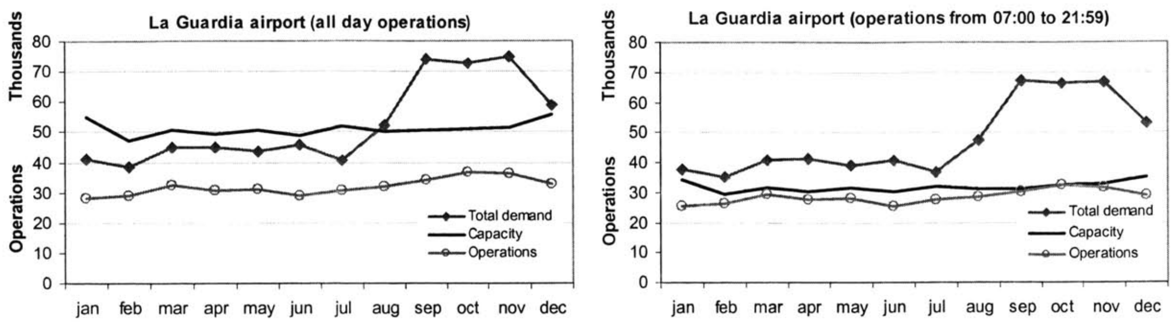


Figure 8: Monthly demand, operations and capacity at LGA in 2000

The sudden increase of demand for La Guardia airport was the result of the adoption by Congress of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21), enacted on April 5th 2000. This act allowed an exemption from the High-Density Rule (HDR)[1] limits for flights performed with aircraft of 70 or fewer seats, between La Guardia and "small hub and non-hub airports"[2]. Slot restrictions were in place to constrain the scheduling behavior of airlines by capping the total number of operations that can be performed at the airport. Without the restrictions, airlines started to add scheduled operations above the airport capacity, which resulted in an over utilization of the airport that materialized into record high volume of delays. By December, the FAA requested airlines to cut a fraction of their operations. The impact of this decision is shown on Figure 8 where demand dropped between November and December 2000. As a result delays decreased significantly between December 2000 and January 2001.

Because airports are part of an integrated network, the irregular behavior of one airport is propagated throughout the network and affects parts or the entirety of the network. This was the case in 2000 when the propagation of delays from La Guardia airport –that accounted for 14% of the national delays- to the entire national network resulted in this early nation wide crisis.

---

[1] As of 2005, the High-Density Rules (14 CFR Part 93) designate four airports as slot-controlled airports. Those airports are Chicago's O'Hare International (ORD), New York's LaGuardia (LGA) and John F. Kennedy International (JFK), and Washington's National Airport (DCA). It was enacted in 1968 (14 CFR part 93, Subpart K, 33 FR 17896; December 3, 1968). Originally, it was scheduled to remain effective until the end of 1969. It was however extended to October 25, 1970. In 1973, it was extended indefinitely. [25]

[2] The FAA defines "Small Hub airports" as airports that handle between 0.25% and 0.05% of the national volume of enplaned passengers. "Non Hub airports" are smaller than "Small Hub airports" and handle less than 0.25% of the national passenger traffic and more than 10,000 enplaned passengers.

ii. Recent State of the Air Transportation System

The recession that started in early 2001 coupled with the post September 2001 decrease of traffic relieved some pressure on the system. In October 2001, delays were at their lowest level since May 1995. Even though delays were not an issue after the end of 2001, concerns reappeared late 2003.

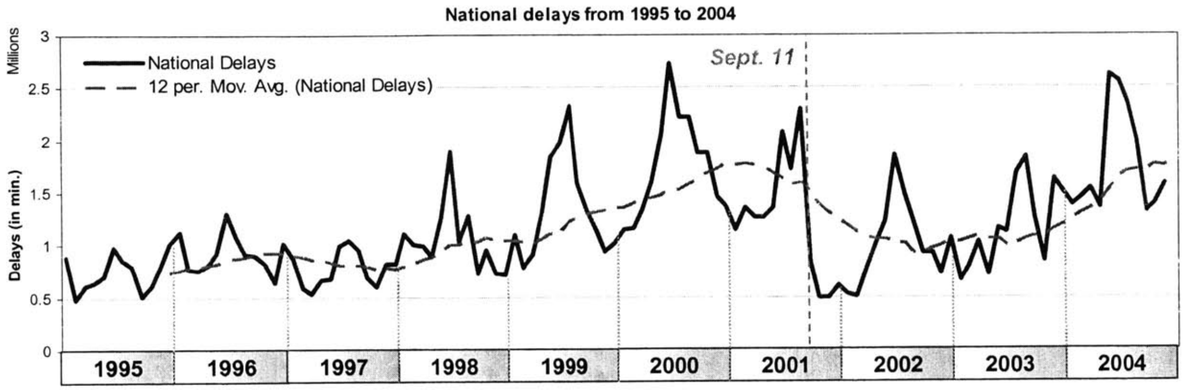


Figure 9: Monthly delays (national level) from 2000 to 2004 [24]

As shown on Figure 9 in November and December 2003, delays at the national level had reached higher levels than they were at the same time in 2000. January 2004 had the highest level of delays since all months of January in the 1990s and 2000s. In addition, the 12 year moving average shows that the same general trend of increasing delays observed both prior to 2001 and after 2002.

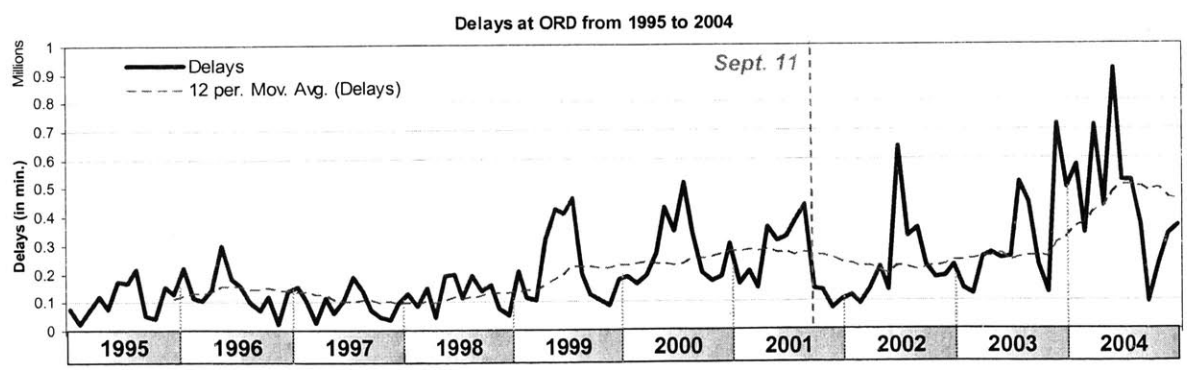


Figure 10: Monthly delays at ORD from 1998 to 2004

As this was the case in 2000, when La Guardia airport was responsible for almost 14% of the national delays, one particular airport was the cause of this increase in system delays.

As shown on Figure 10, Chicago O'Hare airport (ORD) has recorded a significant increase in delays in November 2003. These volumes of delays remained at high levels in December 2003 and January 2004. During the three months from November 2003 to January 2004, delays at Chicago O'Hare represented 40% of the total delays at the national level. Figure 11 shows monthly demand, capacity and performed operations at Chicago over the year 2003. Similarly with La Guardia airport in 2000, the cause of the delays at Chicago O'Hare remains capacity inadequacy due to the over scheduling behavior of airlines and the limited capacity of the airport. For the 07:00 to 21:59 operation period, demand exceeded the capacity by 50%. In other words, for every 3 aircraft that were willing to land or depart, the airport was only able to handle 2 of them. The airport utilization ratio increased from 0.78 levels in the beginning of 2003, to 0.88 in November 2003 resulting in an increase in volumes of delays.

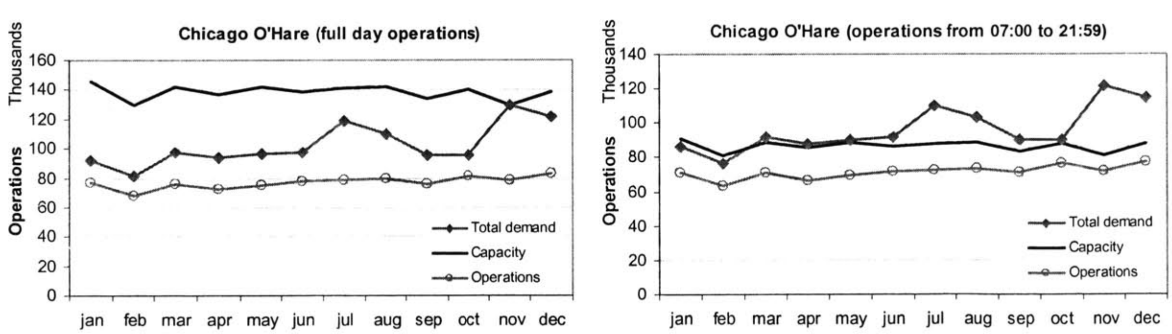


Figure 11: Monthly demand, operations and capacity at ORD in 2003 [24]

In an effort to control this capacity crisis, the U.S. Department of Transportation requested that United Airlines and American Airlines cut 62 (5%) of their flights during the peak-hour period. As delays remained at high levels in March, another reduction was necessary. Therefore, on April 21, 2004 the FAA asked United and American to reduce their scheduled operations by 29 departures and 17 arrivals scheduled between 12:00 and

20:00. This measure was supposed to be valid from June 10, to October 30, in order to face the expected summer congestion problem. The record high delays and the recent decisions from the FAA to cut operations highlight the existence of a capacity crisis at this airport. In addition, the cuts of operations clearly show that demand is not met at this airport.

iii. Future capacity inadequacies

The examples of La Guardia (LGA) and Chicago O'Hare (ORD) and the solutions of regulating the traffic through enforcement mechanisms, highlight the capacity deficit at certain key airports and their inability to meet the current demand.

Table 2: New runway projects at major airports [13]

Airport code	Airport name	Percentage of operations delayed	OEP new runway project (date completion/ capacity benefit)
LGA	LaGuardia	15.6%	
EWR	Newark	8.1%	
ORD	Chicago	6.3%	
SFO	San Francisco	5.7%	
BOS	Boston	4.8%	2006 / +2%
PHL	Philadelphia	4.5%	
JFK	Kennedy	3.9%	
ATL	Atlanta	3.1%	2006 / +33%
IAH	Houston	2.8%	
DFW	Dallas / Ft. Worth	2.4%	
PHX	Phoenix	2.2%	
LAX	Los Angeles	2.2%	
IAD	Dulles	2.0%	
STL	St. Louis	1.8%	2006 / +48%
DTW	Detroit	1.8%	
CVG	Cincinnati	1.5%	2005 / +12%
MSP	Minn./St. Paul	1.3%	2005 / +19%
MIA	Miami	1.1%	
SEA	Seattle	1.0%	2008 / +46%
LAS	Las Vegas	0.8%	
DCA	Reagan National	0.8%	
BWI	Balt.-Wash. Intl	0.7%	
MCO	Orlando	0.6%	
CLT	Charlotte	0.6%	2008 / +11%
PIT	Pittsburgh	0.4%	
SAN	San Diego	0.3%	
DEN	Denver	0.2%	
SLC	Salt Lake City	0.2%	
TPA	Tampa	0.2%	
MEM	Memphis	0.0%	

The plans for airport capacity adjustment that are detailed in the FAA Operational Evolution Plan (OEP) [13] do not directly address the capacity inadequacy of major airports. Table 2 highlights the airports that will receive additional capacity in the upcoming years. Boston Logan airport which was ranked 5^{th} in terms of level of delays in 2000 will be the first airport in the list to receive additional capacity. The following airports are ranked 8^{th}, 14^{th}, 15^{th} etc. Clearly the capacity adjustment plans leave the opportunity for many critical airports to exhibit the same behavior and role that La Guardia and O'Hare played in 2000 and 2003 respectively. In addition, several regions are likely to lack capacity in the next years. For example, the high density New York airport system with its three major airports ranking 1^{st}, 2^{nd} and 7^{th} in terms of delays are not scheduled to receive any capacity improvement in the medium term (nor the long term).

If the growth of demand for air transportation is maintained and the system is operated under the same patterns of traffic concentration, key airports are expected to exhibit severe capacity inadequacies in the upcoming years.

iv. The Air Transport Industry: trends and structural changes

In the past, several factors have contributed to the problem of congestion, such as the decreasing average size of aircraft. New structural changes in the air transportation industry and the reinforcement of recent trends are likely to exacerbate this problem by adding significant volumes of operations in the National Airspace System (NAS).

Average aircraft size:

Because major airports were operated close to their limit capacity in terms of number of operations, the obvious solution would have been to increase the size of aircraft in order to accommodate a larger volume of passengers for a given volume of operations. However, this trend was not observed over the last decade. Figure 12 shows the average number of seats per departure for domestic and international operations. With an averaged ratio of 7.2 domestic departures for each international departure, domestic operations drive the general aircraft fleet size in the United States. A constant decrease in the average number of seats per departure was observed between 1990 and 2000. This trend was strengthened after 2000 when major carriers pulled the oldest and large aircraft out of their fleets during the airline industry downturn that started in early 2001 and was exacerbated by September 11 into an industry crisis.

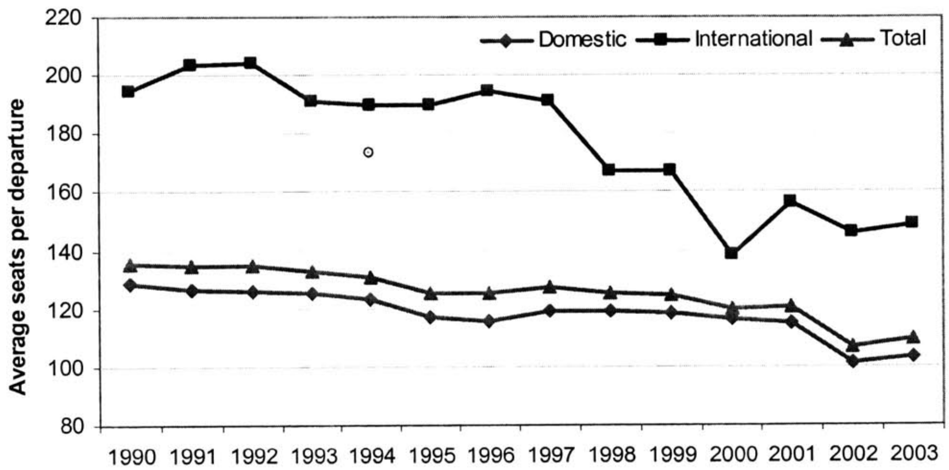


Figure 12: Average number of seats per departure from 1990 to 2003 [11]

This trend was also generated by the emergence of regional jets -50 to 100 seat twin jet aircraft- that exhibited an exponential growth during the 1990s [14]. Willing to gain market share using the "S-curve" effect[1], airlines offered higher flight frequencies with smaller aircraft. Airlines also kept service on small OD markets where operations were not viable with larger narrow body aircraft. This contributed to a reduction in the average aircraft size, which meant that that the number of operations grew more quickly than the passenger traffic. This implies a lower efficiency of airport capacity.

Recent structural changes in the airline industry

What was originally perceived as an industry downturn, as it happens roughly every 11 years due to the cyclicality of the industry [15], finally resulted into a structural change of the entire industry. The market share of low-cost carriers could not be ignored anymore. Better transparency of fares and product availability, gained from internet based

[1] The "S curve" effect refers to the non linear relationship between flight frequency and market share on a market. An airline offering more frequency than another airline will capture more passengers (market share) than the market share proportional to the frequency. This phenomenon is due to the fact that passenger tend to prefer airlines that offer flights with greater frequency because passengers value the flexibility that these more frequent flights provide.

distribution channels, changed passengers' behavior in addition to their willingness to pay. With this increased competition from carriers operating under significantly lower cost structures, legacy carriers survival became an issue. The financial difficulties of legacy airlines also limited their ability to invest in airport infrastructure. From an airport management strand point, this situation creates higher uncertainty for large scale transformation projects.

Development of new segments in the air transportation market

The national air transportation system (national airport system, national airspace system, etc.) is shared by multiple operators including legacy and low-cost scheduled carriers but also business/corporate aviation operators (e.g. charter operators, fractional ownership operators, etc.) that generally fall under the category of general aviation. The fractional ownership program segment -that allows a corporation or an individual to share an aircraft for a fraction of the total cost- has grown at an exponential rate since the late 1980s. These segments of the air transportation industry also generate a significant volume of operations at airports part of high density metropolitan areas [16]. Looking ahead, a new class of aircraft called Very Light Jets is likely to enter the market in 2006 and forecasts [9,10] for these types of aircraft show that there could between 5,500 and 8,000 of these new aircraft in the NAS within the next 10 to 15 years. These new aircraft, in addition to other vehicles such as Unmanned Aerial Vehicles (UAVs), will surely generate additional traffic adding to the overall volume of traffic.

1.1.4 Potential solutions for increasing the capacity of the system

From an economic growth perspective, it is not desirable to limit the growth of demand for air transportation because of its strong links to the economic performance of the country. The air transportation industry contributes to \$80-to-\$90 billion per year to the national economy representing approximately 1% of the GDP and employs 800,000 people [12]. Therefore, there is the need to increase the capacity of the system in order to avoid a crisis or a gridlock of the system and meet future the demand for air transportation.

There are various ways, whether technology based, procedural, infrastructure based, etc. to increase the capacity of regional airport systems. The most effective mean of adding capacity is by utilizing more runways. This can be achieved by either following; a localized strategy -building more runways at major airports- or a region wide strategy –utilizing and developing existing resources like underutilized airports and enable them to emerge as secondary airports-. The following section presents the localized approach focused on major airports in addition to its limitations and constraints. It also presents the region wide approach and the opportunity of using existing resources in order to meet the future demand for air transportation at the regional level.

i. Increasing capacity at key airports

Increasing capacity at key congested airports is the obvious solution to address the congestion problem. However, the ability to increase airport capacity at these airports is limited due to lack of available space, environmental concerns, ground access and political opposition. The mismatch between the scheduled capacity adjustment contained in the FAA Operational Evolution Plan [13] and the needs of key airports highlighted the challenges of this alternative.

In addition, investing at major airports can be extremely expensive from an investment/benefit stand point. Using airport capacity data [6] and airport information data (number of runways) [30], the hourly capacity divided by the number of runways at the airport were computed for 30 major airports in the continental U.S. (Figure 13). Due to configuration issues (non independence of runways, complexity of ground operations like runways crossings…) the hourly capacity per runway is decreasing with the increase of number of runways at the airport. This decreasing marginal benefit of adding capacity implies that adding a new runway at a major airport does not add as much capacity as if this runway was built at a new airport.

One illustration of this phenomenon is clearly illustrated by the project for the new runway 14/32 at Boston Logan airport [13]. The purpose of this runway is to increase the capacity of the airport when strong and gusty winds are blowing from the northwest. Under these conditions, Logan operates under a single runway, for both departures and arrivals, which greatly reduces the capacity of the airport. During operations under any other configuration, the airport capacity will remain the same as before the construction of the new runway. The overall capacity benefit of this new runway is estimated to be roughly 2% [13].

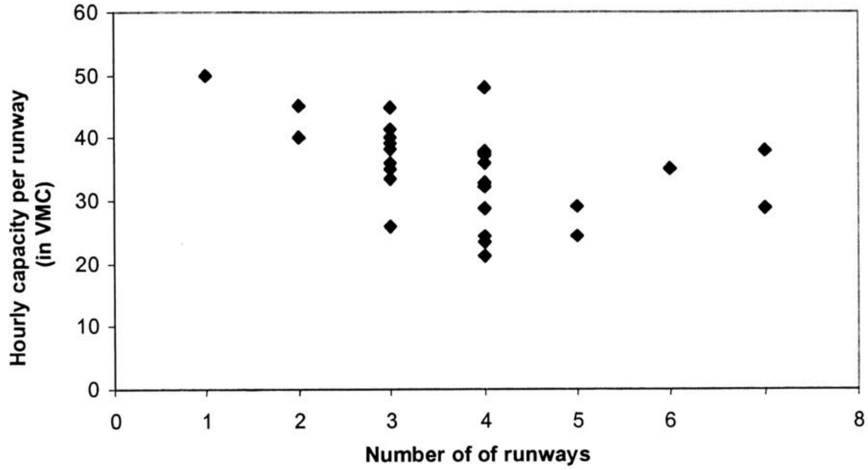


Figure 13: Hourly capacity per runway for the 30 largest airports in the continental U.S. [6]

ii. Using the opportunity of underutilized resources with the emergence of secondary airports

Even though capacity is limited at major airports, there is available capacity at the regional level. Figure 14 shows all airports within 50 miles of Boston Logan airport that have runways longer than 5000 ft.

Boston Logan (BOS) is considered here as the core airport in the metropolitan area. In the close periphery of Logan airport, Hanscom Field (BED) airport serves mostly as a reliever airport for business aviation. This airport is used for joint military/civil operations. In the 20 to 40 miles range, several civil airports, like Beverly (BVY), Lawrence (LWM) and Pawtucket (SFZ) are clearly underutilized. In addition, the South Weymouth Naval Air Station (NZW) closed in 1997, which featured two runways and over 700 acres of land, is a source of capacity. Plans to transform this airport into a recreational park were established in 2001, but have not yet been implemented. Multiple civil and military airports, such as

New Bedford (EWB), Providence (PVD), Manchester (MHT), etc. are also located in the outer ring (35 to 50 miles from Boston city).

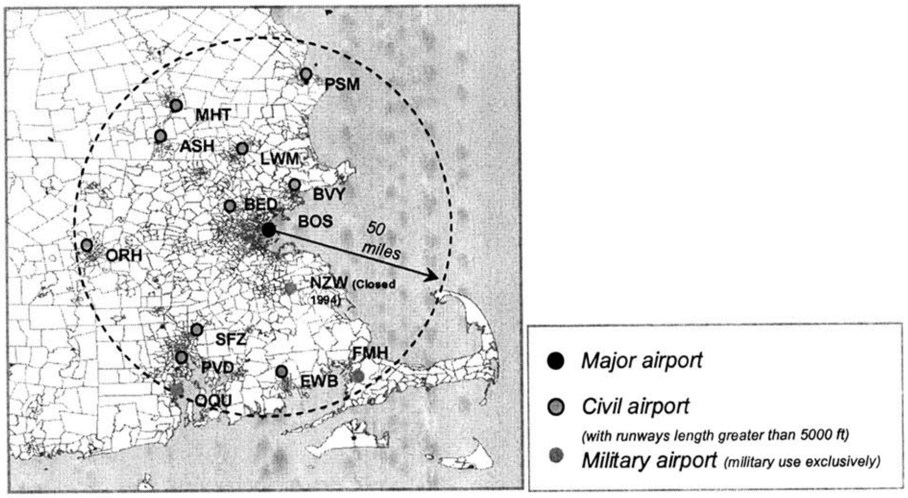


Figure 14: Core and surrounding airports in the Boston region

The Boston regional airport system illustrative case study was expanded to regional airport systems around major airports in the United States. Figure 15, shows the capacity (in number of available runways) at both core airports and at all surrounding airports.

From this study of exiting capacity at the regional level, it was found that there was very limited capacity in terms of runways with lengths greater than 10 000 ft outside core airports. Some airport systems have surrounding airports with runways longer than 10,000 ft like Long Beach (LGB) and Ontario (ONT) in the Los Angeles regional airport system or Oakland (OAK) and San Jose (SJC) at the periphery of San Francisco. However, most regional airport systems only have runways longer than 10,000 ft at their core airport. As the runway length requirements decrease from 10 000 ft to 7 000 ft, 5 000 ft and ultimately 3 000 ft, surrounding airports offer an increasing availability of capacity. In the case of runways with lengths greater than 5 000 ft, the capacity at surrounding airports is twice (on average) the existing capacity at core airports. Similarly, with 3 000 ft runways, this available capacity at surrounding airport is 5 times the capacity at the core airport.

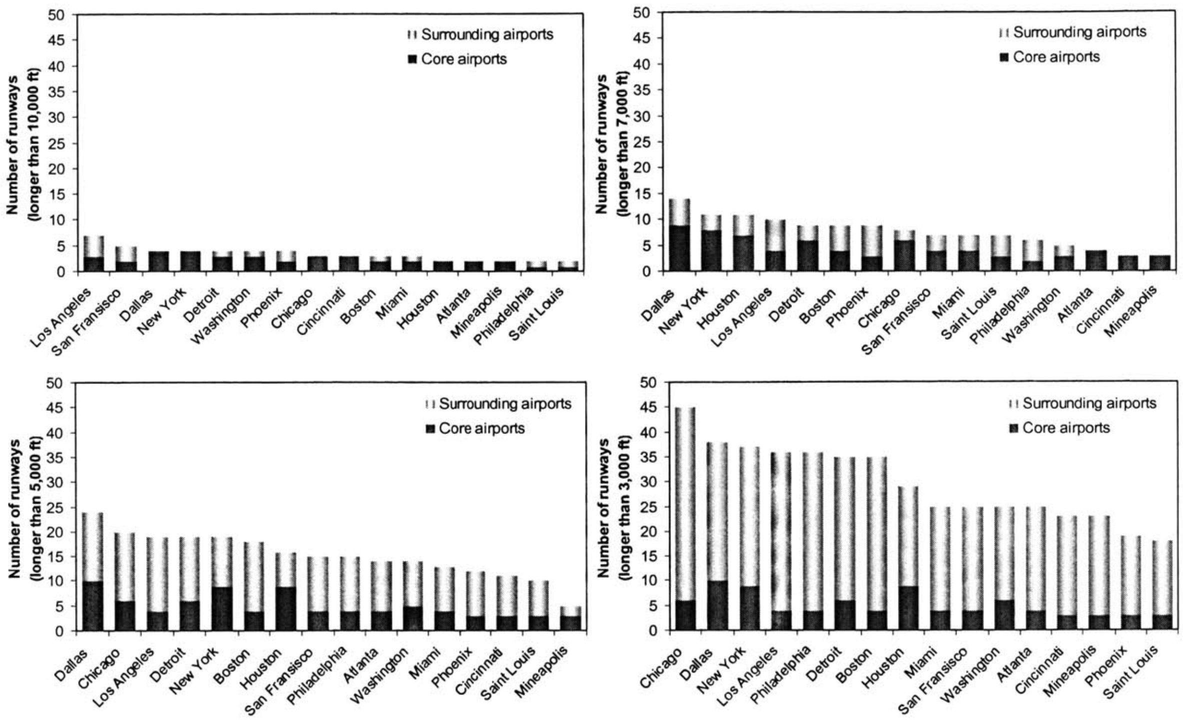


Figure 15: Capacity (number of runways) at major regional airport systems in the U.S. [30]

In the past this available airport capacity at the periphery of core airports has been utilized resulting in the emergence of secondary airports such as Manchester and Providence at the periphery of Boston Logan, or Long Beach, Orange County, Ontario, Burbank at the periphery of Los Angeles airport. These airports have become increasingly popular, and now constitute viable alternatives for accessing metropolitan areas. Most air travel ticket reservation websites now offer the option of searching for flights availability to or from airports located within 50 or 70 miles of a major airport. The phenomenon of secondary airport emergence can be traced back to the end of the 1940s with the emergence of New York International Airport now dedicated as John F. Kennedy International airport which served as a secondary airport to La Guardia. The phenomenon has been amplified over the last 25 years due to the growth of demand for air transportation after the industry deregulation in 1978[1] and capacity limits at major airports. The increased use of secondary

[1] Total passenger enplanements have been multiplied by a factor of 2.4 from 294 million in 1978 when the airline industry was deregulated to 706 million in 2000.

airports is expected to be one of the key mechanisms by which future demand is met in congested metropolitan areas.

1.2 Objectives

Recognizing that existing secondary airports have played a key role in the past for accommodating the growth of passenger traffic and that the emergence of future secondary airports will be key mechanisms for addressing the capacity crisis of congested areas of the air transportation system, there was the need to understand:

- the reasons and conditions that create the need for the emergence of a secondary airport in a regional airport system,
- the factor that lead one particular underutilized regional airport to emerge as a successful secondary airport rather than another closely located airport,
- the dynamics of emergence of these airports,
- identify proactive ways that could accelerate the emergence of future underutilized regional airports.

1.3 Approach

The analysis of the emergence of secondary airport and the dynamics of regional airport systems was performed using a case study approach. Chapter 2 introduces a systematic approach and criteria for identifying secondary airports. This methodology was applied to the U.S. national airport system leading to the identification and classification of secondary airports. These airports were then used and studied throughout the analysis of factors that influence the emergence of secondary airports presented in Chapter 3. In Chapter 4, the factors that were identified are integrated into a system dynamics model that was used as a framework for the understanding of the regional dynamics of multi-airport systems. Finally, Chapter 5 describes the impacts of the emergence of secondary airports at the national and regional levels.

Chapter 2

Identification of Secondary Airports

2.1 Methodology

In order to identify secondary airports and study the dynamics of multi-airport systems, a case study approach was undertaken. The 30 highest volume airports in the United States were selected as reference for the case studies. Table 3 displays the list of these reference airports, ranked by decreasing enplanements handled in 2000.

Table 3: Reference airports for the case studies [17]

Airport code	Airport name	Passenger enplanements
ATL	Atlanta	37 224 000
ORD	Chicago	31 483 000
DFW	Dallas/Ft.Worth	27 581 000
LAX	Los Angeles	24 007 000
MSP	Minn./St. Paul	18 944 000
DEN	Denver	17 435 000
DTW	Detroit	16 563 000
SFO	San Francisco	16 431 000
PHX	Phoenix	16 083 000
LAS	Las Vegas	15 311 000
STL	St. Louis	14 923 000
EWR	Newark	14 904 000
IAH	Houston	14 735 000
SEA	Seattle	13 062 000
MIA	Miami	12 721 000
MCO	Orlando	12 529 000
BOS	Boston	11 066 000
LGA	LaGuardia	10 785 000
PHL	Philadelphia	10 346 000
JFK	Kennedy	10 137 000
CLT	Charlotte	9 442 000
SLC	Salt Lake City	8 709 000
PIT	Pittsburgh	8 014 000
BWI	Balt.-Wash. Intl	8 002 000
CVG	Cincinnati	7 610 000
SAN	San Diego	7 248 000
TPA	Tampa	6 912 000
IAD	Dulles	6 830 000
DCA	Reagan National	6 657 000
MEM	Memphis	4 524 000

Total enplanements at an airport are a better measure of commercial traffic than total operations because general aviation operations generate large volumes of operations, a fraction of operations with no commercial purposes. In addition, aircraft size information is not captured in the measure of volumes of operations. From these 30 U.S. major airports, there were 26 regional airport systems that were identified. A regional airport system was defined as all airports within 50 miles of a reference airport. The reduction from the number of airport selected and the number of regional airport system comes from the fact that the New York airport system includes three major airports La Guardia (LGA), Kennedy (JFK) and Newark (EWR), as well as the Washington regional airport system with Washington National (DCA), Washington Dulles (IAD) and Baltimore (BWI). Figure 16 displays the 26 airport systems that are considered in the case studies.

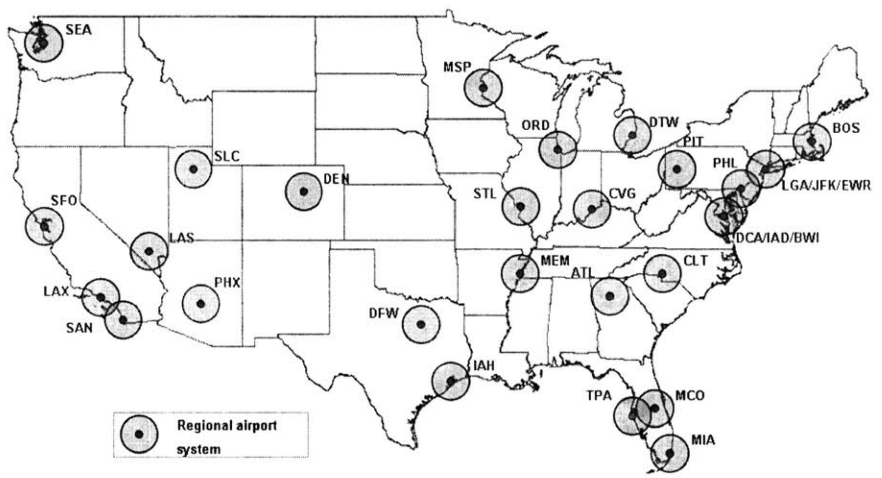


Figure 16: Airport systems selected for case studies

There were 275 airports identified within the 26 regional airport systems. However, a large fraction of these airports were small General Aviation airports. Secondary airports were identified by analyzing traffic shares based on historical records of passenger enplanements [17]. Individual airport traffic shares based on regional airport system traffic were computed as follow:

$$\text{T.S.}_{\text{R.A.S}} = \frac{\text{enplanements at airport i}}{\sum_{i \in A} \text{enplanements at airport i}} \qquad (1)$$

with A = {airports part of the regional airport system}

Airports with traffic share greater than 1% were considered to be core airports or secondary airports. In addition, the 1% threshold captured generally accepted secondary airports.

2.2 Patterns of passenger traffic evolution and airport classification

The methodology of airport identification was applied to the 26 airport systems. From the analysis of historical records of passenger traffic of airports part of the 26 airport systems, typical patterns of traffic were identified.

Table 4: Traffic evolution patterns and classification of regional airport systems

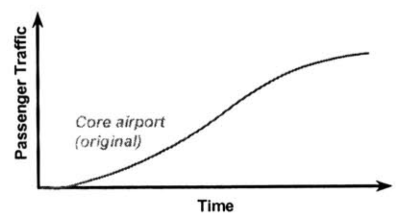
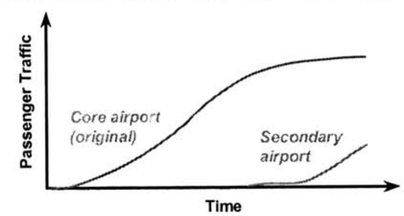
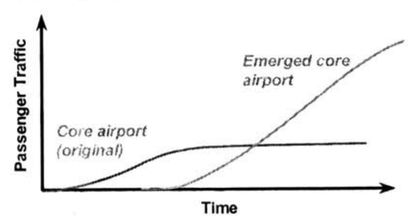
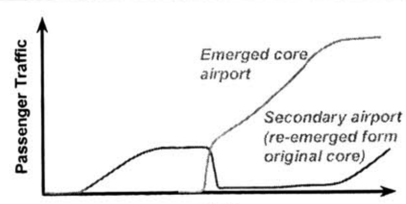
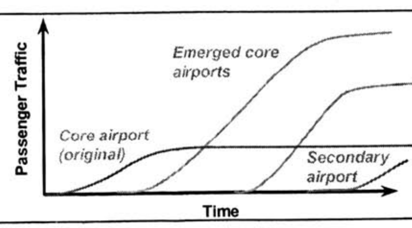
<table>
<tr><th>Type of regional airport system</th><th>Traffic evolution patterns</th><th>Regional airport system</th></tr>
<tr><td>Single core airport (original)</td><td>
</td><td>Atlanta, Philadelphia, Cincinnati, Detroit, Saint Louis, Minneapolis, Phoenix, Seattle, Salt lake City, Las Vegas, Denver, Memphis, Charlotte, Pittsburgh, San Diego</td></tr>
<tr><td>Core airport (original) & Secondary airport</td><td>
</td><td>Boston, San Francisco, Los Angeles, Miami, Tampa,</td></tr>
<tr><td>Core airport (original) & Emerged core airport</td><td>
</td><td>Washington</td></tr>
<tr><td>Emerged core airport & Secondary airport (Re-emerged from original core airport)</td><td>
</td><td>Chicago, Dallas, Houston</td></tr>
<tr><td>Combination of: Core airport (original), Emerged core airport & Secondary airport</td><td>
</td><td>New York</td></tr>
</table>

Table 4 shows the various types of patterns that were identified. Actual traffic evolution patterns for each of the 26 airport systems are presented in Appendix B and Appendix C.

From the analysis of the traffic evolution patterns, airports were sorted based on their traffic in 2000 and their historical role in the regional airport system. Four airport categories were established:

- **Core airports (Original)**: For the purpose of this study, an original core airport was defined as the initial airport in the region from historical and evolution stand points.
- **Core airports (Emerged)**: These airports have emerged while an original core airport was already in place. They grew to a level where traffic now exceeds the passenger traffic of the original core airport.
- **Secondary airports**: A secondary airport was defined as an airport that had a traffic share between 1% and the traffic share of the core airport.
- **Secondary airports (Re-emerged from an original core airport)**: These airports met the secondary airport criteria. However, they were the original core airport in the system. At some point they lost traffic, then regained traffic and re-emerged.

The other airports in the system usually fell into these three categories:

- **General Aviation reliever airports**: These airports are generally located at the periphery of a major metropolitan area and serve as high density General Aviation airports.
- **Other commercial & General Aviation airports:** For the purpose of the study, the airports that did not meet the 1% traffic share are part of a larger set of surrounding airports that generally have general aviation activity and/or low volume of commercial traffic.
- **Military airports:** These airports are used for military purposes. However, some airports are characterized as joint civilian/military use airports.

2.3 Results of the identification of secondary airports

It was found that 32 airports met the 1% regional airport system traffic share criteria. Table 5 shows this set of airports with their respective regional airport system level traffic share.

Table 5: Passenger traffic share at core and secondary airports

Core airport	Traffic Share (based on passenger traffic)	**Secondary** airport	Traffic Share (based on passenger traffic)
Miami (MIA)	**69%**	Fort Lauderdale (FLL)	**31%**
Boston (BOS)	**76%**	Providence (PVD)	**15%**
		Manchester (MHT)	**8%**
Orlando (MCO)	**95%**	Orlando Sanford (SFB)	**3%**
		Melbourne (MLB)	**2%**
Tampa (TPA)	**88%**	St Petersburg (PIE)	**4%**
		Sarasota (SRQ)	**8%**
San Francisco (SFO)	**64%**	Oakland (OAK)	**17%**
		San Jose (SJC)	**20%**
Los Angeles (LAX)	**77%**	Burbank (BUR)	**6%**
		Ontario (ONT)	**8%**
		Orange county (SNA)	**9%**
		Long Beach (LGB)	**1%**
Washington Nat. (DCA)	**27%**		
Baltimore (BWI)	**36%**		
Dulles (IAD)	**37%**		
La Guardia (LGA)	**27%**	Islip (ISP)	**2%**
Newark (EWR)	**37%**		
JF Kennedy (JFK)	**34%**		
Chicago O'Hare (ORD)	**83%**	*Chicago Midway (MDW)*	**17%**
Dallas Fort Worth (DFW)	**89%**	*Dallas (DAL)*	**11%**
Houston International (IAH)	**79%**	*Houston Hobby (HOU)*	**21%**

Note: - Core airports in bold characters are emerged core airports

- Secondary airports in italic characters are secondary airports (re-emerged from an original core airport)

The remaining airport systems that are not presented in Table 5 were all identified as single airport systems and the evolution of their passenger traffic from 1976 to 2002 is presented in Appendix A.

Figure 17 shows the geographical location of the core and secondary airports that were identified. It was found that secondary airports were located on the East coast and in the state of California whereas secondary airports that re-emerged from an original core airport were found in the central part of the U.S. The type of secondary airport and their relative location in the country is linked to the configuration of the U.S. air network. The Hub and Spoke system that connects the airports from one half of the country to the other half through connecting airports (e.g. Dallas Forth Worth, Chicago, Houston, Atlanta, etc.) shaped the evolution of the emergence of secondary airports.

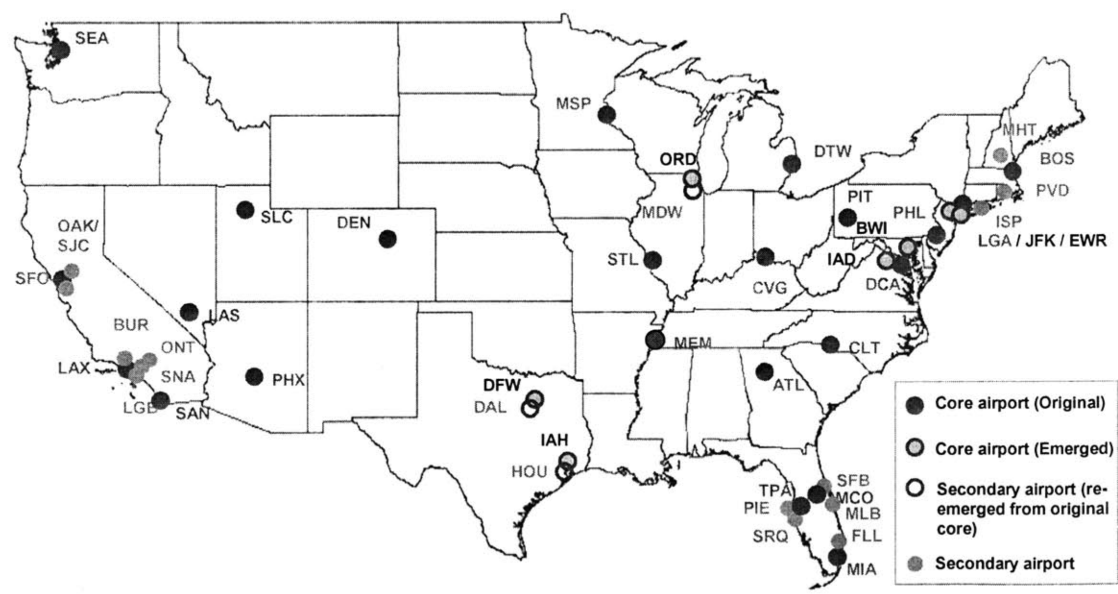


Figure 17: Core and secondary airports in the United States

Chapter 3

Factors Influencing the Emergence of Secondary Airports

The identification of secondary airports triggered the need to understand the reasons that led one particular underutilized airport to emerge as a successful secondary airport rather than another closely located airport. A systematic study of factors such as demographic, socio-economic, infrastructure, business and airline operational behaviors were conducted for all the regional airport systems where secondary airports were identified. The first aspect to be investigated was role of the congestion of the core airport.

3.1 Congestion of the core airport

The selection of the reference airports for the 26 case studies was based on the initial assumption that secondary airports are likely to emerge close to a major airport. Therefore the following analysis is based on the top 30 major airports in the United States. Airport delays are an essential component of the level of service observed at the airport. From a customer perspective, poor level of service implies low airport attractiveness to passengers. Historical data of delays [6,24] were used to quantify the congestion at major airports. This data set was then compared with location of secondary airports. Table 6 shows the results of this comparison. It was found that there is a correspondence between the congestion of the core airport and the existence of secondary airports in the regional airport system. As illustrated, the concentration of airports part of a multi-airport system generally correlates with the ranking of delays at airports. It is believed that the congestion of the core airport due to the inadequacy of capacity of the airport creates externalities and degraded level of service resulting in a decreased attractiveness of the airport to both airlines and passengers. This decreasing attractiveness of the core airport implies an increase of the attractiveness of closely located and underutilized airport that do not exhibit the same congestion problems. Ultimately a secondary airport may emerge. This observation is the result of a "spill" model (core airport congestion model, refer to Section 4.4) where secondary airports emerge close to major airports when they become congested.

Table 6: Delays at the core airports and presence of secondary airports in the system

Airport code	Airport name	Operations delayed	Part of a multi-airport system
LGA	LaGuardia	15.6%	Yes
EWR	Newark	8.1%	Yes
ORD	Chicago	6.3%	Yes
SFO	San Francisco	5.7%	Yes
BOS	Boston	4.8%	Yes
PHL	Philadelphia	4.5%	
JFK	Kennedy	3.9%	Yes
ATL	Atlanta	3.1%	
IAH	Houston	2.8%	Yes
DFW	Dallas / Ft. Worth	2.4%	Yes
PHX	Phoenix	2.2%	
LAX	Los Angeles	2.2%	Yes
IAD	Dulles	2.0%	Yes
STL	St. Louis	1.8%	
DTW	Detroit	1.8%	
CVG	Cincinnati	1.5%	
MSP	Minn./St. Paul	1.3%	
MIA	Miami	1.1%	Yes
SEA	Seattle	1.0%	
LAS	Las Vegas	0.8%	
DCA	Reagan National	0.8%	Yes
BWI	Balt.-Wash. Intl	0.7%	Yes
MCO	Orlando	0.6%	
CLT	Charlotte	0.6%	
PIT	Pittsburgh	0.4%	
SAN	San Diego	0.3%	
DEN	Denver	0.2%	
SLC	Salt Lake City	0.2%	
TPA	Tampa	0.2%	Yes
MEM	Memphis	0.0%	

Delays constitute externalities that airlines have to internalize [23]. In addition, they significantly impact the reliability of service and airlines choice between serving the core or a secondary airport. In order to better understand the implications of delays at airports part of the same regional airport system, a systematic analysis of delays has been performed for both core and secondary airports. This analysis was based on three measures of delays:

- Percentage of operations delayed
- Average delay for delayed flights
- Total time of delays

Because the goal was to compare airport performance in terms of delays at both core and secondary airports, and taking into account the significant difference in activity at both types of airports, the percentage of flights delayed remains a better comparison metrics.

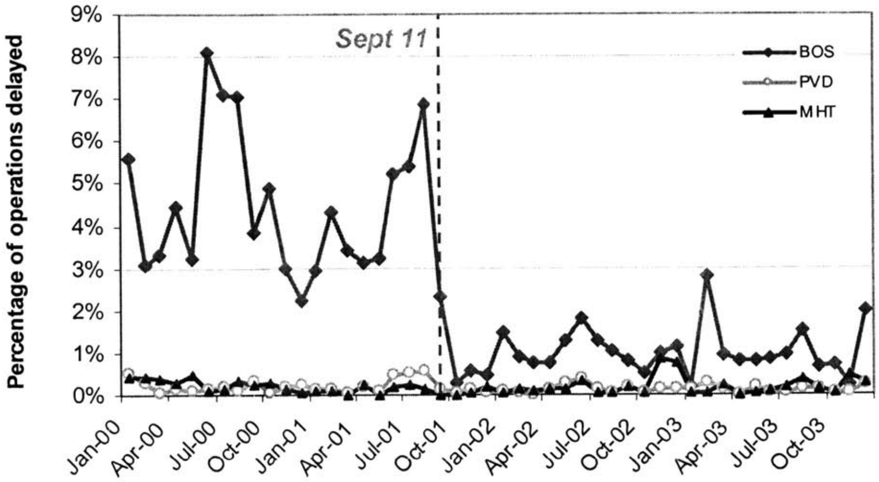


Figure 18: Percentage of operations delayed at BOS, MHT, and PVD [24]

Using FAA OPSNET delay data [24], the study covered the period from January 2000 to December 2003. Figure 18, Figure 19 and Figure 20 show the percentage of operations delayed at both core and secondary airports for Boston, New York and Chicago regions. Manchester (MHT), Providence (PVD), Islip (ISP), and Midway (MDW) are considered as secondary airports. From the case studies of the evolution of delayed operations, it was found that secondary airports exhibited lower levels of delays than core airports.

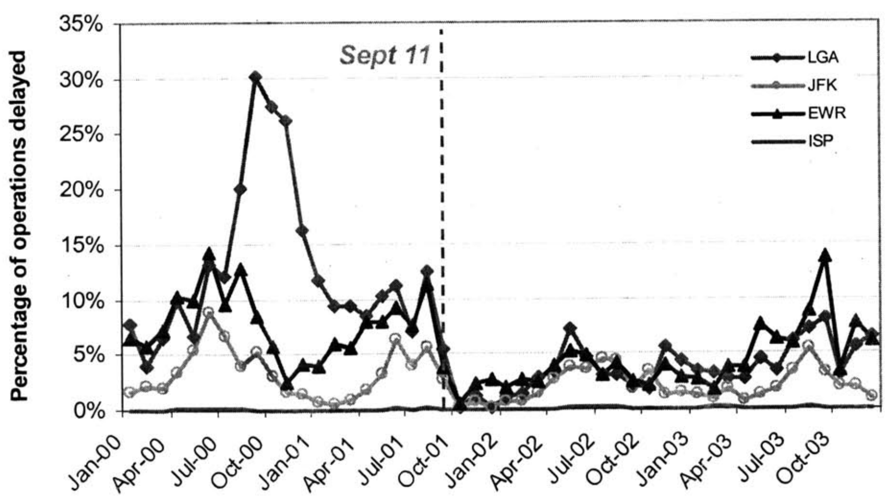


Figure 19: Percentage of operations delayed at LGA, JFK, EWR and ISP [24]

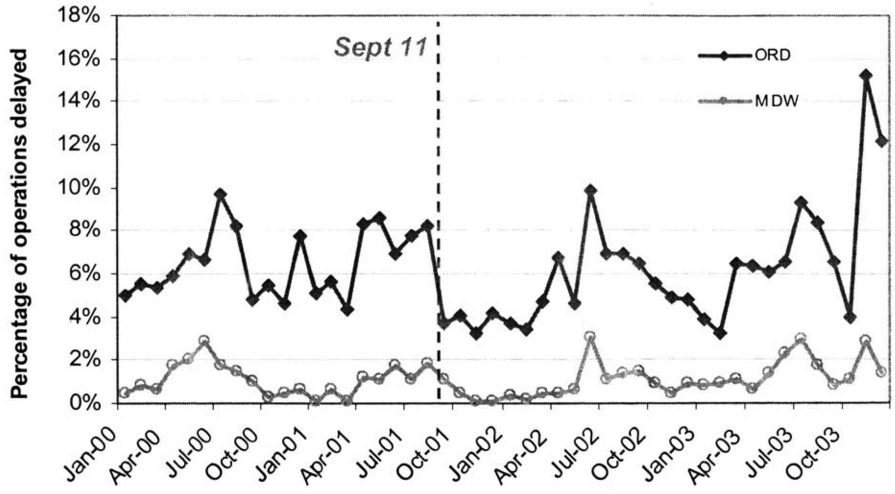


Figure 20: Percentage of operations delayed at ORD and MDW

There are two sub periods within the 2000-2003 time periods that was studied. From 2000 to September 2001, core airports showed significantly higher delays than secondary airports. However, after September 2001, traffic decrease has reduced the pressure on core airport capacity. As the relation between delays and airport utilization ratio is non linear, as described in Appendix B-3, reducing by a few points the utilization of core airport significantly reduces the level of delays. Even though delays at core airports dropped, they were still higher than delays at secondary airports. By the end of 2003, delays started to increase again especially at Chicago O'Hare airport.

Figure 21 shows, the fraction of operations delayed for both core and secondary airports. It was found that over all case studies, the fraction of operations delayed at the secondary airports was lower than at core airports. From an airline management perspective, this measure is critical since these externalities are related to the costs bared by the airlines. Since delays are lower at secondary airports, airlines and especially low-cost carriers, seeking low-cost structures are likely to be interested in entering underutilized airports that would ultimately become secondary airports.

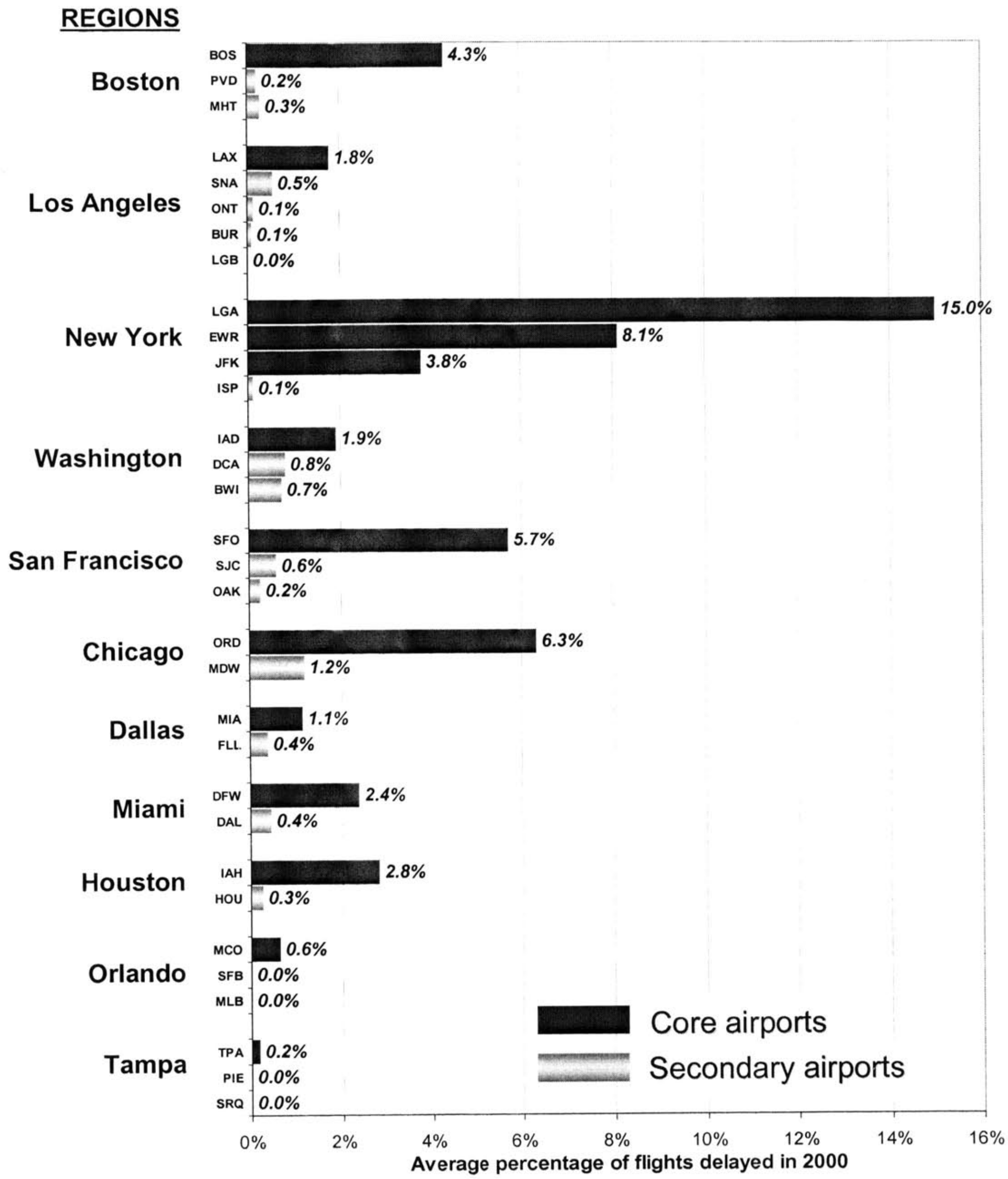


Figure 21: Percentage of delayed flights in 2000 at core and secondary airports

3.2 Air carrier entries at secondary airports

3.2.1 Overview of air carrier entries

In most cases investigated, it was found that the entry of an air carrier – generally a low-cost carrier- corresponded with the emergence of a secondary airport. Using the example of the Boston regional airport system, Figure 22 illustrates the entry of Southwest airlines at both Providence and Manchester respectively in 1996 and 1998 and its impact on passenger enplanements.

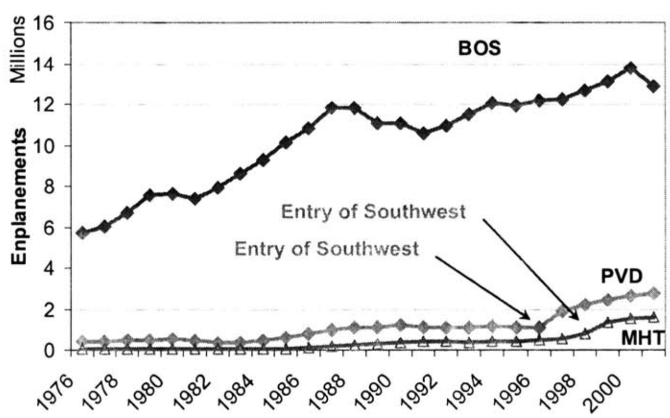


Figure 22: Impact of Southwest entries at secondary airports in the Boston region [17]

In the case of Manchester and Providence airports, the impact of Southwest was substantial. At Manchester airport, the year-to-year growth in passenger enplanements was on average 6% from 1990 to 1997. After the entry of Southwest in 1998, this average year to year growth increased to 45% from 1998 to 2000. The same phenomenon occurred in the case of Providence airport where the year to year evolution of passenger enplanements jumped from stagnation (from 1990 to 1996) to an average of 35% year to year growth during the three years following the entry of Southwest. This analysis of the entry of low-cost carriers has been performed for all airport systems that included a secondary airport.

Table 7: Low-cost carrier entries at secondary airports

Secondary airport	Low-cost carrier	Year of entry
Chicago Midway (MDW)	Midway	1979
	Southwest	1985
Fort Lauderdale (FLL)	Southwest	1996
Providence (PVD)	Southwest	1996
Manchester (MHT)	Southwest	1998
Orlando Sanford (SFB)		
Melbourne (MLB)		
St Petersburg (PIE)		
Sarasota (SRQ)		
Oakland (OAK)	Southwest	1989
San Jose (SJC)	Southwest	
Burbank (BUR)	Southwest	1990
Ontario (ONT)	Southwest	1985
Orange county (SNA)	Southwest	1994
Long Beach (LGB)	jetBlue	2002
Islip (ISP)	Southwest	1999
Baltimore (BWI)	Southwest	1993
Newark (EWR)	People Express	1980
Dallas (DAL)	Southwest	1971
Houston (HOU)	Southwest	1972

Table 7 summarizes the entries of these low-cost carriers. In the vast majority of the cases, Southwest Airlines had an impact on the emergence of the identified secondary airports. Southwest influence on the emergence of secondary airport can be traced back to its origin. In 1971, Southwest started its operations at Dallas Love field (DAL) and increased its presence at this airport in the subsequent years. The entry of service at Love field by Southwest was actually the starting point of the re-emergence of this airport. This airport was the original core airport in the regional airport system before all of its operations were moved to the new Dallas Fort Worth airport. The Wright amendment restricted Southwest operations to intra-state operations with the four contiguous states. Houston Hobby was one of the first destinations offered by Southwest from Love field. An identical dynamics occurred at Houston Hobby airport. It re-emerged in 1971 after its operations were moved to Houston International airport (IAH) in 1969.

Southwest was not the only carrier to initiate the emergence of secondary airports. People Express also influenced the emergence of Newark airport that ultimately became an emerged core airport after exceeding La Guardia's traffic in 1984.

3.2.2 New dynamics at the airport level

Even though all the traffic before and after the entry of a low-cost carrier was not performed by low-cost carriers, these entries had a stimulating effect in the emergence process which was identified through the observations and study of the regional airport systems. Before the entry of a low-cost carrier, secondary airports offered high fare service with limited destinations. However, the entry of a low-cost carrier, with its low fares changed this situation. For example, in the case of Manchester (MHT) airport, where Southwest Airlines entered service in 1998, the average aggregate yield at the airport level dropped by 27% (Figure 23) between 1997 and 1999, while the enplanements increased by 154%.

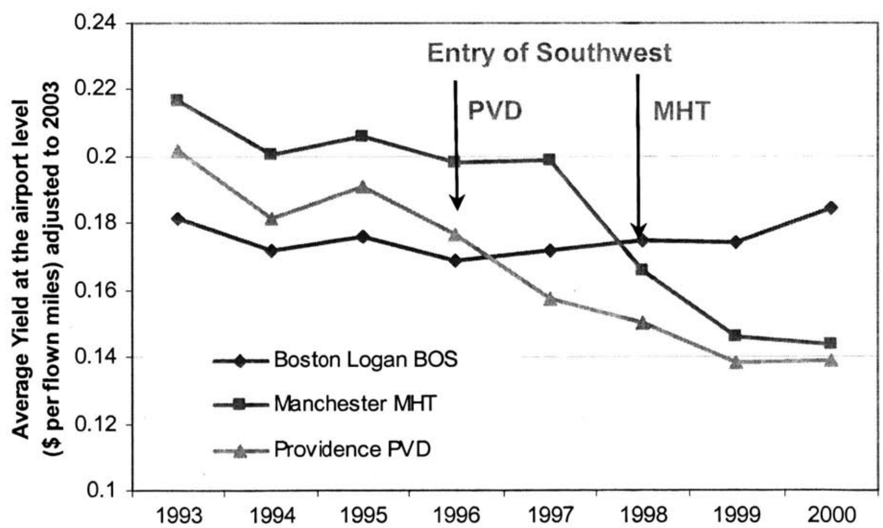


Figure 23: Average yield at the airport level for BOS, MHT, and PVD [26]

The traffic stimulation resulting from the new availability of service (new destinations) at lower fares than in the past is clearly shown on Figure 24. When the average yield at the airport decreased at Manchester and Providence, traffic increased substantially. A similar dynamic was also observed at Fort Lauderdale airport. The entry of Southwest resulted in a 22% decrease in average yield while traffic increased by 32%.

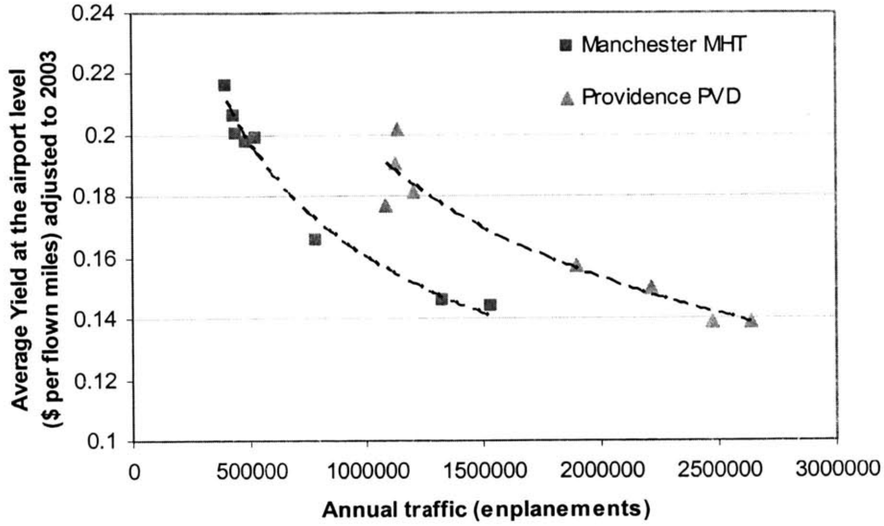


Figure 24: Traffic stimulation by fare reduction at MHT, and PVD [17,26]

Due to the limited availability of data on fares before 1994, it was difficult to capture these changes in airport dynamics resulting from the entry of a low-cost carrier when these entries occurred before 1994. However, the results of the analysis on the change in airport dynamics after the entry of a low cost carrier is consistent with a study performed in 1993 by the FAA Office of Aviation [20] that focused on the impact of Southwest entry on the routes between airports part of the Los Angeles and San Francisco airport systems. The impact of the Southwest entry on fares and market stimulation was named the "Southwest effect". However, this effect was only studied and demonstrated at the route level between airports that are part of the Los Angeles and San Francisco airport systems. In the case of Manchester, Providence and Fort Lauderdale the impact of the entry of a low-cost carrier is clearly observed at the airport level.

The entry of a specific carrier and the drop of fares were not the only changes in the dynamics of the secondary airport. Following the entry of the new carrier –generally a low - cost carrier- several other carriers entered service at the secondary airport, resulting in changes in the dynamic at the airport level. Figure 25 shows the number of departures per day out of Manchester, Providence, Islip, Fort Lauderdale and Midway airports from 1996 to 2003[1]. For example, in the case of Manchester airport, it was found that following the entry of Southwest in 1998, several other carriers, such as Northwest, Continental, Delta and ACA, started service at this airport. These subsequent entries increased the level of competition at this airport by increasing the overall number of air carriers serving the airport. Similar phenomena are observed at other secondary airports as shown in Figure 25.

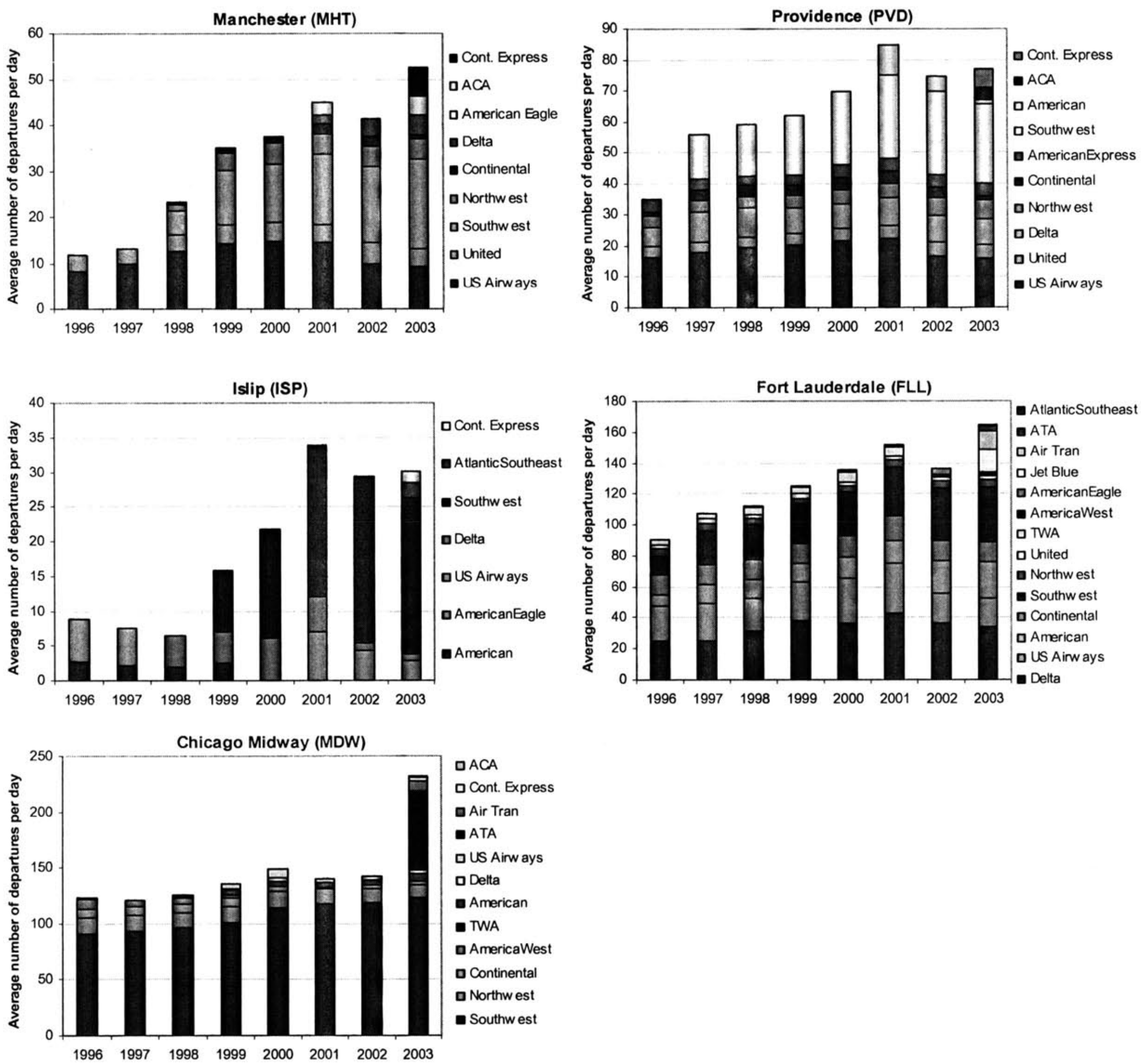


Figure 25: Traffic share [26] of airlines operating at secondary airport from 1996 to 2003 [27]

[1] Due to limited availability of traffic data, only recently emerged secondary airports such as Manchester, Providence, Islip, Fort Lauderdale and Midway have been analyzed. The literature review also covered cases of secondary airports that emerged prior to the 1990s [20].

It was found in all cases that the number of air carriers increased following the entry of a specific carrier. It is believed that the increased level of competition at the secondary airport was also a significant factor in the success of its emergence. As a result, an in depth analysis of the change in airport competitive environment was performed. In order to measure the change in competition levels, Herfindahl-Hirschman Indexes (HHI) were computed. In economics, the Herfindahl-Hirschman Index is a measure of the size of firms in relationship to the industry and an indicator of the competition level among them. It is defined as the sum of the squares of the market shares of each individual firm. As such, it can range from 0 to 10,000, moving from a very large amount of very small firms (HHI = 0) to a single monopolistic firm (HHI = 10,000). Decreases in the Herfindahl-Hirschman index generally indicate a loss of pricing power and an increase in competition, whereas increases imply the opposite. In order to measure the competition level at various airports and study the evolution of this competition level, HHIs were computed for each airport. The market was defined as the airport and airlines operating at this airport were considered as firms. The HHI were computed as the sum of the squared airlines market shares (traffic shares of airlines based on Form 41 annual number of departures in 1991 and 2000):

$$HHI_i = \sum_{\substack{airlines\_at \\ airport\_i}} MS^2 \qquad (3)$$

Table 8: Evolution of market concentration at the airport level

Airport	HHI		Variation
	in 1991	in 2000	
LGA	1200	1300	8%
ISP	3600	2900	**-19%**
BOS	1300	1200	-8%
PVD	2300	1700	**-26%**
MHT	3000	1800	**-40%**
MIA	2000	2400	20%
FLL	1700	1100	**-35%**
ORD	2900	2600	-10%
MDW	5100	2800	**-45%**

Table 8 shows the HHI values for each secondary airport for 1991 and 2000. In addition, HHIs were computed at core airports in order to have a reference within each regional airport system. Table 8 also shows the variation of the competition level between 1991 and 2000.

It was found that the market concentration significantly decreased at secondary airports over the time period of study. The decrease in HHI at secondary airports ranged from 19% at Islip to 45% at Chicago Midway. HHIs at the reference airport –the core airport- did not decrease as much (the largest decrease was observed at Chicago O'Hare with -10% compared to the 45% decrease at Midway) and even increased in the case of La Guardia and Miami (+20% for Miami). The sharper decrease in HHI at secondary airport due to the entry of a low-cost carrier and several followers (Table 8) implies that airlines that were operating at secondary airports lost monopolistic and pricing power. It is believed that this loss of pricing power combined with the presence of low-cost carriers offering low fares, in addition to more destinations and frequency play a fundamental role in the successful emergence of the secondary airport and their sustainable growth.

The entry of a low-cost carrier which triggered the emergence of a secondary airport was the result of a business decision by a single air carrier. However, this decision was based on factors such as market potential (demographics, economics, etc.), airport capabilities (infrastructure capabilities, etc.), easiness to compete for traffic with the core airport, etc.

3.3 Distribution of population

From a literature review of airport demand models [21], the population and its distribution was identified as a potential factor influencing the success of the emergence of an airport. In order to validate this hypothesis, three studies were performed.

Using ArcGIS[1] database of population, a systematic study of the distribution of the density of population was performed at regional airport systems where secondary airports were identified.

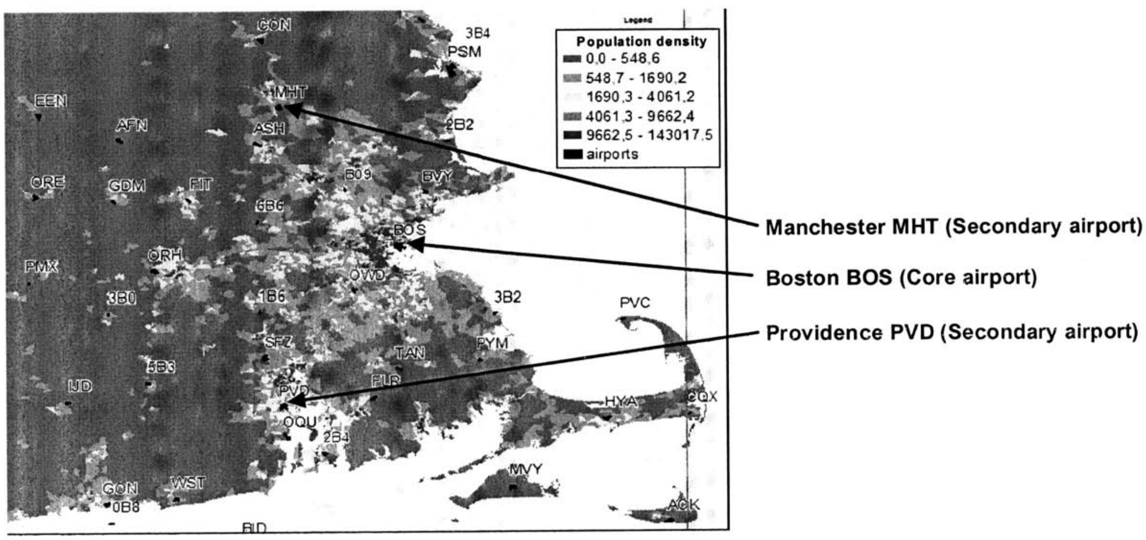


Figure 26: Population density in the Boston region

As shown on Figure 26 and Figure 27, secondary airports such as MHT, PVD, SJC, and OAK are located close to medium to high density of population areas.

[1] ArcGIS® database (version 8.3).

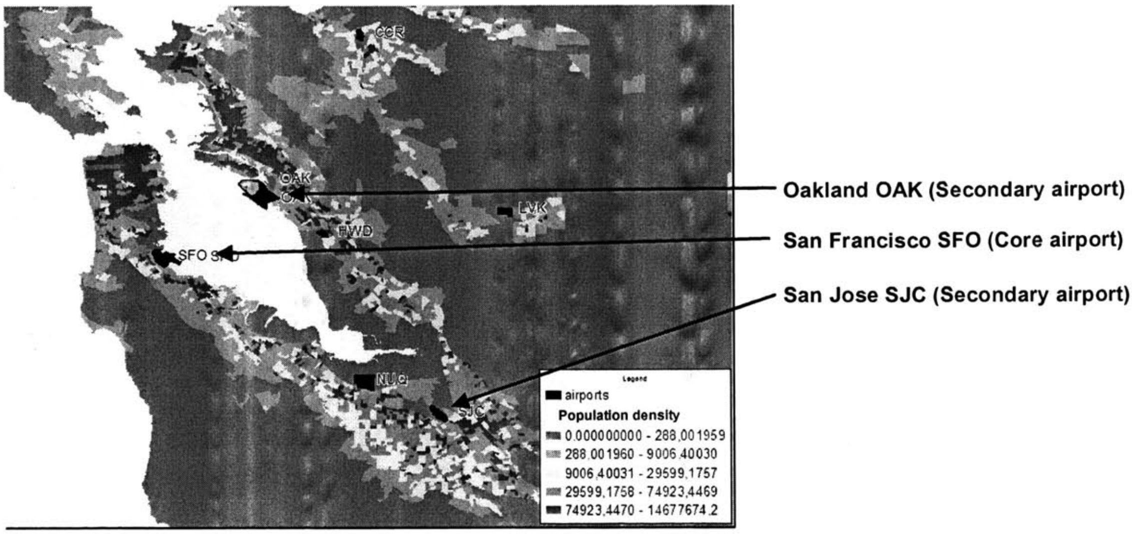


Figure 27: Population density in the San Francisco region

The study was extended to the distribution of population around both core and secondary airports. The Census county[1] division database is appropriate for large scale analysis, such as the entire country or large fraction of the country (e.g. North-East U.S.). However, because the analysis is performed within a 50 mile radius area around specific locations, a higher resolution was required. As a result, the study was performed using 2000 U.S. Census Bureau tracts [28]. This database contains 65,443 population divisions covering the 50 states and the District of Columbia. Using all relevant tracts, identified by the relative location of their geographical center to airport position, population distribution functions were plotted for each core and secondary airports.

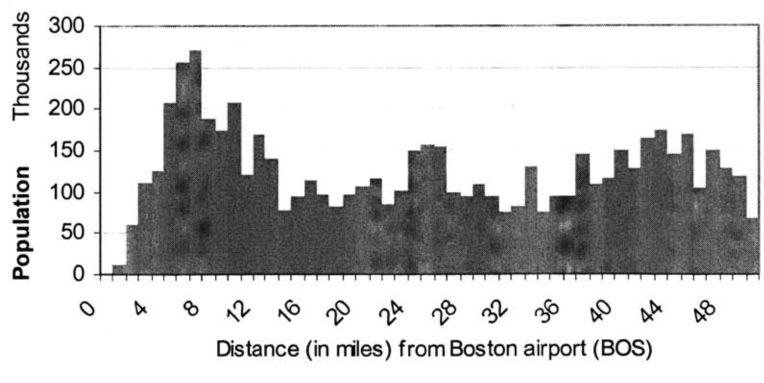


Figure 28: Distribution of population around BOS [28]

[1] The county division databases contain one record for each of the 3091 counties in the Continental United States.

As shown on Figure 28, in the case of the Boston region, the population is concentrated within 20 miles, where there exists a basin of 2.7 million inhabitants. The location of core airports - either in the center of metropolitan area (e.g. Miami, Boston, etc.) or at the close periphery (e.g. San Francisco, etc.) – explains the peak of population within a few miles of the airport. On the opposite, as shown on Figure 29 and Figure 30, the distribution of population around secondary airports is slightly different. The large fraction of the population is now found in the 30 to 50 miles range and still corresponds to the core metropolitan area basin of population. However, there exist local basins of population in the closer range 0 to 20 miles of a secondary airport. For example, a basin of 1.3 million inhabitants, almost half of the Boston population basin, inhabitants surrounds (20 miles) Providence airport.

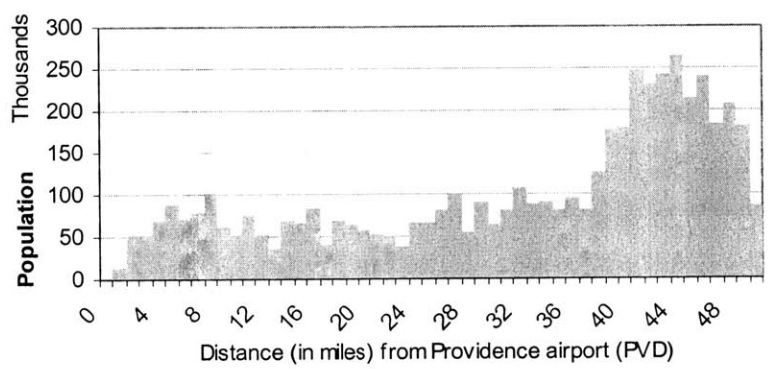


Figure 29: Distribution of population around PVD

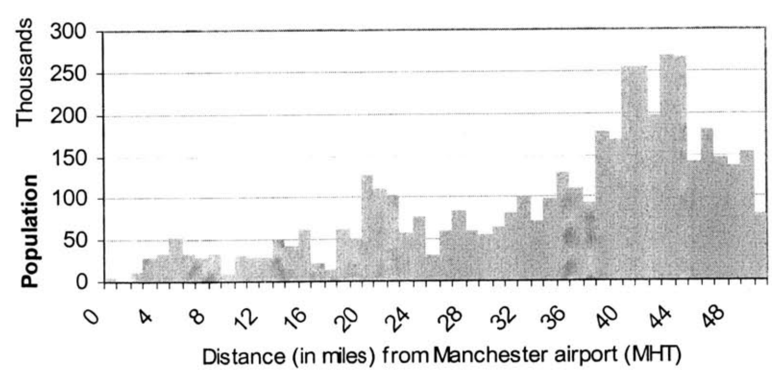


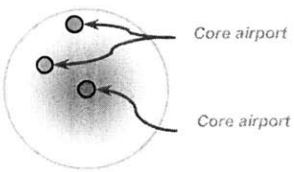
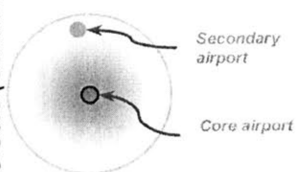
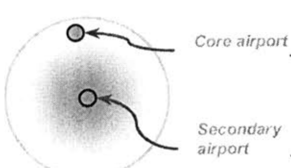
Figure 30: Distribution of population around MHT

In order to quantitatively assess the relative size of the local basin of population around key airports, a systematic analysis was performed. The analysis was based on a gravitational model that solely included the distribution of population as input. FAA Form 5010 airport database was utilized and a set of 900 airports (all airports with a runway longer than 5500ft[1]) was taken as reference. Using a database containing more than 65,000 geographical divisions (tracts) of the continental U.S. [28], the population corresponding to each tract was assigned to the closest airport. The results of this distribution model give the size of the local basin of population for each airport. Table 9 gives a summary of airports with the relative size of their local basin of population.

It was found that in regional airport systems that feature an original and emerged core airports (i.e. New York, Washington) the original core is surrounded by the largest local basin of population and the emerged core airports are located in areas with lower local basin of population. The observation is easily explained by the evolution of the multi-airport system. The original core airport was located downtown where the densities of population are large. When this airport reached saturation, airports further away from the city center emerged. These airports were surrounded by lower density of population areas.

[1] The choice of 5,500 ft minimum runway length resulted from the study of the infrastructure necessary for the emergence of a secondary airport (section 3.4). This runway length corresponds to the minimum length that can be used by narrow body aircraft which are in most cases the type of aircraft used by carriers like Southwest, jetBlue, etc.

Table 9: Population share at airports with runways longer than 5500 ft.

Type of Regional Airport System	Region	Airports and population share							
Multi Core 	New York	LGA	JFK	EWR	*TEB*	MMU	FRG	BLM	ISP
		32%	18%	15%	*11%*	8%	7%	5%	5%
	Washington	DCA	BWI	MTN	HEF	JYO	IAD	ESN	
		39%	22%	14%	9%	7%	6%	4%	
Single Core (Centralized) 	Boston	BOS	PVD	*BED*	ORH	ASH	MHT	PSM	
		38%	20%	*16%*	11%	6%	6%	4%	
	San Francisco	SFO	SJC	OAK	APC				
		31%	27%	24%	18%				
	Miami	MIA	OPF	FXE	FLL	BCT			
		34%	24%	20%	12%	11%			
	Tampa	TPA	PIE	LAL	SRQ	BKV			
		29%	25%	19%	16%	11%			
Single Core (Decentralized) 	Los Angeles	LGB	BUR	SNA	LAX	*VNY*	ONT	CNO	CMA
		24%	17%	15%	14%	*10%*	8%	7%	2%
	Orlando	*ORL*	SFB	ISM	MLB	TIX	DED	MCO	
		40%	16%	14%	12%	7%	6%	6%	
	Chicago	MDW	ORD	DPA	GYY	UGN	LOT	RFD	ARR
		31%	26%	10%	10%	8%	7%	4%	3%
	Dallas	ADS	DAL	RBD	FTW	DFW	TKI	DTO	MWL
		22%	17%	15%	14%	12%	5%	5%	4%
	Houston	SGR	HOU	IAH	EFD	CXO	GLR		
		30%	24%	22%	14%	7%	3%		

Legend: Core airport (original); Secondary airport; Core airport (emerged); Secondary airport (re-emerged from an original core airport)

Airport systems like Boston, San Francisco, Miami, and Tampa did exhibit the same evolutionary dynamics. As a result, identical airport type vs. local basin population patterns are observed. The original core airport is surrounded by the largest local basin of population, whereas the secondary airports are located at the periphery of the metropolitan area. As a result they are surrounded by smaller local basin of population than the original core airport that has a significant location advantage.

In the case of regional airport systems that feature emerged core airport and secondary airport (re-emerged from an original core airport) the airport type vs. local basin patterns are different then in the previous case. The core airport (emerged) is surrounded by weak local basin of population due to its location at the periphery of the metropolitan area. On the opposite, secondary airports have strong local basin of population compared to the emerged core airport. This observation was explained by their historical role as original core airport. These airports are generally located close to the center of the city. Due to their inability to accommodate growth in the past, their operations were transferred to a larger airport that became the emerged core airport. However, as these airports regained traffic due the attractiveness of their central location, they kept these strong local basins of population which are attractive to airlines.

The previous analyses addressing the impact of population distribution and local basin sizes did not include the effects of the evolutionary dynamics of secondary airport emergence. Figure 31 shows the evolution (based on the year of emergence of the secondary airports) of the distance from the primary basin of population to the secondary airport.

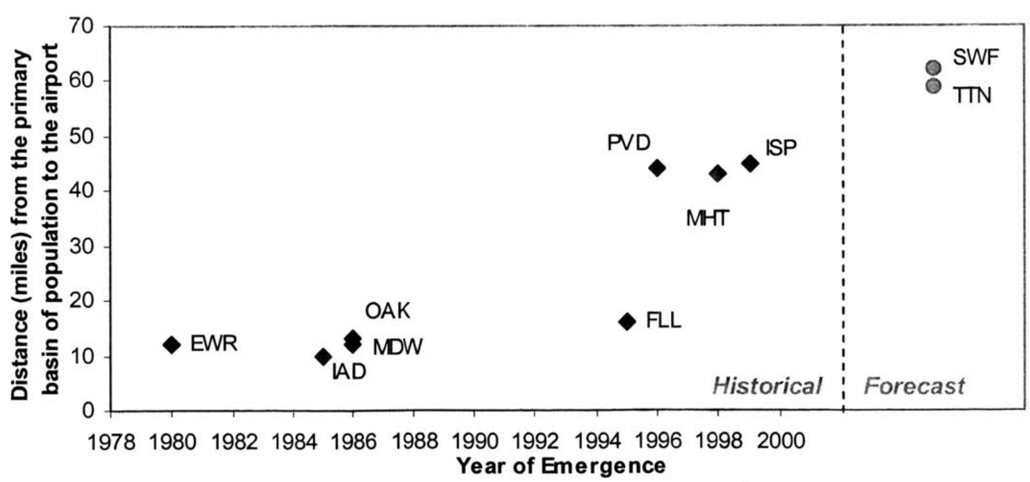


Figure 31: Evolution of distance between the secondary airport and the primary basin of population

Even though, airport system can be considered as independent -when they are not part of the same macro airport system (case of the New York – Philadelphia – Washington system)- new secondary airports emerge further away from the primary basin of population.

This argument has greater strength if we are considering a single regional airport system with multiple generations of secondary airports. For example, the New-York airport system is an illustration of this phenomenon. When LGA and JFK combined reached their limit capacity, a new secondary airport (EWR) emerged and was located in the 10 to 15 miles range from the center of the primary basin of population. Once Newark airport became a core airport and finally reached saturation, a new secondary airport was ready to emerge. Currently, Islip (ISP) meets the secondary airport criterion that was established in Chapter 2 with 2% of traffic share. It is considered as a secondary airport in early stage of development. The distance between its location and the center of the primary basin of population significantly increases (45 to 50 miles) compared to the airport that emerged as core airports (EWR, JFK). Because Islip has a weak local basin of population and the access from the North, West and South periphery of New York city is not convenient Islip may not emerge as the next major airport in the system. Airports like Trenton (TTN) or Stewart (SWF) constitute potential candidates for future secondary airports. These airports are in the 55 to 60 miles range from the primary basin of population. On the other hand, Philadelphia may, in the future, relieve more traffic from the New York region by serving its Southern population basin. Considering Philadelphia as a partial secondary airport for the New York region highlights the trend that secondary airports tend to emerge further away from the initial primary basin of population as the system becomes more developed.

3.4 Airport infrastructure

A minimum level of infrastructure is required in order for airports to host commercial flights:

Air side:

! Runways; the most constraining component of an airport system is generally its runways. An airport must provide runways with suitable length and pavement type in order to host specific type of aircraft and attract airlines.

! Taxiways,

! Navigation aids; ILSs,

! Air traffic control capabilities,

Land side:

! Gates

! Terminals (with sufficient capacity)

! Maintenance facilities, hangars, etc.

! Customs and Immigration offices for international flights (potentially for flights to/from Canada or Mexico for early stage of development of secondary airports)

! Parking,

! Ground access to the airport; roads, convenient link to the nearest highway.

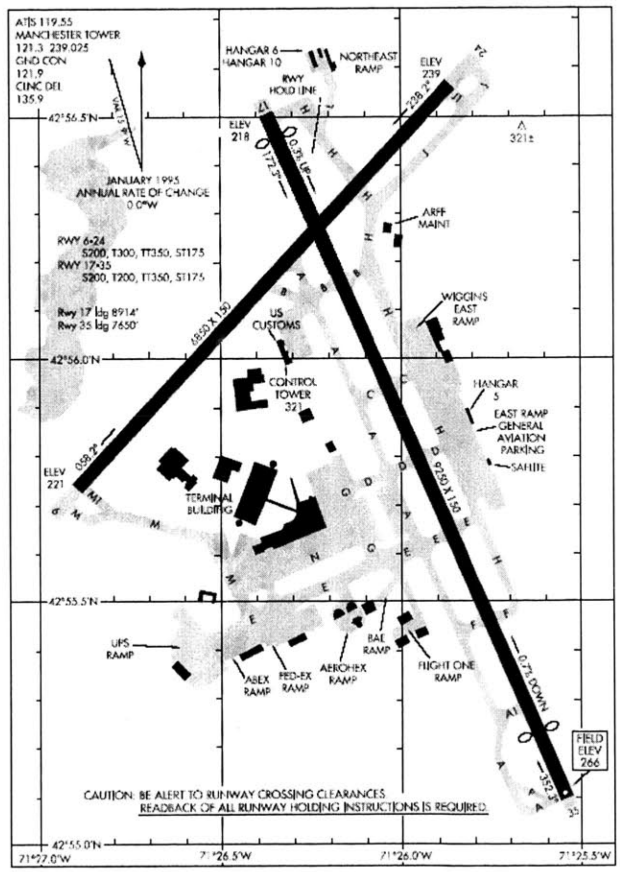


Figure 32: Airport diagram of Manchester (MHT) [29]

Figure 32 illustrates with the example of Manchester airport chart, some of the airport infrastructure, runways, taxiways, terminals, etc.

Because a passenger journey does not start and stop at the boarding gates, but is rather a door to door itinerary, the airport must also provide sufficient ground connectivity through transportation services such as car rentals, parking spaces, public transit, etc.

Runways:

Runways are the most constraining element in an airport system, as it defines the type of aircraft allowed to operate at this airport (Figure 33). Typically, wide body aircraft require 7000 ft to 10,000 ft runways. As the size of the aircraft gets smaller, runway length requirement are reduced. Narrow body jets can operate at airports featuring runways from 5300 ft to 6900 ft. Even though regional jets carry fewer passengers than narrow body jets, they have similar requirements. Turbo-props can operate at airports with smaller runways typically from 3500 ft to 4500 ft. These aircraft performance requirements limit the access to airports where infrastructure is adequate.

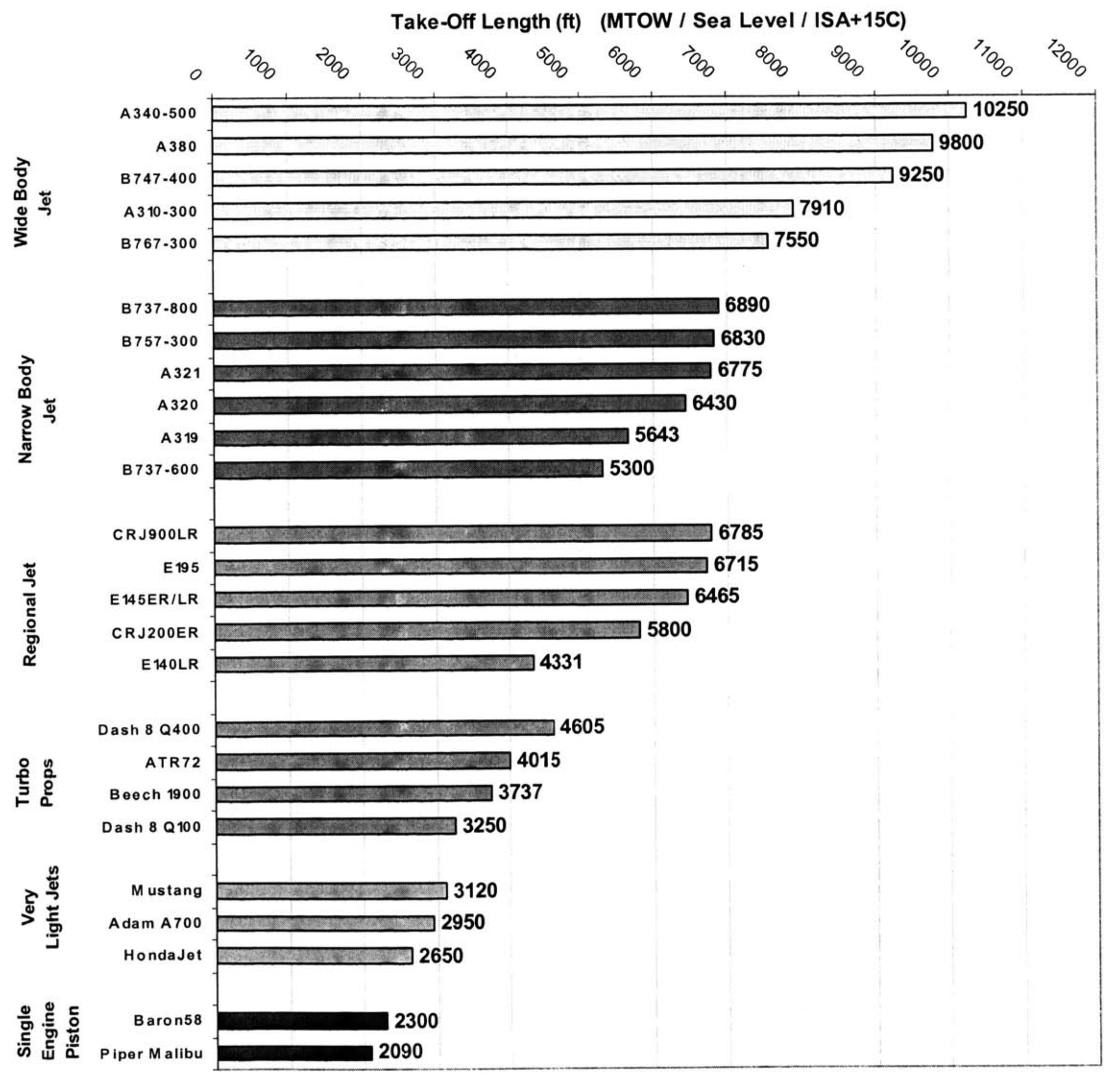


Figure 33: Take-off field length by aircraft type [31]

Aircraft performance and the resulting runway minima define the set of airport that a specific aircraft type can utilize. Figure 34 shows the comparison between available maximum runway lengths at all airports within 50 miles of Boston Logan[1], to the take-off field length (balanced field length) of several types of aircraft. Boston Logan (BOS) and Pease (PSM) are able to handle most wide body aircraft and all smaller type of aircraft. The next group of airports composed of Manchester (MHT), Providence (PVD), Bedford (BED), and Worcester (ORH), with 7000 ft runway length, cannot handle wide body aircraft, but rather narrow body and smaller aircraft. The remaining airports do not have suitable runways for narrow body jets. However, all have runway length capabilities for hosting turbo props, very light jets and single engine piston aircraft.

[1] Identical analyses have been performed for airport systems where secondary airports were identified (Appendix D).

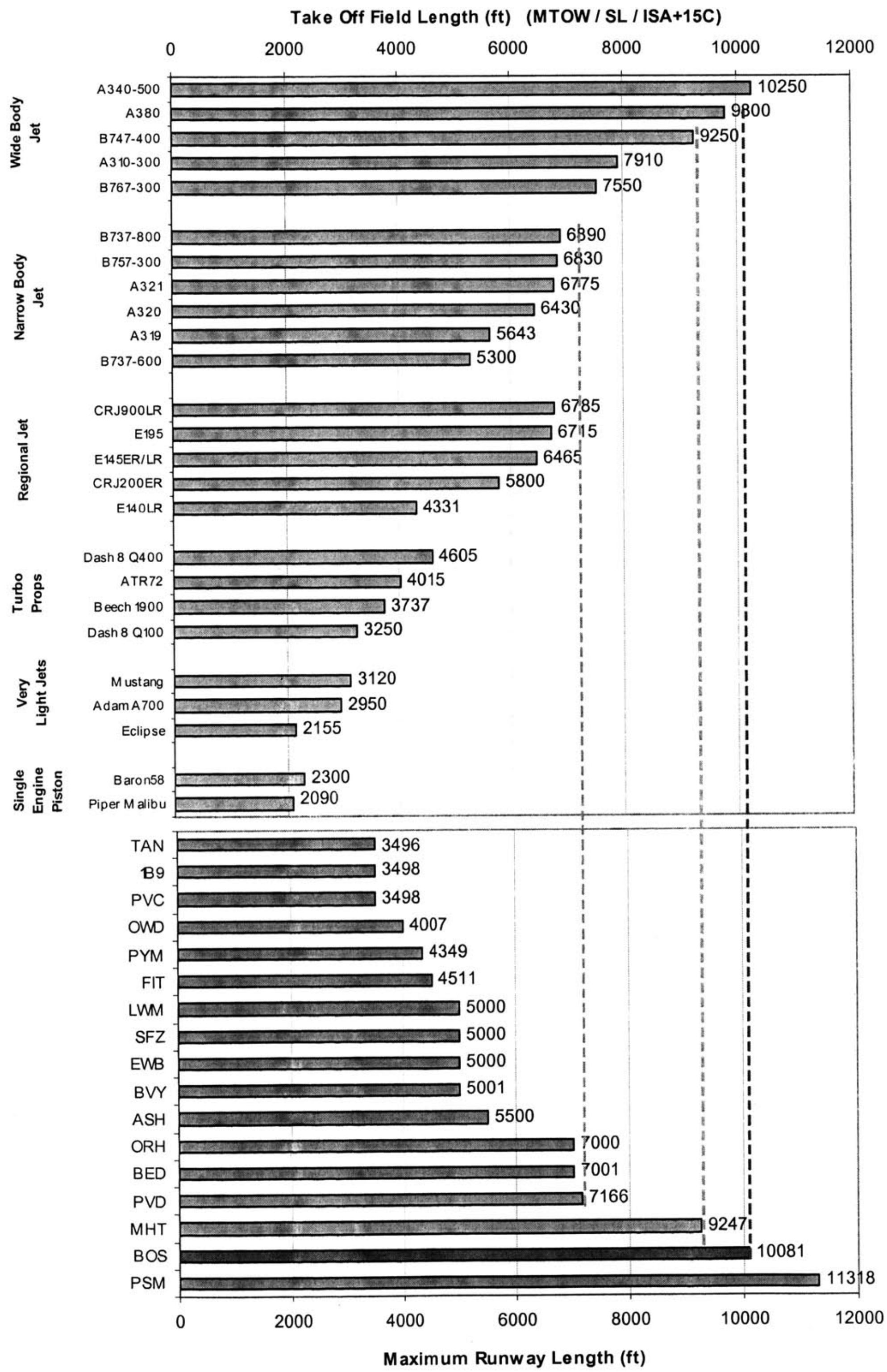


Figure 34: Take-off field length and maximum runway length: Boston regional airport system [30,31]

The comparative analysis of aircraft requirements and maximum runway length availability was helpful in determining the ability of an airport to host specific types of aircraft. From the comparison between aircraft take-off capabilities and airport infrastructure, secondary airports like Manchester (MHT) and Providence (PVD) are anticipated to be utilized for commercial purposes by narrow body jets, regional jets and turboprops. In order to corroborate these expectations, a study of aircraft type utilization was performed using Form 41 traffic data [27].

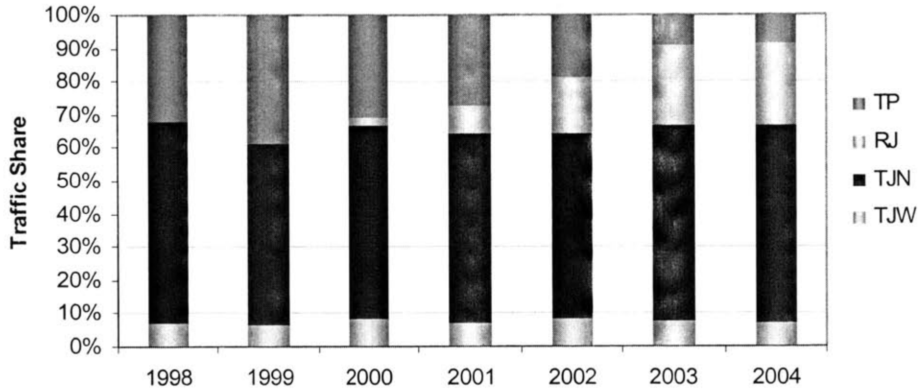


Figure 35: Categories of aircraft operated at BOS [27]

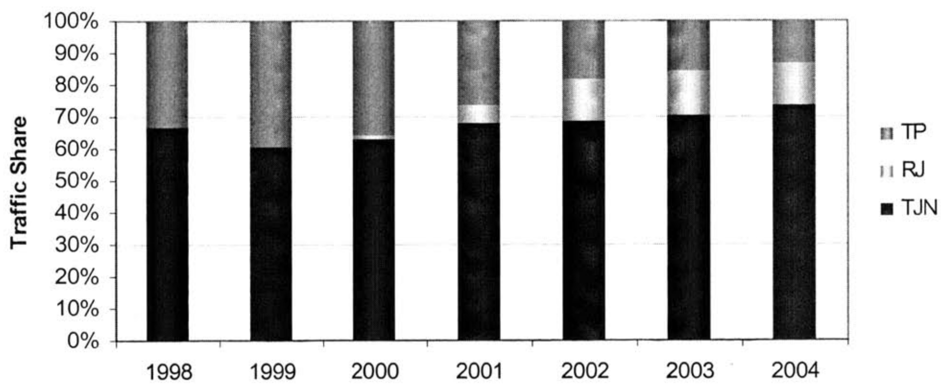


Figure 36: Categories of aircraft operated at PVD [27]

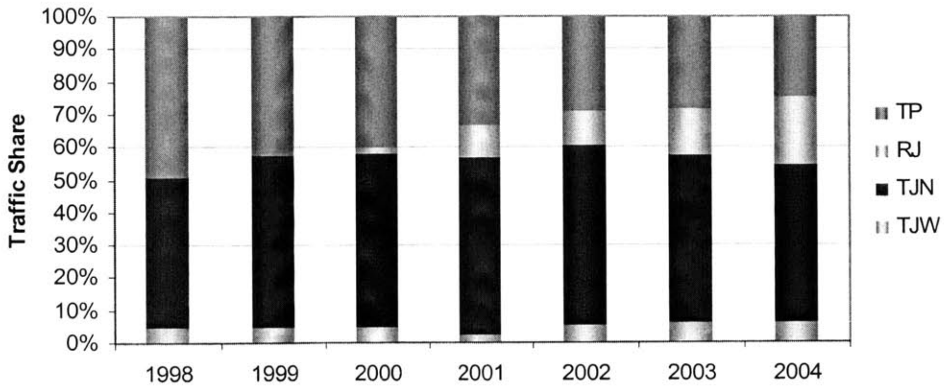


Figure 37: Categories of aircraft operated at MHT [27]

Figure 36 and Figure 37 show that Manchester (MHT) and Providence (PVD) are largely utilized by narrow body aircraft. This observation should be put in the perspective of the airlines operating at these airports. Southwest airlines, the dominant carrier at both of these airports, operate B737s (narrow body jets). Interestingly, the share of regional jets has increased at both airports since 2000 and now account for 15% (at Providence PVD) and 20% (at Manchester MHT) of the commercial traffic. Regional jets have actually replaced turboprops. From the analysis of aircraft operated at secondary airports, it was found that carriers mostly operate narrow body aircraft. Therefore, under the same mode of operations future secondary airports will need to have sufficient infrastructure to host narrow body jets. As on Figure 34, this implies that runway need to be at least 5500 ft long to host operations of narrow body jets.

An extended analysis of existing core and secondary airports was performed. Table 10 provides a summary of the maximum runway length analysis for both core and secondary airports. The current set of core airports have maximum runway lengths ranging from 6869 ft to 13,000 ft. In the case of secondary airports, runways range from 5700 ft (Orange county airport) to 12,198 ft for (Ontario airport). There exists a large overlap of runways length range between these two categories of airport, which significantly restricts or permits the operations at those airports. A core airport like Washington National is only able to handle narrow body and regional jets, whereas a secondary airport like Ontario airport can accommodate wide body aircraft.

Since Orange county airport is able to handle 4 million passenger enplanements per year with only one usable runway of 5700 ft[1], airports which possess one or more runways with length greater than 5700 ft constitute potential secondary airports.

Table 10: Maximum runway length at core and secondary airports and ILSs [30]

Core airports				Secondary airports			
Code	Name	RWY length (ft)	ILS	Code	Name	RWY length (ft)	ILS
BOS	Boston, MA	10081	Yes	PVD	Providence	7166	Yes
			Yes	MHT	Manchester	7001	Yes
LAX	Los Angeles, CA	12091	Yes	LGB	Long Beach	10000	Yes
				ONT	Ontario	12200	Yes
				BUR	Burbank	6885	Yes
				SNA	Santa Ana	5700	Yes
JFK	New York, NY-JFK	14572	Yes	ISP	Islip	7000	Yes
EWR	Newark, NJ	9300	Yes				
LGA	New York, NY-LGA	7000	Yes				
DCA	Washington, DC-Natl	6869	Yes	BWI	Baltimore	9519	Yes
IAD	Washington, DC-Dulles	11500	Yes				
SFO	San Francisco	11870	Yes	SJC	San Jose	11050	Yes
				OAK	Oakland	10000	Yes
MIA	Miami	13000	Yes	FLL	Fort Lauderdale	9000	Yes
TPA	Tampa	11002	Yes	SRQ	Sarasota	9503	Yes
			Yes	PIE	St Petersburg	8800	Yes
MCO	Orlando	12005	Yes	SFB	Orlando Sanford	9600	Yes
			Yes	MLB	Melbourne	10181	Yes
ORD	Chicago	13000	Yes	MDW	Chicago-Midway	6521	Yes
DFW	Dallas Fort Worth	13401	Yes	DAL	Dallas Love Field	8800	Yes
IAH	Houston Bush	12001	Yes	HOU	Houston Hobby	7602	Yes

[1] This airport also has a second runway, but due to its length less than 3000 ft is not usable by turbo props, regional jets or larger aircraft.

3.5 Connecting passengers at the core airport

Once secondary airports were identified, a study of their role in the nation air transportation network was performed. From a location stand points, it was found from Figure 17 that secondary airports were generally located on the coasts of the United States.

It is believed that the emergence of secondary airports is more likely to happen at an airport where connecting passengers are not predominant (Figure 38). Figure 38 shows that simple secondary airports emerged around core airports that had low level connecting passenger (below 25%).

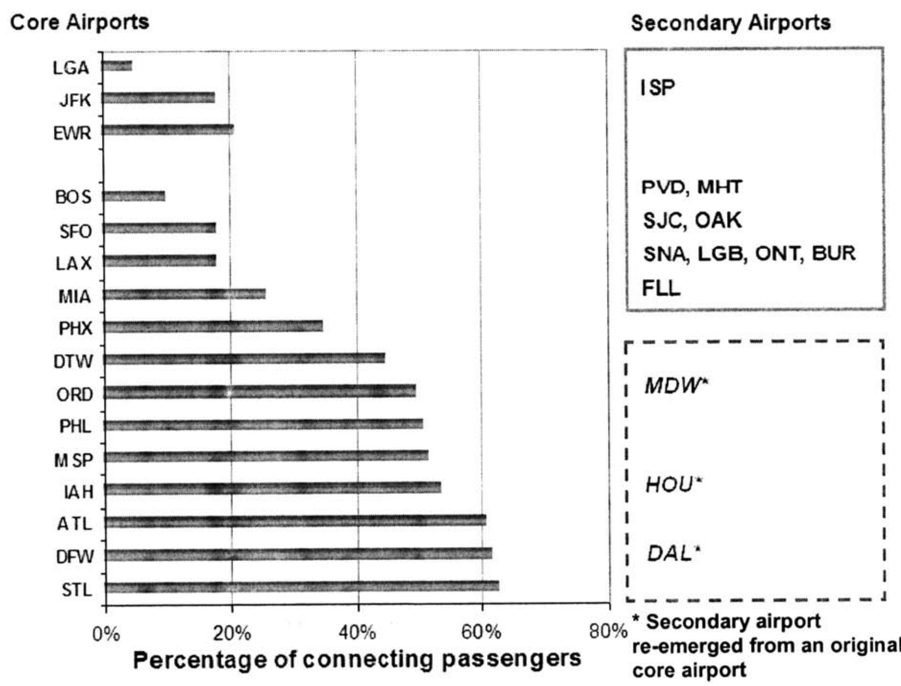


Figure 38: Degree of connectivity at the core airport and relation with the presence of secondary airports [32]

It is thought that a secondary airport is less likely to emerge close to a major hub because it is more challenging for the emerging airport to compete in terms of service with the core airport. This is especially true when the local demand is not strong and the core airport relies heavily on connecting passengers. The case of the St. Louis region illustrates this dynamics. The failure of the St. Louis Mid America airport was partially due to the fact that Saint Louis is a transfer hub with 64% of its passengers connecting. In addition, a low-cost carrier (Southwest airlines with a traffic share of 13%) already operated at Saint Louis (the core airport), which made it difficult for the secondary airport to be significantly more competitive.

The only secondary airports that are found close to core airports with high level of connecting passengers are secondary airports that re-emerged from an original core airport (e.g. Chicago Midway (MDW), Houston Hobby (HOU) and Dallas (DAL), which is inland, located close to a major hub airport Chicago O'Hare (ORD), Houston International (HOU) and Dallas Fort-Worth (DFW) respectively). From the perspective of the evolution of regional airport systems, future secondary airports part of regional airport systems that are located inland and have a role of connecting hub will have to compete with location.

From comparative studies of the passenger enplanements that were performed for all regions, the nature of the regional airport system was highlighted with the case of Atlanta airport. Figure 39 shows the enplanements at the regional level for both single airport and multi-airport systems. The single airport systems are distinctly segregated into two subsets. Atlanta with almost 40 million enplanements needs to be separated from the group of airports with enplanements below 18 million per year. A transition threshold, around 17 to 18 million enplanements per year, seems to exist between single and multi-airport systems.

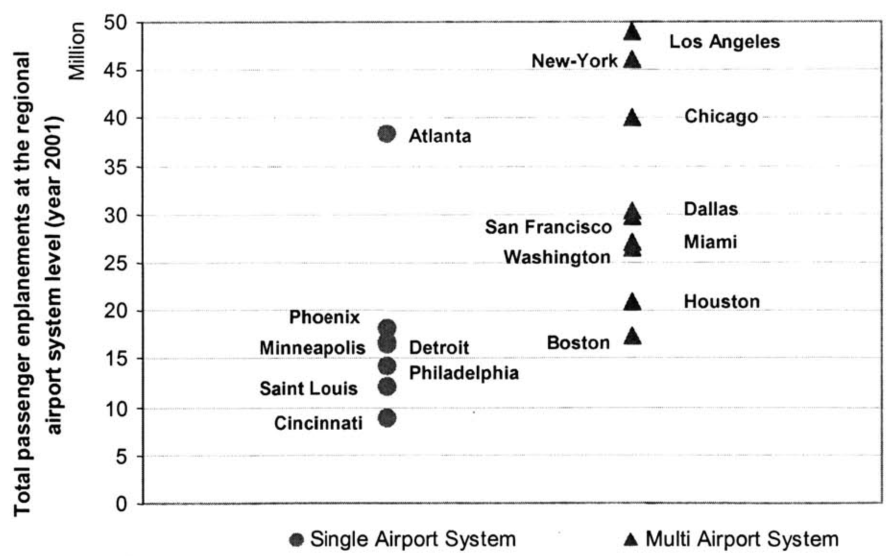


Figure 39: Passenger enplanements at single and multi-airport systems [17]

However, Atlanta has almost 40 million enplanements, well above the threshold where a second airport becomes viable. Atlanta is a major hub, with 62% of connecting traffic. In this case, the nature of the core airport seems to play a role in the development of the regional airport system.

From these analyses, it was found that the nature of the traffic at the core airport – connecting hub versus non connecting hub- was a significant factor that was influencing and could even be preventing the emergence of secondary airports. In order to emerge close to a connecting hub, an airport has to compete with the core airport on a location basis as illustrated with the re-emergence of Chicago Midway, Dallas Love Field, Houston Hobby.

3.6 Economic advantages for operating at secondary airports

Airlines face various direct and indirect costs for operating at a specific airport. In 2003, Southwest airlines estimated that airports related costs were accounting for 7% of the overall operating expenses [34], the other expenses being salaries and wages, fuel and oil, maintenance and repair, aircraft depreciation and other operating related costs. The costs related to the airport are generally terminal rents and landing fees. Airports also charge Passenger Facility Charges that are included in air fares. Some other costs are less tangible such as externalities.

Landing Fees

Landing fees are generally charged on an aircraft weight basis each time an aircraft lands at an airport. In 2000, Southwest airlines estimated that the landing fees were representing 54% of their airport related costs [34]. Landing fees represented roughly 3.5% of the overall operating expenses.

Terminal and gates rents

Terminal and gate rents are negotiated between the airport management authorities and the airlines. Each contract is different and contains multiple clauses that are hard to quantify. Therefore it is difficult to quantitatively compare the costs of gates at both core and secondary airports. However, it is reasonable to assume that based on demand and supply relation; gates at underutilized airports are less expensive than gates at core airports where the demand is often greater than the supply.

Passenger Facility Charges (PFC)

Even though passenger facility charges are not directed to the airlines, this cost is included in air fares. From an analysis of Passenger Facility Charges at both core and secondary airports, it was found that PFCs were lower at secondary airports then at core airports in the case of the Los Angeles, Chicago, Miami, Orlando, Tampa and Dallas airport systems. In some cases however, PFCs were as high at secondary airport than at the core airport.

Table 11: Passenger Facility Charges at core and secondary airports[1]

Core airports			Secondary airports		
Code	**Name**	**PFC Level**	**Code**	**Name**	**PFC Level**
BOS	Boston	$3.00	PVD	Providence	$3.00
			MHT	Manchester	$3.00
LAX	Los Angeles	$4.50	LGB	Long Beach	$3.00
			ONT	Ontario	$3.00
			BUR	Burbank	$3.00
			SNA	Santa Ana	$0.00
JFK	New York JFK	$3.00	ISP	Islip	$3.00
EWR	Newark	$3.00			
LGA	New York LGA	$3.00			
DCA	Washington, DC-Natl	$4.50	BWI	Baltimore	$4.50
IAD	Washington, DC-Dulles	$4.50			
SFO	San Francisco	$4.50	SJC	San Jose	$4.50
			OAK	Oakland	$4.50
ORD	Chicago	$4.50	MDW	Chicago Midway	$3.00
MIA	Miami	$4.50	FLL	Fort Lauderdale	$3.00
MCO	Orlando	$3,00	SFB	Orlando Sanford	$1,00
			MLB	Melbourne	$3,00
TPA	Tampa	$3,00	PIE	St Petersburg	$0,00
			SRQ	Sarasota	$3,00
DFW	Dallas Fort Worth	$3,00	DAL	Dallas Love Field	$0,00
IAH	Houston Int.	$0,00	HOU	Houston Hobby	$0,00

Externalities

Delays have a cost to airlines also referred to as externalities and airlines have to internalize a fraction of those costs (externalities). Even though the externalities are not clearly included in the airlines balance sheet, they impact the operations – efficiency of the fleet, reliability of operations, etc. - that indirectly translate into costs or loss of revenues. As demonstrated in Chapter 2, secondary airports exhibit lower level of delays than core airports. Therefore airlines that operate at secondary airports face significantly lower externalities than the airlines that operate at core airports. The lower levels of delays also impact the reliability of the airline operations. Airlines like Southwest have based their

[1] Data source: FAA, Airport Financial Assistance, Passenger Facility Charges Program, [URL: http://www.faa.gov/arp/financial/pfc/, Last accessed: October 2004].

business model on the utilization of less congested secondary airports that enable them to run lean operations. The lower variability of arrival and departure time allow the airline to build schedule with fast turn-over. This implies that aircraft can spend more time flying and generating revenues.

Even though landing fees and terminal rents can be lower at secondary airports then at core airports, airlines operating at secondary airports have a clear cost advantage compared to airlines that operate at core airports that are congested and exhibit high level of delays.

3.7 Political factors

As described in the sections above, the factors that influence the emergence of a secondary airport are related to the current and future economical viability of airlines that will operate at this airport. However, the emergence of an airport is influenced over its development process by non economical factors such as the political willingness of the local and regional administrations. Although this factor is hard to quantify, the efforts of regional development entities are clearly visible. In the case of the New England region, in the early and mid-1990s, the FAA, Massport (the airport authority managing Boston, Worcester and Hanscom Field airports), representative from Manchester and Providence airports, and the Massachusetts Aeronautics Commission (MAC), extensive planning has been done in order to ensure that the region will provide infrastructures that will be able to meet the demand for air transportation in the future. This development effort has been made possible by the collaboration of all agencies and results are clearly visible today, with the successful emergence of both Manchester and Providence.

"This [effort] was all part of a carefully crafted plan developed by local aviation officials, Massport and the FAA to create a more coordinated aviation system for our area. And to help keep that momentum going, Governor Paul Cellucci refiled legislation to extend commuter rail service to Providence's T.F. Green Airport and refiled plans to expand Route 3 to Manchester."[1]

A secondary airport will certainly not emerge if its is not economically viable for airlines, but in the case where the conditions for a successful emerge exist, regional agencies and the political willingness of local and regional representatives play a significant role in developing adequate infrastructure and attracting new airlines at underutilized airports as illustrated with the New England case study.

In addition, political factors also played a key role in the dynamics of regional airport systems like Dallas, Houston, and Chicago where the traffic was transferred from an original core airport to a future emerged core airport. The example of Dallas with the Wright amendment governing Southwest operations at Dallas Love field illustrates the role

---

[1] Source: Massport, [URL: http://www.massport.com/airports/about.html, Last accessed : December 2004]

and the impact of political influence mechanisms in the development of regional airport system and how they are shaped and evolve.

Chapter 4

System Dynamics Model of Regional Airport Systems

4.1 Airport life cycle

From the study of the emergence of secondary airport, growth and eventually its transformation into an emerged core airport, a general evolution pattern was observed. Figure 40 shows the general airport life cycle.

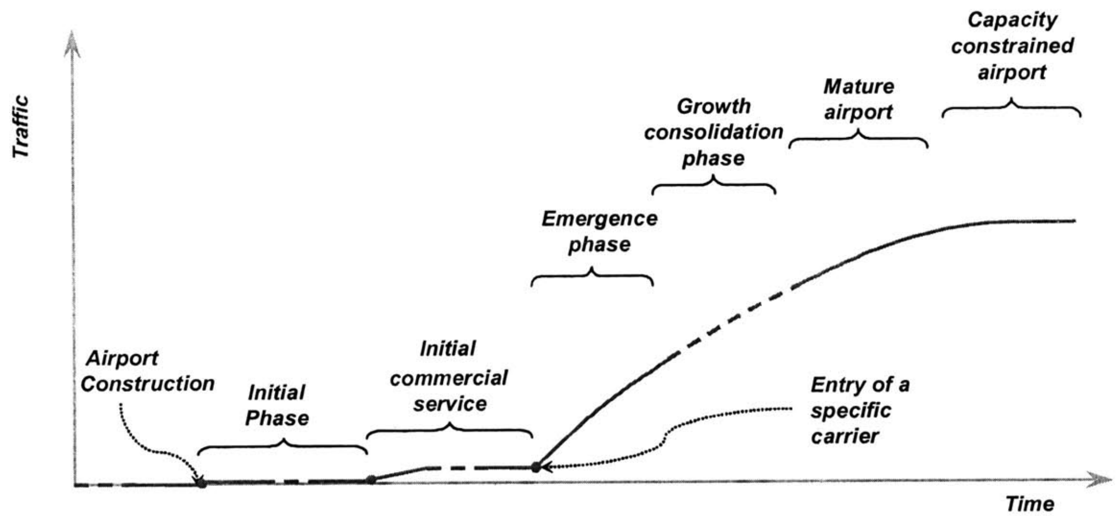


Figure 40: Airport life cycle

Initial phase:

In this phase the airport exists but with limited activity.

Initial commercial service phase:

Commercial activity exists in this phase. The airport is then connected to a hub. In fact, for airports with low service, this is the most efficient way to gain access to the largest number of cities. Adding the first liaison from the small airport to the hub, virtually adds access to all cities connected to the hub. However, because of the low activity and low competition, air transportation services are in this stage performed under a high fare structure. In some cases, due to levels of traffic unable to sustain profitability of the legs operated by the carrier in place, government subsidies are provided to these carriers. In the United States, a subsidies program called "Essential Air Service" was put in place after deregulation to ensure that small communities keep a minimum level of service through connection to a hub. As of June 2003, the program ensured service to 102 small airports serving communities that otherwise would probably have lost air transportation services.

Emergence phase:

This phase is initiated most of the times by the entry of a specific carrier. In the vast majority of cases that were studied, a low-cost carrier was at the origin of the emergence phenomenon. This carrier enters with significantly lower fares, new destinations, and increased frequency of service. Demand is stimulated in this phase.

Growth consolidation phase:

This phase is characterized by the entry of several new carriers, low-cost and/or traditional carriers. These additional entries induce an increased competition at the airport level, leading to better chances of sustainable growth.

Mature airport phase:

Under this phase capacity increases are often performed in order to accommodate growth.

Capacity constrained phase:

In this last phase, airports cannot increase their capacity to the level required to accommodate demand growth. Limitations on operations occur; delays start to increase, and most of the times, if capacity cannot be added the need for diverting operations to a closely located airport is required.

In the common concept of life cycles, whether it is used to describe products or technologies life cycle, the last phase is often described as the death of the entity. However, in the case of airports, this last phase rarely observed. Airport can in rare cases be close and their traffic transferred to another case. It was more frequent in the mid twentieth century. However, it is less likely that major airports will be closed and dismantled in the future, due to the several factors:

! Successful airports are often located in areas where the demand for transportation remains strong or grows. This demand justifies the need to keep these airports open.

! New and larger airports that could replace existing airports (often in the heart of cities) can only be built outside metropolitan areas (case of Dallas Fort Worth, Houston International, etc). In this case, the original core airport, due to its critical location, keeps its attractiveness and remains active.

4.2 Summary of the factors influencing the emergence of secondary airports

The analysis of the factors that influenced the emergence of secondary airports led to the identification of the following factors (Table 12):

! Level of service at the core airport (congestion of the core airport resulting in delays)

! Availability of capacity at the regional level

! Distribution of population (density)

! Size of the local basin of population

! Airport infrastructure

! Political factors

! Connecting passengers at the core airport

! Entry of a low-cost carrier

However, as it was demonstrated throughout the analyses, the weight of these factors was different for each regional airport system. Some regional airport systems emerged due a certain combination of factors whereas the emergence of secondary airports in of other regional airport systems was the result of a different combination. For example, Washington Dulles (IAD) emerged because of the heavy congestion at Washington

National[1]. However, the local basin of population around Dulles was not sufficient provide enough activity. This airport was aimed at diverting traffic from DCA. On the opposite, some secondary airports like Sarasota International airport (SRQ) emerged because of a local market and not specifically because Tampa (TPA) was congested. The emergence of Manchester airport is a combination of these to extremes. Manchester airport emerged because Boston airport was becoming congested and because a local basin of population represented a potential market for airlines that ultimately served Manchester.

Because of the multitude of factors, the fact that the emergence is a combination of those factors and because of their role in the dynamics of the emergence phenomenon, there was a need to understand the impact of each factor on the airport systems dynamic. For this purpose, a system dynamics model of the regional airport system was developed. Then another model coupled multiple airports with different initial conditions and characteristics in order to capture the impact of the performance of an airport on the other airports in the region.

[1] Washington National (DCA) is also one of the four airports in the United States that is slot restricted. This means that the capacity is actively regulated. The ability to accommodate growth of demand at this airport was quasi non existent when Dulles emerged.

Table 12: Summary of the factors influencing the emergence of secondary airports

	Factors					
Airport	**Congestion**	**Fraction of connecting passengers**	**Entry of a low-cost carrier**	**Runway length in m (ft)**	**Population**	**Political Willingness**
ORD	High	50%		3962 (12998)	26%	√
MDW	Low		√	1988 (6522)	31%	√
MIA	Medium	26%		3962 (12998)	34%	
FLL	Low		√	2743 (8999)	12%	
BOS	High	10%		3073 (10082)	38%	√
PVD	Low		√	2184 (7165)	20%	√
MHT	Low		√	2134 (7001)	6%	√
MCO	Medium	≈ 0%		3660 (12005)	6%	
SFB	Low			2926 (9600)	16%	
MLB	Low			3103 (10181)	12%	
TPA	Low	≈ 0%		3354 (11002)	29%	
PIE	Low			2682 (8800)	25%	
SRQ	Low			2897 (9503)	16%	
SFO	High	18%		3618 (11870)	31%	
OAK	Low		√	3048 (10000)	24%	
SJC	Low		√	3368 (11049)	27%	
LAX	High	18%		3685 (12089)	14%	√
BUR	Low		√	2099 (6886)	17%	√
ONT	Low		√	3719 (12201)	8%	√
SNA	Low		√	1737 (5698)	15%	√
LGB	Low		√	3048 (10000)	24%	√
DAL	Low		√	2682 (8800)	17%	√
DFW	High	62%		4085 (13401)	12%	√
HOU	Low		√	2317 (7602)	24%	√
IAH	High	54%		3658 (12001)	22%	√
DCA	Medium			2094 (6870)	39%	√
BWI	Medium		√	2901 (9517)	22%	
IAD	High		√	3505 (11499)	6%	√
LGA	High	5%		2134 (7001)	32%	
EWR	High	21%	√	2835 (9301)	15%	
JFK	High	18%		4442 (14573)	18%	
ISP	Low		√	2134 (7001)	5%	

4.3 Single airport System Dynamics model

The basic single airport model is built based on the standard system dynamics approach using stock and flow diagram and causal loops.

4.3.1 Stock and flow diagram

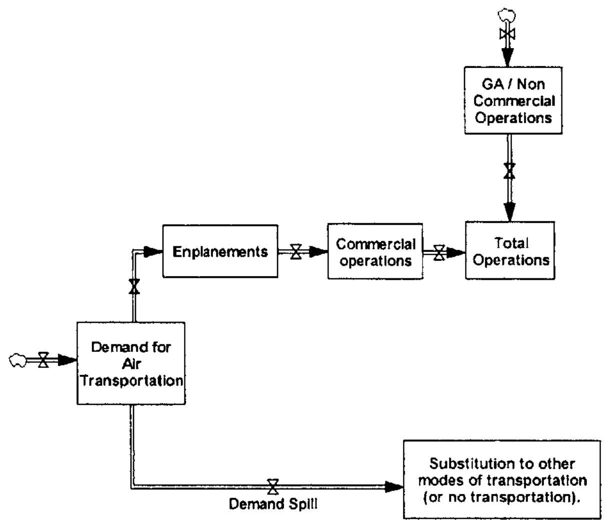


Figure 41: Stock and flows diagram of the single airport model

The stock and flow diagram starts with the demand for air transportation, and then distribute this demand through the actual passenger enplanements if the demand is materialized. If this is not the case, the demand is spilled and "flows" to substitution modes of transportation (e.g. car, train, etc). If the demand is not materialized in any of the available mode of transportation, it is simply spilled. The potential passenger chooses not to travel.

4.3.2 Causal loop diagram

The factors that influence the stocks and flows are captured in the causal loops. A causal loop is composed of a series of relations (arcs) between factors (variables) that represent the dynamics of sub-parts of the system.

Figure 42 shows the system dynamics representation of both the stock and flow diagram and the causal loops diagram for a single airport. The factors that were identified in the analysis of emergence of secondary airports were included in those causal loops.

Basically the model is centered on two main composite variables;

- the airport attractiveness to airlines
- the airport attractiveness to passengers

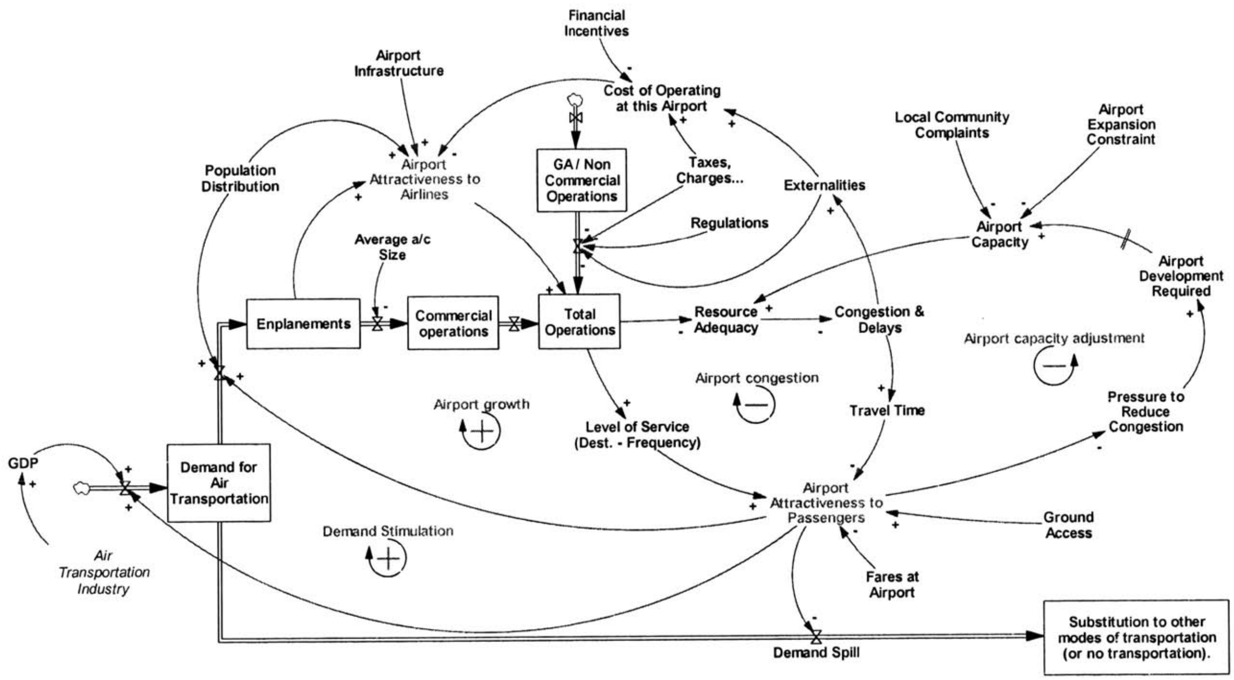


Figure 42: System dynamics model of a single airport

These composite variables are also included into four major loops that capture the core dynamics of the system:

The airport growth loop:

Starting from the "level of service" variable, an improvement in level of service at an airport will increase the attractiveness of this airport to passengers. Based on passenger choice models [21], the relative attractiveness of transportation modes dictates the market share of each mode. If the airport becomes more attractive, it is likely to capture demand that was "flowing" to other modes. This excess of demand will translates into an increased airline capacity and level of service. This loop is a self reinforcing loop and will be triggered until a balancing loop limits its strength.

The demand stimulation loop:

Starting from the "level of service" variable, an improvement in level of service at an airport will increase the attractiveness of this airport to passengers. As it was demonstrated at the airport level (Chapter 3) and at the OD market level in California and called the "Southwest effect" [20] the level of service at an airport triggers stimulation of demand for air transportation. If the airport is able to accommodate this new excess demand, it will materialize into passenger enplanements. Assuming that airlines keep a maximum load factor, a capacity adjustment will be performed, leading to an increase in the number of operations. This upsize adjustment of capacity translates into increased frequency and/or new destinations, which in turn increases the overall airport attractiveness to passengers. As described, this loop is a self reinforcing loop and will be triggered until a balancing loop limits its strength.

The airport congestion loop:

The key variable in the airport congestion loop is the resource adequacy. This resource adequacy was defined as the difference between the airport capacity (annual theoretical airport capacity – refer to Appendix B-3 for details) and annual operations. This "gap" is proportional to the inverse of the utilization ratio presented in Appendix B-3 (Figure 52). Thus the lower the resource adequacy, the more likely the airport will incur high delays. Delays are also a measure of airport attractiveness to passenger since they influence the door to door travel time. Since the attractiveness of the airport diminishes, some passengers will choose other modes of transportation, thus limiting the growth in the number of enplanements and operations. As the airport growth loop remains active and the resource adequacy diminishes (with constant airport capacity) the congestion loop will balance the growth and level off the number of operations at the airport to a level of delays (and level of service) that passengers will be willing to bear.

The capacity adjustment loop:

In the previous loop, we have assumed that the capacity of the airport remained constant in time. As the attractiveness to passenger decreases, there will be more pressure to reduce the congestion through airport capacity adjustment. However, there exists a delay between the moment when airport improvements are required and the time the physical capacity is added to the air or land side. This delay is due to the time required for planning, design, project approval and construction. Ultimately, additional capacity will be added thus increasing the resource adequacy.

4.4 Multi-airport System Dynamics model

The previous section illustrated the dynamics at the single airport level. In order to understand how the factors that were identified combine together and result in the successful emergence of a secondary airport, there was the need to integrate single airport models into a multi-airport model. This required the creation of relationships between the variables of each model, in order to replicate the influence of a specific airport on another airport in the region.

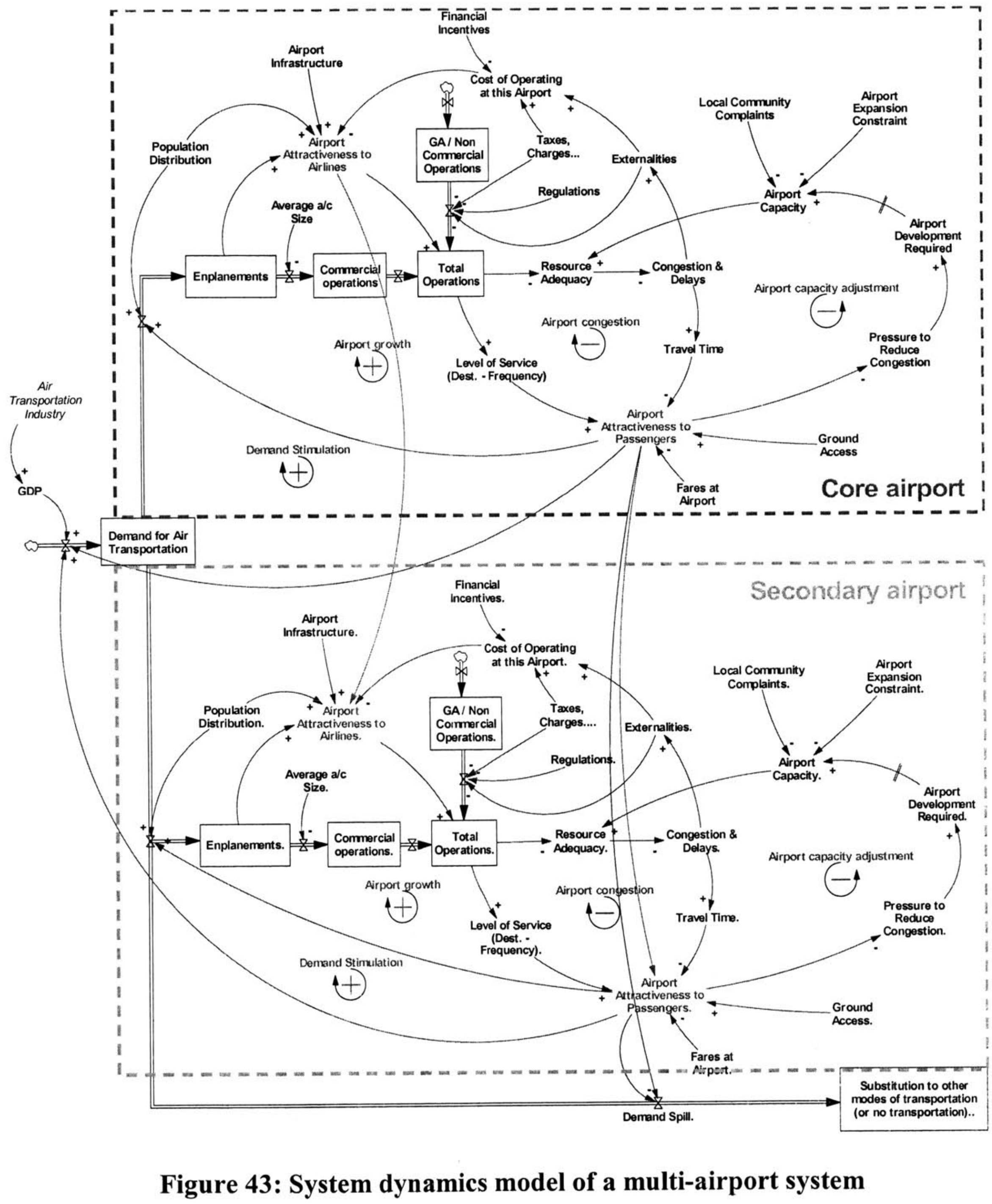


Figure 43: System dynamics model of a multi-airport system

Figure 43 shows the model that couples two airports (a core airport and a secondary airport). Links were created between the airport attractiveness for both airlines and passengers. From the structure of the multi-airport system, two models explaining the emergence of secondary airports. Figure 44 shows these two subparts in the system dynamics model:

! **the core airport congestion model (congestion/capacity inadequacy)**

! **the local market demand model (local market/unmet demand)**

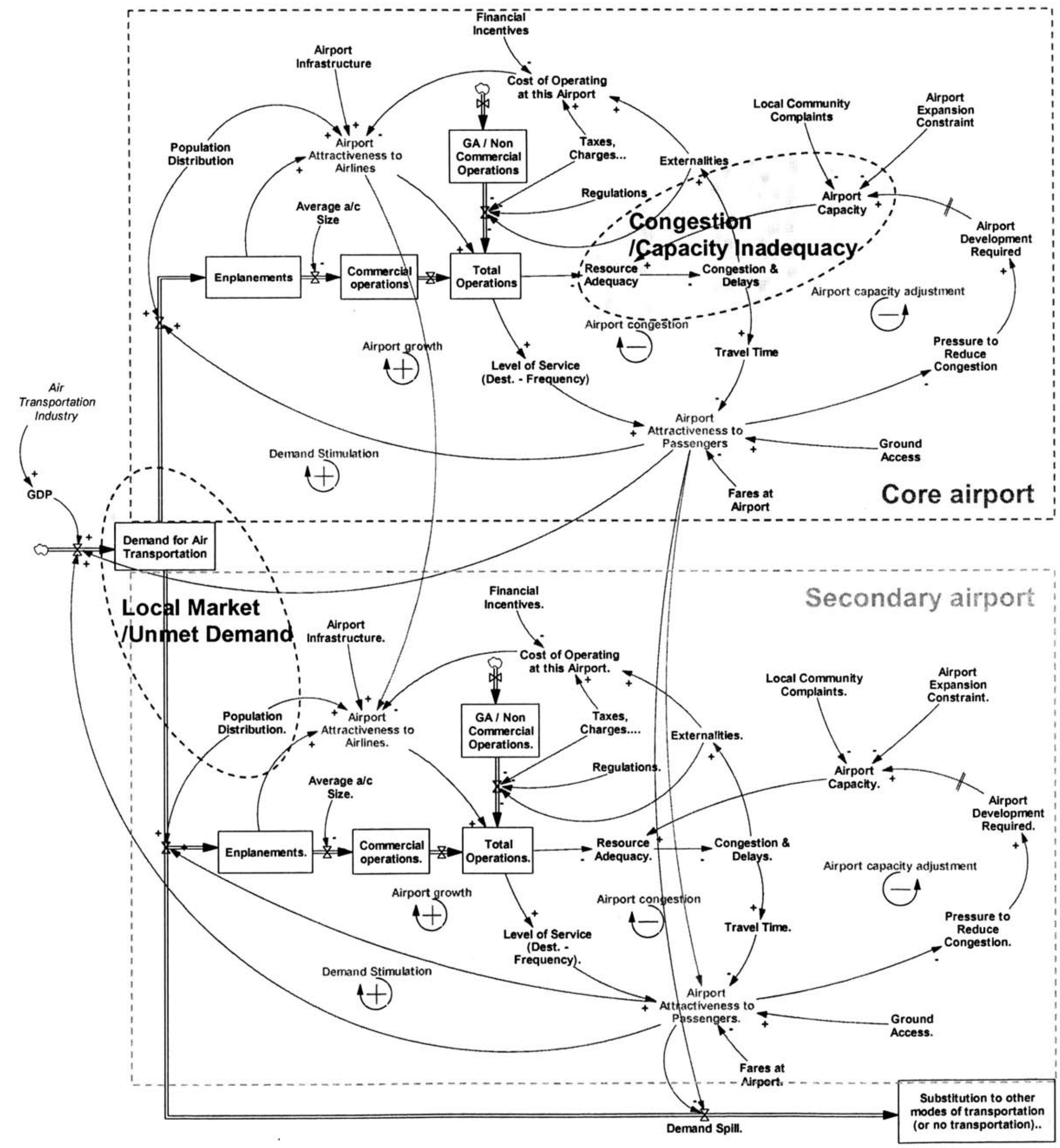


Figure 44: System dynamics model of a multi-airport system with key factors influencing the emergence of a secondary airport

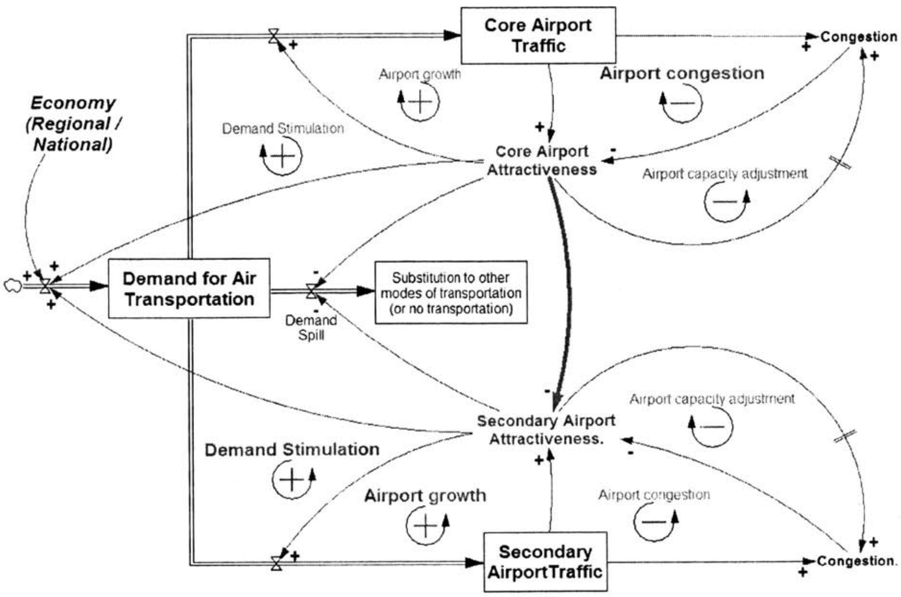


Figure 45: Simplified version of the System Dynamics model of a multi-airport system

The **core airport congestion model** is triggered by the lack of supply (capacity) at the core airport. It impacts negatively the attractiveness of the core airport to passengers which translates into an increase in regional airport attractiveness to passengers. However, this attractiveness will only materialize in actual enplanements and operations if an airline is willing to enter this airport. This dynamics includes several of the factors that were identified:

- Lack of capacity at the core airport
- Availability of capacity at the regional level
- Airport infrastructure
- Entry of a low-cost carrier (and subsequently legacy carriers)
- Connecting passenger at the core airport
- Political factors

The **local market demand model** is triggered by the unmet demand at the local level. It directly impacts the attractiveness of the secondary airport to airlines. A carrier that decides to enter this market and serve this unmet demand will trigger both the stimulation and the airport growth loops, resulting in the emergence of the secondary airport. This dynamics includes several of the factors that were identified:

- Availability of capacity at the regional level
- Airport infrastructure
- Distribution of population
- Size of the local basin of population
- Entry of a low-cost carrier (and subsequently legacy carriers)

However, the cut between those two models is not clean. The emergence of some airports is clearly driven by the congestion of the core airport. Dallas Fort Worth and Washington Dulles are illustrations of this model. On the other hand, airport like St Petersburg-Clearwater (PIE), Sarasota (SRQ), etc. are influenced by local market forces. Driven by these two models, we find airports like Manchester (MHT) and Providence (PVD). These two airports captured traffic that was previously flowing to Boston Logan (BOS), but they also serve local markets that were stimulated by the new services offered at the secondary airport.

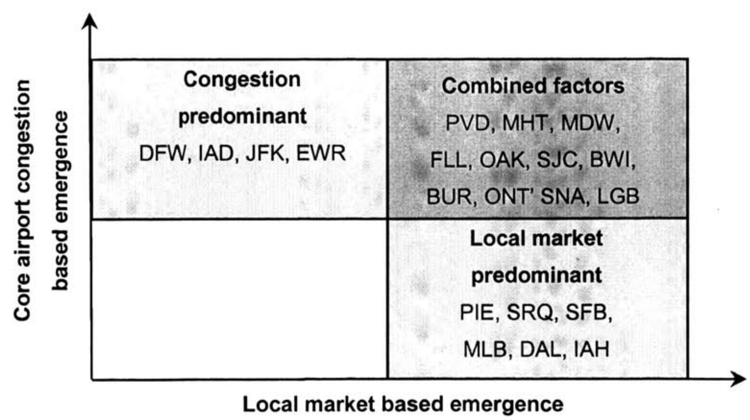


Figure 46: Congestion vs. market based emergence models.

Chapter 5

Implications of the Emergence of Secondary Airports

5.1 Implications at the regional level

5.1.1 Dynamics at the regional level

The emergence of secondary airports and more generally the transition from a single airport system to a multi-airport system modify the dynamics at the regional level. Secondary airports offer both advantages and disadvantages depending on stakeholder perspectives.

As it was demonstrated, in most cases secondary airports are a response to congestion at core airports. From this perspective, the newly emerged airports relieve core airports by diverting traffic while providing additional capacity to the system. From a passenger stand point, the expanded set of regional airports with service provides new options of travel, which translates into better access to air transportation for suburbs and neighborhood towns' residents. In general, passengers originating from the local basin of population have a facilitated access to air transportation since they avoid congested highways often serving the core airport (e.g. Los Angeles region, Boston region). As it was demonstrated earlier, in addition to relieving the core airport, often, secondary airports and their new service stimulate a local market. From a regional economy development stand point, the new airport activity provides direct employments, revenues sources for cities from taxes, etc. It also generates indirect impacts by attracting new companies, etc. It is difficult to isolate and quantify the impacts of the emergence of a secondary airport on the local economy since it is usually not the only cause of regional development. In the cases of the emergence of secondary airports based on the combined *core congestion* and *market* (refer to Chapter 4: Models) it is believed that there was a potential for regional economical development before the emergence of the secondary airports.

Secondary airports also offer several disadvantages. From an environmental stand point, the development of secondary airports increase the population exposure to noise. Long term strategies applied at the beginning of the airport development can reduce these negative impacts by protecting land areas from housing development.

From an airline perspective, the transition from a single airport system to a multi-airport system dilutes the operations, in the case where the same airlines decide to operate at both airports. This reduces the opportunity for economies of scale. For network carrier, operating at both the core and secondary airports reduces the efficiency of its network since it cuts the connections. Connecting passengers are less likely to transfer between two airports. It is not cost efficient since it implies ground transportation costs for passengers and requires additional slack time (between two flights) accounting for ground transportation time variability.

5.1.2 Impacts on the regional airspace system

The spread of operations has great impacts on the way the airspace is managed. Once traffic grows at secondary airports, interactions between airports appear and airport operations become dependent. In the case of the Boston region, since both Manchester and Providence are about 50 miles away from Boston Logan airport and traffic at secondary airports remains limited, the interactions are still weak (Figure 47). However, in the case of multi-airport systems where airports are more closely located, this dependence increases. The airports in the New York airport system face operational constraints due to these interactions [35].

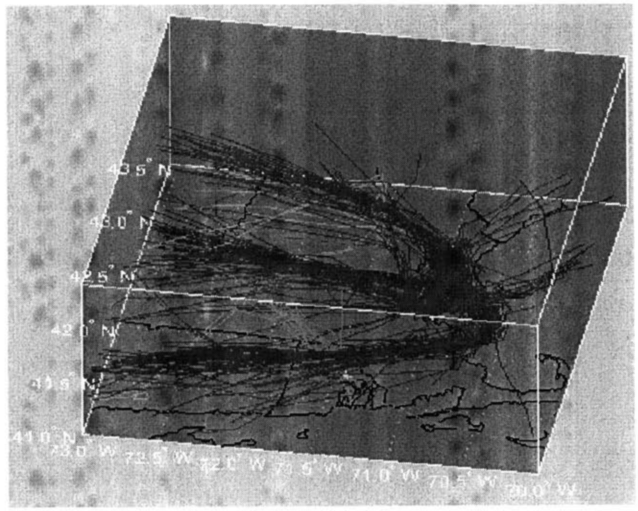


Figure 47: Traffic patterns over the BOS, MHT and PVD[1]

The impact of the emergence and growth of secondary airports is illustrated by the recent consolidation of TRACONs (Terminal Radar Control). In 2003, the Potomac TRACON in Washington was the result of the merger of 4 single airport TRACONs that became inefficient because of the greater interactions between Washington National, Washington Dulles, Baltimore and the Andrews Air Force base airports, due to the large increase in operations at both Dulles and Baltimore. The same merger phenomenon also happened in February 2004, in the Boston region, where both Boston and Manchester TRACONs merged in order to run more efficient operations at both airports. Therefore the impact of emergence and growth of secondary airports forces the National Airspace Structure (at least at the TRACON level) to become more centralized. With the emergence of secondary airport, interactions appeared inside regional airport system. As multi-airport systems tend to spread laterally, in addition to being closely located to each other, as this is the case in the North East of the United States, inter-dependence will appear between systems. A new level of centralization may be needed to manage these inter-related multi-airport systems.

[1] Data source: Enhanced Traffic Management System data, (ETMS).

5.2 Implications at the national level

5.2.1 Implications on the national infrastructure

The inability of core airports to accommodate the growth of demand at the local level has led, in part, to the development of secondary airports and the creation of multi-airport systems. This dynamic implies a decreasing concentration[1] of activity at major airports (Figure 48), but it also implies that the air transportation system relies on a larger set of airports.

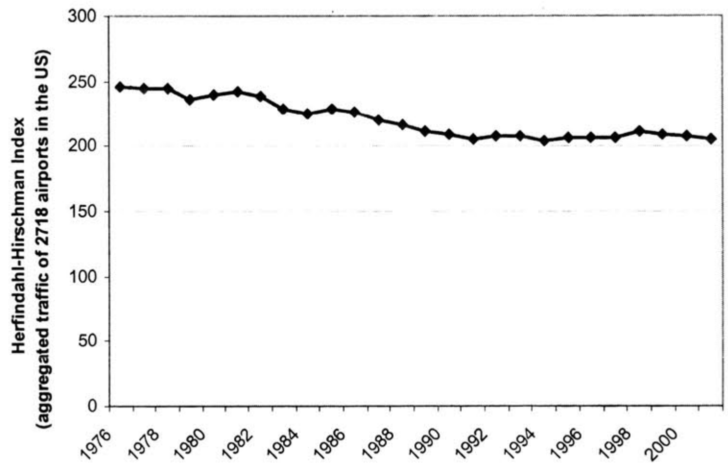


Figure 48: Concentration of activity at the national level from 1976 to 2001[17]

From reliability stand point; this trend is actually beneficial since the effects of a disruption of activity at an airport are lower than what they would have been if all activities were located at the same airport. For example, during intense fog condition due to Los Angeles airport's exposure to the ocean, some of the traffic that cannot be handled at LAX is diverted to Ontario airport, a closely located secondary airport [65]. On the other hand, from an infrastructure investment stand point, the expansion of the set of critical airports requires a greater dilution of funds and a more difficult fund allocation process.

---

[1] The concentration of activity is measured by the Herfindhal-Hirschman Index (HHI). This index is computed as the sum of the squared market shares expressed in percentage. Therefore, in a close market (two airports share the total traffic), the maximum value of the index is 5000. For a set of 2718 airports, the minimum value is 3.7 (all 2718 have the same market share). A decreasing HHI means that the concentration of the activity is decrease. Reciprocally, an increasing HHI means that the concentration of activity increases.

5.2.2 Implications of multi-airport systems at the national level

The emergence of a new secondary airport implies new connections to the rest of the network of airports. For example, the emergence of Providence airport part of the Boston regional airport system has lead to the creation of OD pairs such as PVD-ORD (a secondary to core airport market) and PVD-MDW (a secondary to secondary airport market). These routes are parallel to the core to core airport route; BOS-ORD.

In order to quantify the impact of the emergence of secondary airports on the national air transportation network, a systematic analysis of 16 regional airport systems has be performed. Three categories of OD pairs were studied:

- Core to core airports (base network)
- Core to secondary airports or secondary to core airports (semi-parallel network)
- Secondary to secondary airports (parallel network)

Figure 50 shows the regional airport systems that were taken as reference in the analysis.

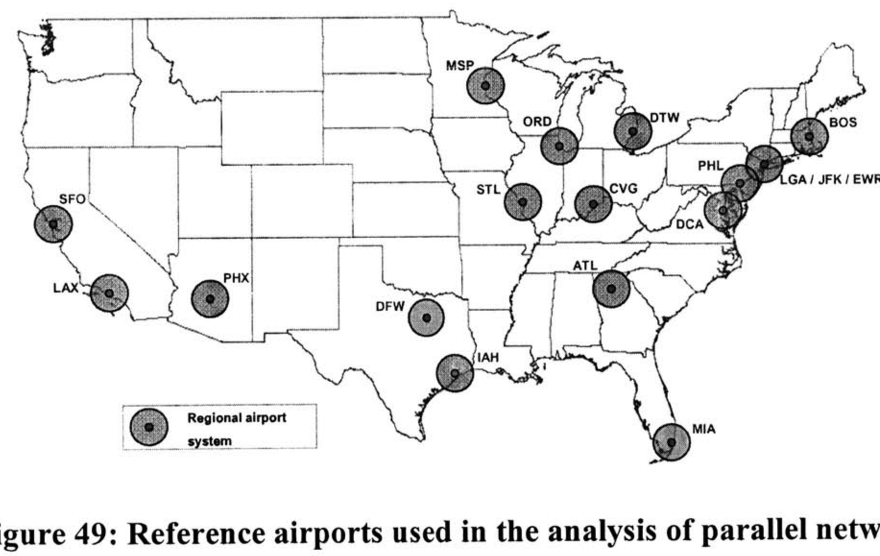


Figure 49: Reference airports used in the analysis of parallel networks

Using Form 41 traffic [11] data for the month of March in 1990 and 2003, respectively representing a total of 18,000 and 15,000 distinct OD pairs, the number of OD pairs for each category was computed for both periods. Figure 50 shows the results of this analysis for both 1990 and 2003. The arcs in the network are directional arcs. This means that BOS-ORD is considered as different as ORD-BOS. Therefore, the result on 240 connections between core airports means that the network of 16 airports is fully connected[1].

As shown on Figure 50, the size of the semi-parallel network has increased from 13 % in terms of connections, from 439 to 193 connections between 1990 and 2003. More over, the major growth was observed in the parallel network category where a 49% growth occurred between 1990 and 2003. This phenomenon is mainly due to the emergence and growth of secondary airports in the 1990s (Providence, Manchester, etc). The introduction of new OD pairs between secondary to secondary airports is the result of the strategy of carriers like Southwest that operate largely at secondary airports and connect them together with point to point flights.

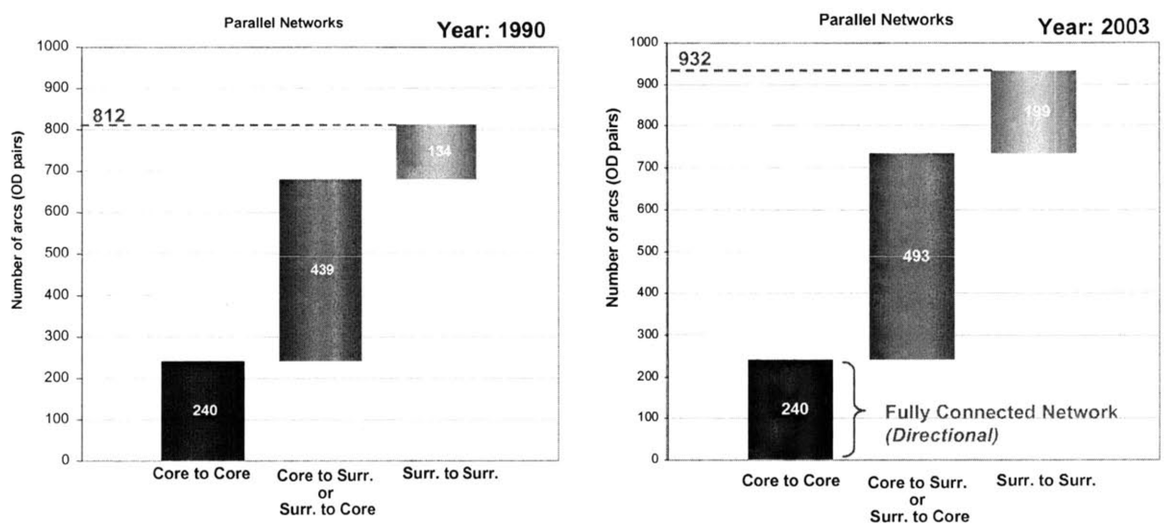


Figure 50: Parallel networks evolution from 1990 to 2003 [11]

[1] For a network of n nodes, the number of directional connections required to connect all nodes between each other is equal to n*(n-1).

Conclusions

The emergence of secondary airports is the expression of the adaptation of the national air transportation system to capacity constraints and emergent market opportunities. As major airports in the United States reached capacity limits and became congested, available capacity at surrounding airports was utilized resulting in the emergence of secondary airports and meeting the demand of these key areas. These airports have proven to be a viable option for increasing the capacity of regional air transportation systems. As traffic is expected to grow in the upcoming years the phenomenon of secondary airport emergence is likely to continue and develop in other major metropolitan areas. In addition, current secondary airports will grow to a point where some will become considered as core airports and ultimately become congested. In these regions additional secondary airports will emerge to accommodate this growth and avoid major capacity crises or a gridlock of the air transportation system.

This study found that the distribution of population at the regional level and the existence and proximity of a secondary basin of population close to secondary airports were major factors in determining which surrounding airports were likely to emerge. Airports with runway length as low as 5700 ft, were found to be viable secondary airports. The nature of the regional airport system, in terms of percentage of connecting passengers at the core airport was also identified as a contributing factor. It is believed that secondary airports are not likely to emerge close to a core airport with high connecting traffic unless it competes on a location advantage basis and re-emerges from an original core airport. Most importantly, market stimulus through the entry of a specific carrier – generally a low-cost carrier- was determined to be a key factor in the emergence phenomenon. These entries modify the airport dynamics, in terms of fares and new destinations, resulting in a stimulation of the local and peripheral markets. Following the entry of a low-cost carrier several other carriers, both legacy and low-cost, enter and consolidate the growth of the emerging airport.

The future secondary airports are to be found in metropolitan areas where the core airports are reaching saturation and capacity adjustments are limited (e.g. New York, Philadelphia, Chicago, Miami, etc.). Because of the high barriers to new airport construction, most of new secondary airports are likely emerge from existing underutilized regional airports. They will require runways longer than 5500 ft in order to accommodate narrow body jets or regional jets in addition to a good access to the ground transportation infrastructure for connectivity purposes. In addition to access convenience competitive advantage, future secondary airports will need to attract airlines seeking new market opportunities resulting in new destinations at fares competitive what will be offered at the core airport.

However, the transition from single core airport to region wide multi-airport systems and the emergence of new secondary airports in existing multi-airport systems, impose new constraints that need to be taken into account in the management and modernization of the National Airspace System. In addition, the expansion of the set of critical airports impacts the funding and resource allocation for future airport improvements. Extending the operations at a larger number of airports also results in the creation of parallel networks that impact airlines strategies.

The results of this research highlight the need to consider existing underutilized resources as an opportunity to exploit through the emergence of secondary airports. These airports can add significant amount of capacity to the system in addition to enhancing people's access to air transportation. Acknowledging that secondary airports will be key mechanisms for meeting future demand for air transportation, there is a real need for establishing national and regional strategic plans for the development of regional airport systems.

Bibliography

1. United States Department of Transportation Federal Aviation Administration, *National Plan for Integrated Airport System 2005-2009*, 2005.
2. Bureau of Transportation Statistics, National Transportation Statistics, Statistical Abstracts URL:http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_01_32.html)
3. United States Department of Transportation Federal Aviation Administration, *National Plan for Integrated Airport System*, 2002.
4. U.S. Census Bureau, *Population density maps,* available at: http://www.census.gov/popest/gallery/maps/PopDensCounties_2004.pdf.
5. US Department of Commerce, Bureau of Economic analysis, Gross Domestic Product, (URL: http://www.bea.gov/bea/dn/home/gdp.htm)
6. United States Department of Transportation, Federal Aviation Administration, *Airport Capacity Benchmark Report*, 2001.
7. Tam R., *Air Transportation and Socioeconomic Connectivity in the United States Since Deregulation,* Master Thesis Massachusetts Institute of Technology, 2003.
8. United States Department of Transportation Federal Aviation Administration, *Capacity Needs in the National Airspace System*, June 2004.
9. Federal Aviation Administration, Aerospace Forecasts 2005-2016, available at: http://www.api.faa.gov/forecast05/Forecast_for_2005.htm
10. Aviation International News, *Forecasts predict growth for business aviation*, available at: http://www.ainonline.com/issues/11_04/11_04_forecastp10.html), 2004.
11. Bureau of Transportation Statistics, Air Carrier Statistics, From 41 traffic database, available at: http://www.transtats.bts.gov.
12. NASA-FAA Socio-Economic Demand Forecast Study, 2003.
13. Federal Aviation Administration, Operational Evolution Plan, available at http://www.faa.gov/programs/oep/, Last accessed: December 2004

14. Mozdzanowska, A., *Evaluation of Regional Jet Operating Patterns in the Continental United States,* Master Thesis Massachusetts Institute of Technology, 2004.
15. Hong Jiang H., *An Analysis of Profit Cycles In the Airline Industry*, Master Thesis Massachusetts Institute of Technology, 2004
16. Bonnefoy P., *Light Jet Operating Patterns in the United States,* Joint University Program, January 2005.
17. Federal Aviation Administration. *Terminal Area Forecasts, (historical records).* available at http://www.apo.data.faa.gov/faatafall.htm, 2004.
18. De Neufville, R., *Management of Multi-Airport Systems: A Development Strategy*, Journal of Air Transport Management, Vol.2, No. 2, June, pp. 99-110, 1995.
19. El Alj Yasmine, *Estimating the true extent of air traffic delays,* Master of Science Thesis, Department of Environmental and Civil Engineering Massachusetts Institute of Technology, Cambridge, MA 2003.
20. Benett R. and Craun J., Office of Aviation Analysis, U.S. Department of Transportation, *The Airline Deregulation Continues; The Southwest Effect*, 1993.
21. Ben-Akiva, M., *Structure of Passenger Travel Demand Models*, Ph.D. Thesis, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1973.
22. De Neufville Richard and Odoni Amadeo, *Airport Systems: Planning, Design and Management*, Aviation Week McGraw-Hill, 2003.
23. Mayer Christopher and Sinai Todd, *Network effects, congestion externalities, and traffic delays: or why not all delays are evil,* The American Economic Review. *2003*
24. Federal Aviation Administration, *APO/OPSNET Data*, available at http://www.apo.data.faa.gov/, 2005.
25. Subcommittee on Aviation Hearing on Air Traffic Congestion in the New York City Area, July 16th 2001.
26. Bureau of Transportation Statistics, Aviation, *Airline Origin and Destination Survey DB1B*, available at: http://www.transtats.bts.gov/, last accessed: December 2004.
27. Bureau of transportation statistics, *Form 41 Traffic, T100 Domestic market,* available at http://www.transtats.bts.gov/, last accessed: November 2004.

28. U.S. Census Bureau, *2000 U.S. Gazetteer*, available at http://www.census.gov/geo/www/gazetteer/places2k.html.
29. National Aeronautical Charting Office (NACO), *Airport diagrams*, available at: www.naco.faa.gov
30. United States Department of Transportation Federal Aviation Administration, Form 5010 data, available at: http://www.gcr1.com/5010web, Last accessed: July 2004.
31. Jane's All the World aircraft, 2004-2005 Edition
32. Louis Berger Group, SH&E Consulting et al., *New England Regional Aviation System Plan Technical Paper 3*, 2003.
33. Batten F., Karlsson C., *Infrastructure and the Complexity of Economic Development,* Springer-Verlag Berlin Heidelberg 1996.
34. Montgomery B., *How Airports: How much do they cost and who pays for them?* Southwest Airlines website: http://www.southwest.com/swatakeoff/airport_cost.html.
35. Beaton E., De Armon J., et al., *New York Airspace Effects on Operations,* MITRE Corporation Technical Paper, 2000.
36. Bonnefoy P., *Emergence and Impacts of the Emergence of Secondary Airports in the United States,* American Institute of Aeronautics and Astronautics, ATIO6497, 2004.
37. Cohas Francois, *Market-Share Model for a Multi-Airport System,* Master of Science Thesis, Department of Aeronautics and Astronautics and Technology and Policy Program, Massachusetts Institute of Technology, Cambridge, MA 1993.
38. Donohue, G., Shaver, R., *United States Air Transportation Capacity: Limits to Growth,* Transportation Research Board 79th Annual Meeting, 2000.
39. United States Department of Transportation Federal Aviation Administration, *Potomac Consolidated TRACON Airspace Redesign*, 2003.
40. Stephen Dempsey P., *Airport Planning and Development Handbook: A global Survey,* McGraw-Hill, 2000.
41. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Logan_International_Airport
42. Providence airport (PVD) website, last accessed: May 2005, available at: http://www.pvdairport.com/riac/history.htm

43. Port Authority of New-York New Jersey website, last accessed: May 2005, available at: http://www.panynj.gov/aviation/lhisfram.htm
44. Port Authority of New-York New Jersey website, last accessed: May 2005, available at: http://www.panynj.gov/aviation/ehisfram.htm
45. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/EWR
46. Port Authority of New-York New Jersey website, last accessed: May 2005, available at: http://www.panynj.gov/aviation/jhisfram.htm
47. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/John_F._Kennedy_International_Airport
48. Airwise website, last accessed: May 2005, available at: http://www.airwise.com/airports/us/DCA/DCA_07.html
49. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Ronald_Reagan_Washington_National_Airport
50. Metropolitan Washington Airport Authority website, last accessed: May 2005, available at: http://www.metwashairports.com/Dulles/history.htm
51. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Washington_Dulles_International_Airport
52. Department of Transportation, Maryland Aviation website, last accessed: May 2005, available at:http://www.marylandaviation.com/welcome/bwi_timeline.html
53. Orlando airports website, last accessed: May 2005, available at: http://www.orlandoairports.net/goaa/marketing/diary.htm
54. Orlando Sanford airport website, last accessed: May 2005, available at: http://www.orlandosanfordairport.com/history.htm
55. Melbourne International airport website, last accessed: May 2005, available at: http://www.mlbair.com/b-about.htm
56. Tampa International airport website, last accessed: May 2005, available at: http://www.tampaairport.com/about/development/airport_history.html
57. St. Petersburg – Clearwater airport website, last accessed: May 2005, available at: http://www.fly2pie.com/about/history.asp

58. Sarasota Bradenton airport website, last accessed: May 2005, available at: http://www.srq-airport.com/history.htm
59. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Miami_International_Airport
60. Florida Broward County website, last accessed: May 2005, available at: http://www.broward.org/airport/about_history.htm
61. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/San_Francisco_International_Airport
62. Oakland airport website, last accessed: May 2005, available at: http://www.flyoakland.com/tex/history.shtml
63. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/San_Jose_Airport
64. Airwise website, last accessed: May 2005, available at: http://www.airwise.com/airports/us/LAX/LAX_07.html
65. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Lax
66. Burbank airport website, last accessed: May 2005, available at: http://www.burbankairport.com/begin3.htm
67. Los Angeles World Airports website, last accessed: May 2005, available at: http://www.lawa.org/ont/ontHistory.cfm
68. Orange County airport website, last accessed: May 2005, available at: http://www.ocair.com/newsandfacts/airporthistory.htm
69. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Long_Beach_Airport
70. California National Guard website, last accessed: May 2005, available at: http://www.calguard.ca.gov/sli/history.htm
71. Santa Monica airport website, last accessed: May 2005, available at: http://santa-monica.org/airport/n_airport_h.aspx
72. Airwise website, last accessed: May 2005, available at: http://www.airwise.com/airports/us/ORD/index.html

73. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/ORD
74. Chicago O'Hare Air Traffic Control website, last accessed: May 2005, available at: http://www.thetracon.com/MidwayHistory.htm
75. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/Midway_Airport
76. Airwise website, last accessed: May 2005, available at: http://www.airwise.com/airports/us/DFW/DFW_07.html
77. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/DFW
78. Dallas Love Field airport website, last accessed: May 2005, available at: http://www.dallas-lovefield.com/lovenotes/lovechrono.html
79. Houston Bush International airport website, last accessed: May 2005, available at: http://iah.houstonairportsystem.org/about
80. Houston Hobby airport website, last accessed: May 2005, available at: http://hou.houstonairportsystem.org/about
81. Wikipedia, Online Encyclopedia, last accessed: May 2005, available at: http://en.wikipedia.org/wiki/William_P._Hobby_Airport

Appendix

Appendix A: Airport Data

Appendix A-1: Airport Identifiers

ATL	Atlanta Hartsfield International
BOS	Boston Logan International
DEN	Denver International
DFW	Dallas-Fort Worth International
DTW	Detroit Metro Wayne County
EWR	Newark International
HNL	Honolulu International
IAD	Washington Dulles International
IAH	Houston Bush Intercontinental
ISP	Mc Arthur Islip Long Island
JFK	New York Kennedy International
LAS	Las Vegas McCarran International
LAX	Los Angeles International
LGA	New York LaGuardia
MCO	Orlando International
MDW	Chicago Midway
MEM	Memphis International
MIA	Miami International
MSP	Minneapolis-St. Paul International
ORD	Chicago O'Hare International
PHL	Philadelphia International
PHX	Phoenix Sky Harbor International
PIT	Greater Pittsburgh International
SAN	San Diego Lindbergh Field

SEA	Seattle-Tacoma International
SFO	San Francisco International
SLC	Salt Lake City International
STL	Lambert St. Louis International
TPA	Tampa International

Appendix A-2: Hourly Rates for 31 U.S. Airports [6]

	Airport	Optimum Rate	Reduced Rate
ATL	Atlanta Hartsfield International	185–200	167-174
BOS	Boston Logan International	118–126	78–88
BWI	Baltimore-Washington International	111–120	72–75
CLT	Charlotte/Douglas International	130–140	108–116
CVG	Cincinnati-Northern Kentucky	123–125	121–125
DCA	Washington Reagan National	76–80	62–66
DEN	Denver International	204–218	160–196
DFW	Dallas-Fort Worth International	261-270	183-185
DTW	Detroit Metro Wayne County	143–146	136–138
EWR	Newark International	92–108	74–78
HNL	Honolulu International	120–126	60–60
IAD	Washington Dulles International	120–121	105–117
IAH	Houston Bush Intercontinental	120–123	112–113
JFK	New York Kennedy International	88–98	71–71
LAS	Las Vegas McCarran International	84–85	52–57
LAX	Los Angeles International	148–150	127–128
LGA	New York LaGuardia	80–81	62–64
MCO	Orlando International	144–145	104–112
MEM	Memphis International	150–152	112–120
MIA	Miami International	124–134	95–108
MSP	Minneapolis-St. Paul International	115–120	112–112
ORD	Chicago O'Hare International	200–202	157–160
PHL	Philadelphia International	100–110	91–96
PHX	Phoenix Sky Harbor International	101–110	60–65
PIT	Greater Pittsburgh International	140–160	110–131
SAN	San Diego Lindbergh Field	43–57	38–49
SEA	Seattle-Tacoma International	90–91	78–81
SFO	San Francisco International	95-99	67–72
SLC	Salt Lake City International	130–132	95–105
STL	Lambert St. Louis International	104–112	64–65
TPA	Tampa International	110–119	80–87

Appendix A-3: Airport Theoretical Capacity [22]

i. Airport hourly capacity

From a system stand point, an airport can be modeled using flow analysis and queuing theory. At the airport level, aircraft and passengers constitute input flows that enter queues (taxiways, aprons, waiting lines for boarding and ticketing, etc.) waiting to be served by a service facility (runways for take-off and landing, gates, ticket counters, boarding gates, etc.) and ultimately leave the system. Each service facility has a finite capacity to serve its incoming flow. As the airport is defined as a network of servers, the overall airport has a finite capacity.

Because runways are usually the most constraining component in an airport system, and since runway capacity is measured in number of operations handled in a specific time period, this metric generally defines the overall airport capacity. This airport throughput is both defined for incoming and outgoing aircraft. The Average Arrival Rate (AAR), often measured by hour, reflects the number of aircraft that can land during one hour, while the Average Departure Rate (ADR) defines the number of aircraft that depart in one hour. These rates are specific to an airport and are directly function of airport characteristics such as:

- number of runways at this airport,
- runway configuration at a specific time,
- weather conditions (Instrument Meteorological Conditions IMC, or Visual Meteorological Conditions VMC). Arrival and departure rates are given as a function of the weather conditions, because low ceilings and visibilities (IMC) significantly reduce the capacity of the airport, by increasing the authorized separation minima. In fact, modes of operation such as parallel runway approaches that are authorized in VMC become prohibited in IMC. This restriction significantly reduces the airport capacity in IMC.
- mix between AAR and ADR, as runways can be used for both departure and arrivals.

In 2001, the FAA established, in the Capacity Benchmark Report [6], the hourly rates for both VMC (optimum rate) and IMC (reduced rate) for 31 U.S. major airports.

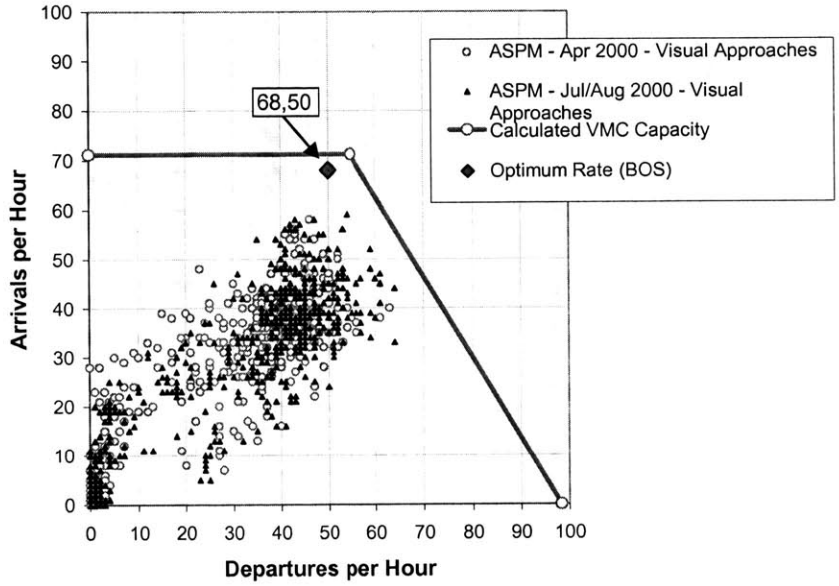


Figure 51: Departure and arrival hourly rates at Boston Logan airport[1]

An example of a more detailed analysis of the different combinations of arrivals and departures actual rates for Boston Logan airport is shown on Figure 51. Because the actual sequence of aircraft movements, both arrivals and departures, are dictated by the airlines scheduling, the mix of departure and arrivals is usually not 50/50. This is especially true at airports that are operated as connecting hubs, and that are not de-peaked. In this case, large and out-of-phase waves of departures and arrivals can significantly unbalance this hourly mix.

Figure 51 shows the hourly rate of departure and the arrivals at Boston Logan airport for several months. From this plot a Pareto envelope is defined as the boundary of departure/arrival mix. This boundary defines two regions. The inner region corresponds to the set of combination of arrivals/departures rates that are achievable. The outer region represents an unachievable set of rates mix, due to airport capacity and configuration. In the case of the Boston Logan airport, the maximum hourly arrival rate is 72 (Figure 51). The

[1] Source: United States Department of Transportation, Federal Aviation Administration, Airport Capacity Benchmark Report, 2001.

maximum rate of departures –only departures- is approximately 100 movements per hour. When arrivals are included in the flow of departures the rate of departures drops gradually. The optimum and reduced rates for 31 airports in the United States are given in Appendix A. For example, Dallas Forth-Worth (DFW) airport handles between 261 and 271 aircrafts (arrivals or departures) in good weather conditions. However, the capacity drops to 183-185 operations per hour in Instrument Meteorological Conditions (IMC). Smaller airports like San Diego (SAN) with only a single runway can handle 38 to 57 operations per hour depending on the meteorological conditions.

ii. General method for computing airport annual capacity

From the hourly rates of arrival and departure, a theoretical annual capacity can be derived [22]. However, several factors need to be taken into account.

- The fraction of time an airport is under IMC or VMC condition affects the airport throughput. In fact, the FAA gives both optimal (in VMC conditions) and reduced (in IMC conditions) hourly rates.
- Airports are only operating during a certain period of time during the day. Therefore, effective capacity should not be computed during night hours.
- As airports are not uniformly operated during the week days and week-end days, a weekly adjustment of effective capacity is required.

The theoretical annual capacity for a specific airport is expressed as:

$$\textbf{Annual Capacity}_{(\text{Airport } i)} = [(HR_{VFR\,i} \times f_{VFR\,i}) + (HR_{IFR\,i} \times f_{IFR\,i})] \times 24 \times 365 \times C_{day} \times C_{week}$$

with:

- HR_{VMC} : Optimum Hourly Rate (in VMC conditions)
- HR_{IMC} : Reduced Hourly Rate (in IMC conditions)
- f_{VFR} : Fraction of the time in VMC conditions
- f_{IFR} : Fraction of the time in IMC conditions
- C_{day} : Correction factor for daily operations adjustment
- C_{week} : Correction factor for weekly operations adjustment

Application: Example of Boston Logan (BOS)

Variable	Value	Comment
HR_{VMC}	107	[movements/hour]
HR_{IMC}	98	[movements/hour]
f_{VFR}	82%	
f_{IFR}	18%	
C_{day}	0.67	Corresponds to a concentration of activity during 16 hours per day (16/24) between 06:00AM and 10:00PM.
C_{week}	0.9	Accounts for the reduced activity during the week-end (over the 06:00AM to 10:00PM period)
Annual Capacity	604335	[movements/year]

iii. Airport utilization ratio and relation with delays

The computation of annual airport capacity from the hourly airport capacity requires certain assumptions as presented in the previous section. In order not to have to assume correction factors for night and day activity unbalance, utilization ratios can also be computed with a reduced time window of observation, for example using operations occurring during 07:00 to 22:59 only. The theoretical annual capacity was also defined for this time window. In this case, the airport utilization ratio is defined for the period 07:00 to 22:59 as follow:

$$\rho = \frac{Total\_Annual\_Operations_{\_from\_0700\_to\_2259}}{Annual\_Capacity_{\_from\_0700\_to\_2259}}$$

With this formulation, we do not need to assume any correction factor for the capacity, as the correction is implicitly performed on the total operations (as we only select operations that occur during the 07:00 to 22:59 period). FAA delay data[1] of total annual operations and the theoretical annual capacity was used to compute the airport utilization factor. For each airport a utilization ratio was computed and plotted against the observed delays at this airport.

As an airport can be modeled as a network of queuing systems, we can approximate the general relation between the delays and the utilization ratio as an M/G/1 system. M/G/1 is the standard notation in queuing theory for single server system with memory less (M) behaviour of the arrivals and general (G) law for the service response. Figure 52 shows the percentage of flight delayed versus the utilization ratio.

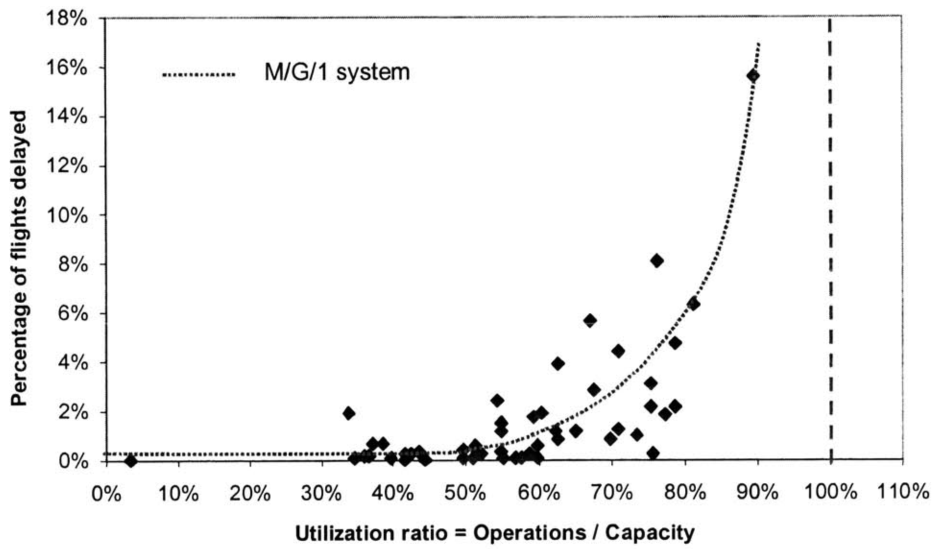


Figure 52: Airport utilization ratio and delays[2]

In this case, the approximation by the M/G/1 systems seems reasonable. From the general behavior of the M/G/1 system we can anticipate the impact of a variation of the number of operations. The closer an airport is run to its limit capacity, the higher the amount of delays. In addition, this trend is nonlinear, the higher the airport utilization ratio, the greater the effect. For example, an increase of the airport utilization ratio from 60% to 61% leads in an increase in delays of about an average of 1 extra delay per 1000 flights.

---

[1] FAA/APO Aviation policy and Plans, *OPSNET databases*, [URL: http://www.apo.data.faa.gov, last accessed: May 2005]

[2] Data source: FAA/APO Aviation policy and Plans, *OPSNET databases*, [URL: http://www.apo.data.faa.gov, last accessed: May 2004]

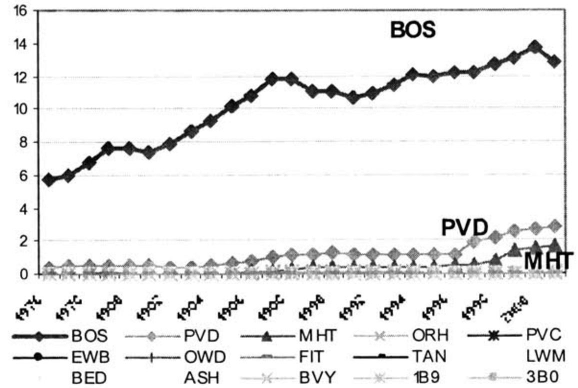
However, increasing the utilization ratio from 90% to 91% now generates about 10 extra delays per 1000 flights. As capacity is fixed (in the short term), increasing the number of operations at an airport that has already high utilization ratio generates disproportionate effects in terms of delays.

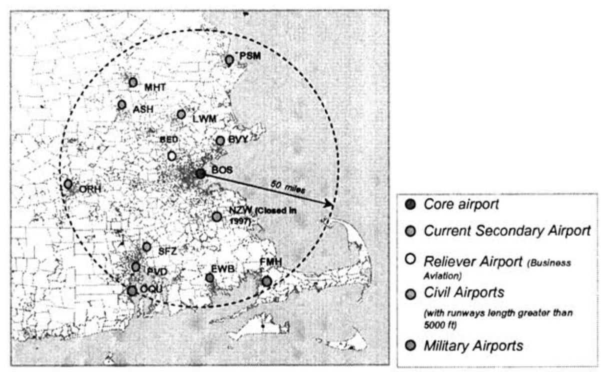
Appendix B: Multi-airport systems

Appendix B-1: Boston Regional Airport System

Overview:

The Regional Airport System surrounding Boston Logan airport was found to be composed of one core airport; Boston Logan representing 76% of the regional passenger traffic and two secondary airports Providence (PVD) and Manchester (MHT) representing respectively 15% and 8% of the regional passenger traffic. Providence airport (PVD) and Manchester airport (MHT) are located respectively 45 miles south-west and north-west of Boston city. The remaining 2% of traffic were distributed between New Bedford (EWB), Worcester (ORH), Bedford (BED) and Pease (PSM). Based on the definition of airport categories established in Chapter 2, no emerged core airport was identified in the Boston region. BOS was and still remains the original core airport in the region.



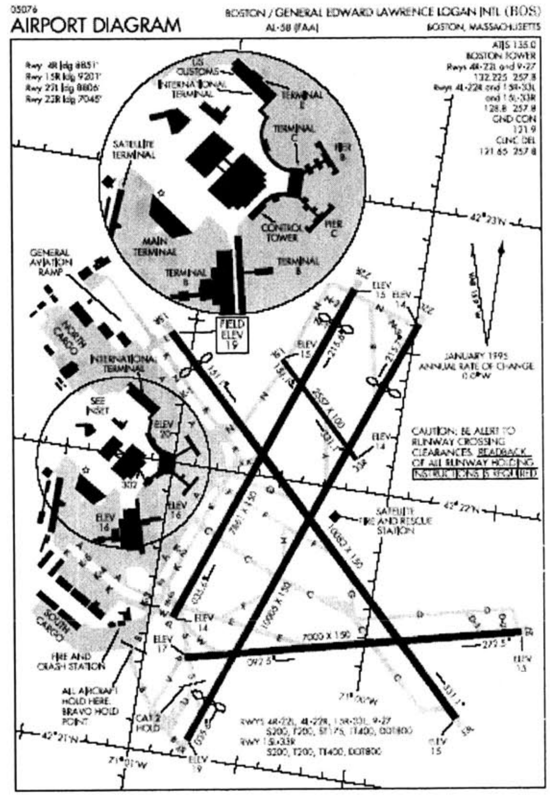


Core airport (Original and Emerged)	Traffic Share	Secondary airport	Traffic Share
Boston (BOS)	**76%**	Providence (PVD)	**15%**
		Manchester (MHT)	**8%**

Airport history:

Boston (BOS) [41,29]

Boston airport opened on September 8, 1923 as the result of a funding campaign led by the local business community interested in developing the airport for air mail services. At its beginning, the airport was also used by the Massachusetts Air Guard and the Army Air Corp. It offered its first scheduled commercial passenger flights in 1927 between Boston and New York city. Initially, the runways were only 1500ft long but they were lengthened in 1928. The airport also received several improvements such as, paved access roads, new administration building, etc. Traffic grew in the 1930s despite the Great Depression. At the beginning of World War II, in 1941 the airport airside land area was expanded by 1,800 acres by the further filling of Boston Harbor. Additional runways, apron areas and three new hangars were built. Originally, designated as Boston airport, it changed name in 1943 for General Edward Lawrence Logan Airport.



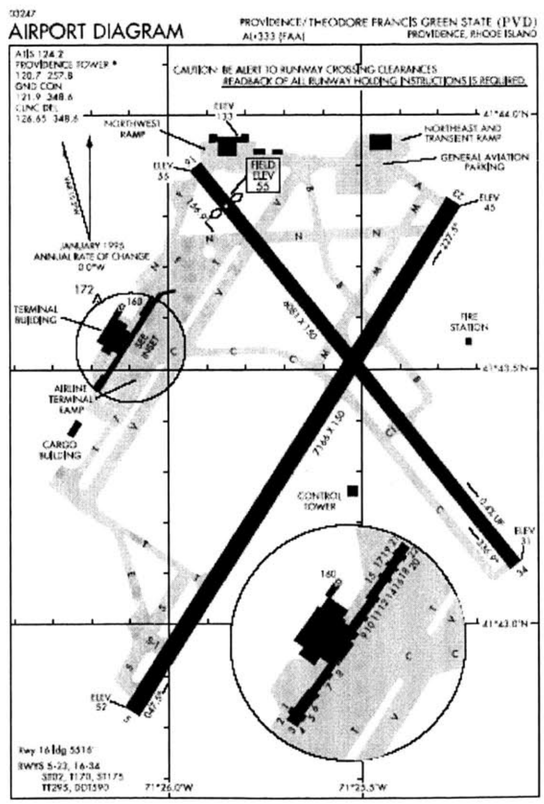
In the 1950s the airport received several infrastructure improvements such as loop access roadway system, runways and gates so that at the end of the 1950s, the airport featured 4 runways and 45 gates. From an airline service perspective, the 1950s were time of improvements. In the 1940s only two airlines were operating at Logan serving mostly the North East part of the United States. In the 1953 the first non-stop transcontinental flight was introduced. In 1959, Pan American started offering daily flights to Europe with the 707. In the 1960s, the airport received major improvements including the construction of the International Terminal, extension of runway 15R/33L, to accommodate the movement toward larger aircraft. In the 1970s, major improvements continued with a new

285 foot control tower in 1973, a new terminal (Terminal E) and additional land fill of 234 acres allowing the construction of cargo and other facilities.

After several decades of continuous expansion, the 1980s were time for addressing environmental concerns with the soundproofing of classrooms in East Boston in addition to thousands of homes.

In the 1990s improvements of the airport focused on increasing Logan's efficiency without expanding the airport's borders or compromising on environmental benefits for its neighbors by performing several improvements. Today, Logan is scheduled to receive an additional runway (14/32) which is part of the OEP improvements [13] which will improve Logan's capacity in North West wind conditions.

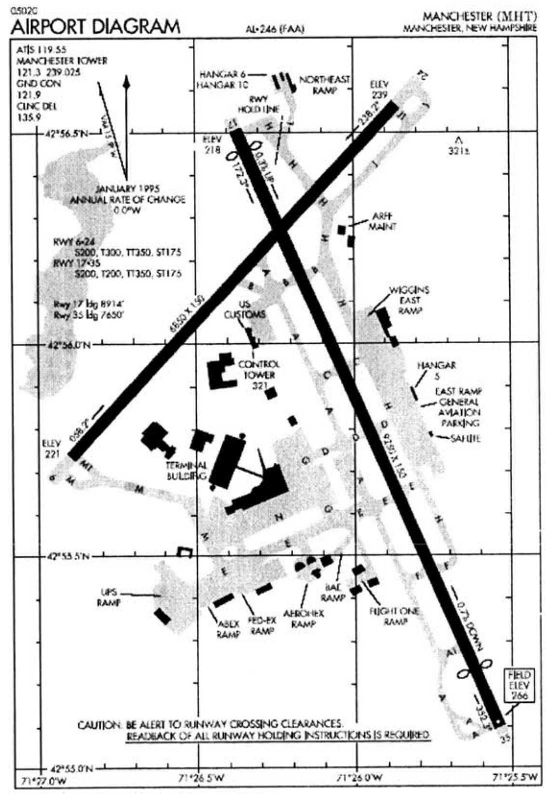
Providence (PVD) [42,29]



Originally, named Hillsgrove State Airport, the airport was dedicated on September 27th 1931. In 1935, cement runways (3000 ft long) were added. In 1938, the airport was renamed Theodore Francis Green State Airport after Rhode Island's Governor from 1933-1937. In the early 1940s, the airport became Hillsgrove Army Air Base, an Air Force fighter base and a transition-training base for officers. After the end of World War II in 1945, Hillsgrove Airport was returned to the state of Rhode Island. The 1960s were the time for significant improvements at the airport. A new airport terminal opened and runways were expanded. In 1993, the Rhode Island Airport Corporation (RIAC) was created replacing the Division of Airports , a public agency, fully owned and operated by the State of Rhode Island. Additional infrastructure improvements were made to Providence airport in 1995 with the construction of the current airport terminal (Bruce Sundlun Terminal Building). In 1996, Southwest entered service at Providence airport, leading to significant growth in passenger traffic. In 2001, the airport handled 2.7 million enplanements.

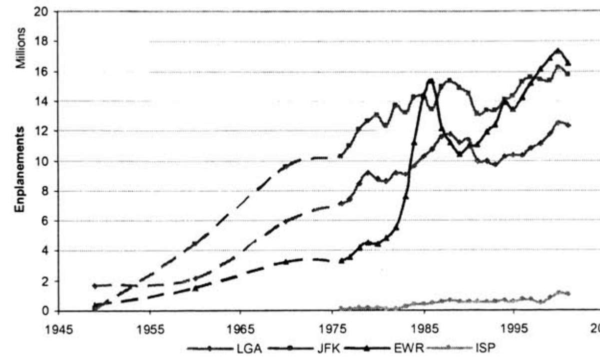
Manchester (MHT) [29]

Manchester airport was dedicated in 1927 and was the first commercial airport in New Hampshire. During World War II, the airport played an important role as a pilot training base. The passenger traffic remained very weak until the late 1990s when Southwest entered service at the airport and triggered the emergence of the airport as a successful secondary airport in the region. In 2000, the airport handled 1.5 million enplanements accounting for 8% of the regional passenger traffic.



Appendix B-2: New York Regional Airport System

Overview:



The New-York airport system remains the most complex and mature multi-airport system in the country. In the 1920s, Newark airport was the largest commercial airport in the metropolitan area. However, it was closed in 1939 as traffic decreased as a result of the opening of La Guardia airport. La Guardia airport was the only major commercial airport in the New-York metropolitan area until the emergence, in the early 1950s of New York International airports that was renamed John F Kennedy International airport in 1963. By the beginning of the 1980s, JFK had reached its mature state. In the mid 1980s, the entry of a low-cost carrier (People Express) initiated the emergence of Newark airport (EWR). In 1988, the failure of this airline created a significant decrease of traffic. However, the airport was in place and able, over the 1990s, to accommodate a significant fraction of the air transportation growth in the New York region. Both JF Kennedy airport and Newark are considered as emerged core airport since they have passenger traffic share that now exceed (34% and 37% respectively) the traffic share of La Guardia airport (27% passenger traffic share). In 2000, La Guardia capacity crisis[1] highlighted the overall capacity of the airport system was inadequate. In 2001, the entry of Southwest at Islip (ISP) induced a significant increase of traffic at this airport. The airport had a 2% passenger traffic share in 2001 and therefore meets the 1% traffic share criterion. This airport is the latest secondary airport in the regional airport system.

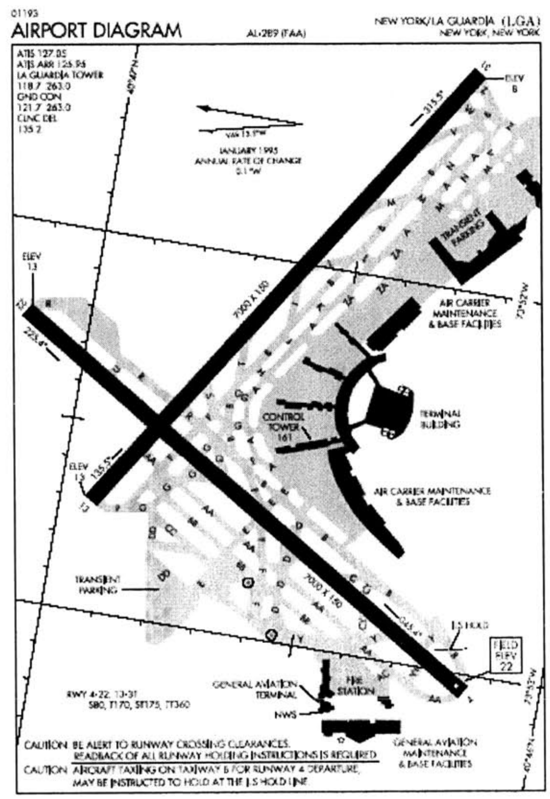
Core airport **(Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
La Guardia (LGA)	**27%**	Islip (ISP)	**2%**
Newark (EWR)	**37%**		
JF Kennedy (JFK)	**34%**		

[1] Greater details on the La Guardia capacity crisis are presented in Chapter 1.

Airport history:

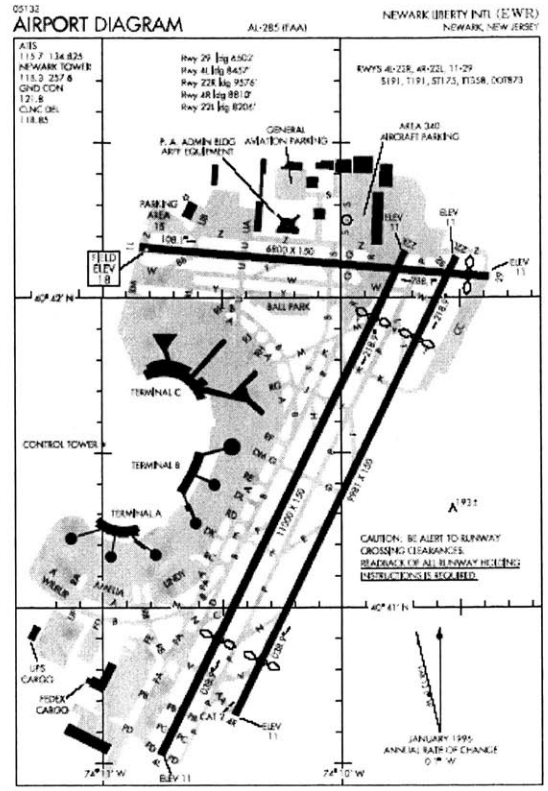
La Guardia (LGA) [43,29]

LaGuardia Airport was built, in 1929, into a 105-acre private flying field. It was dedicated on October 15, 1939 as New York City Municipal Airport and later that year its name was changed for New York Municipal Airport-LaGuardia Field. The airport was open to commercial traffic on December 2, 1939. It was then renamed LaGuardia Airport in 1947. During the 1960s, several improvements were made to the airport such as the construction of a new Central Terminal Building, that was opened in 1964. A new 150-foot control tower was also opened on May 1964. The runways were also extended over water to 7,000 ft and 150 ft wide in 1967. The configuration of the airport did not significantly evolve since the 1960s and still features two runways of 7000 feet by 150 ft.



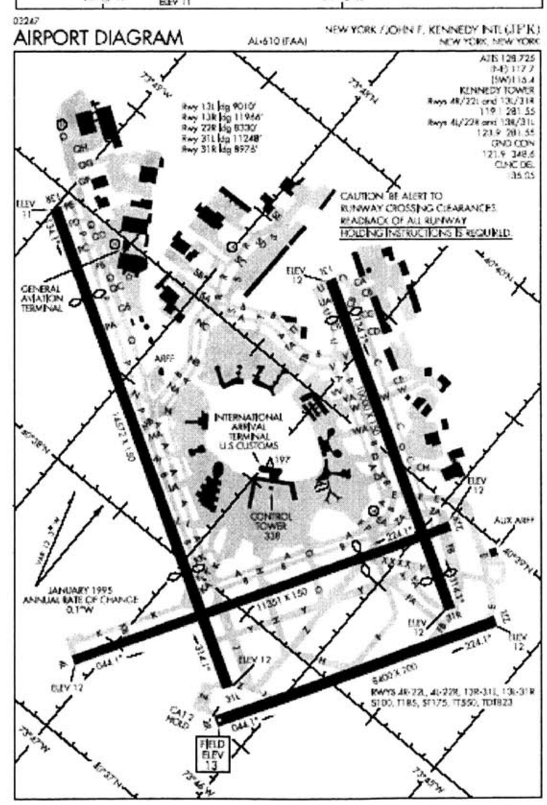
Newark (EWR) [44,45,29]

Newark Airport was opened on October 1, 1928. It was in fact the first major airport in the metropolitan areas in the 1920s and 1930s until the opening of La Guardia airport in 1939. Traffic then shifted to La Guardia as Newark was closed to passenger traffic and taken over by the United States Army Air Corps during World War II. The Port Authority of New York and New Jersey took over the airport in 1948. In the 1950s, major investments were performed including the opening of a new instrument runway, a new terminal building a control tower and an air cargo center. The Central Terminal Area was constructed and opened in 1973. A new runway 4L/22R was built in 1970 and the previously existing runway 4-22 was rebuilt and renamed 4R-22L in 1973. The airport remained underutilized in the 1970s, but the entry of People Express in 1981 generated tremendous growth in passenger enplanements and ultimately propelled the airport to the largest airport in the region in terms of passenger traffic, above JF Kennedy and La Guardia.



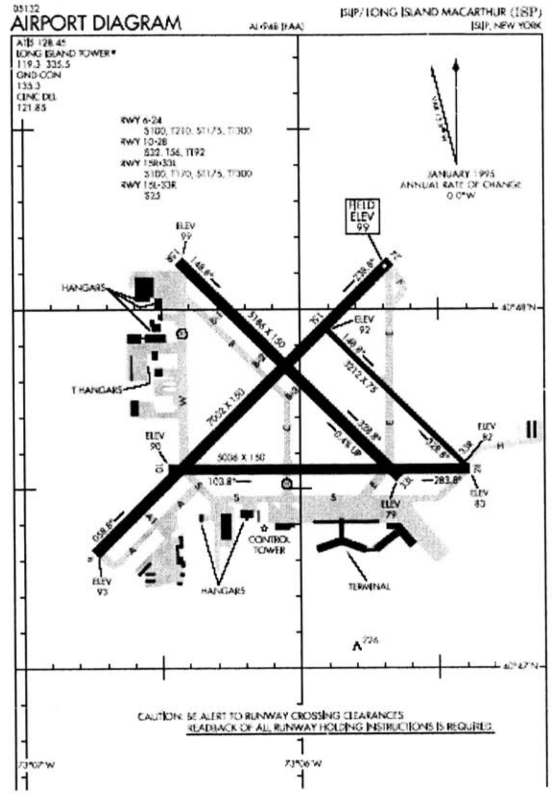
JF Kennedy (JFK) [46,47,29]

The airport construction started in April 1942 and was originally named Idlewild airport after the name of the golf course it was built on. The airport was opened to commercial traffic in July 1948 and dedicated as New York International Airport. Since 1948 the airport featured only one terminal until 1957 when a new international arrivals terminal was built. In the 1960s, several ground side improvements were made with the opening of eight new terminals. The airport was also re-dedicated on December 24 1963 as John F. Kennedy International Airport and received the new IATA airport code of JFK replacing IDL. Today, the airport features four runways in two parallel pairs that surround the central terminal area.



Islip (ISP) [29]

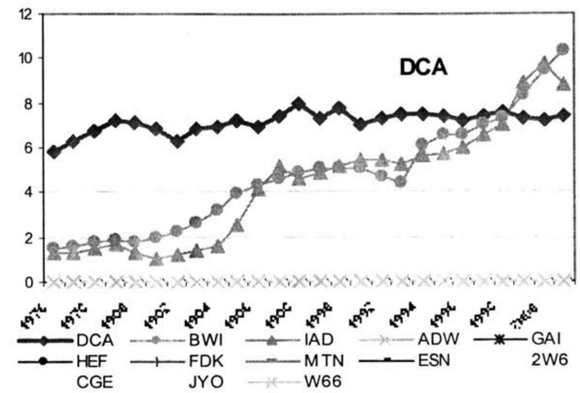
Macarthur Airport is located in Islip, New York about 45 miles east of La Guardia airport. Until 1999, the airport was only served by American Airlines and US Airways. In 1999, Southwest Airlines entered service at the airport and soon became the dominant carrier at this airport. In 2003, Southwest airlines represented about 80% of the airport market share in terms of movements. In 2000, the airport handled 1.1 million enplanements and accounted for 2% of the New York regional passenger traffic.



Appendix B-3: Washington Regional Airport System

Overview

As of 2000, the Washington regional airport system was composed of three core airports: Washington National airport (DCA) that accounted for 27% of the regional passenger traffic and located in the center of Washington City, Baltimore airport (BWI) north of the Washington City with 36% of the regional traffic and



Washington Dulles airport located west of the metropolitan area and that had the largest share of traffic with 37%. Dulles and Baltimore are considered as core airports in the region and not secondary airports due to their relative size compared to Washington National. The Washington regional airport system is then a multi-core airport system with no secondary airport.

Core airport (**Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
Washington Nat. (DCA)	**27%**		
Baltimore (BWI)	**36%**		
Dulles (IAD)	**37%**		

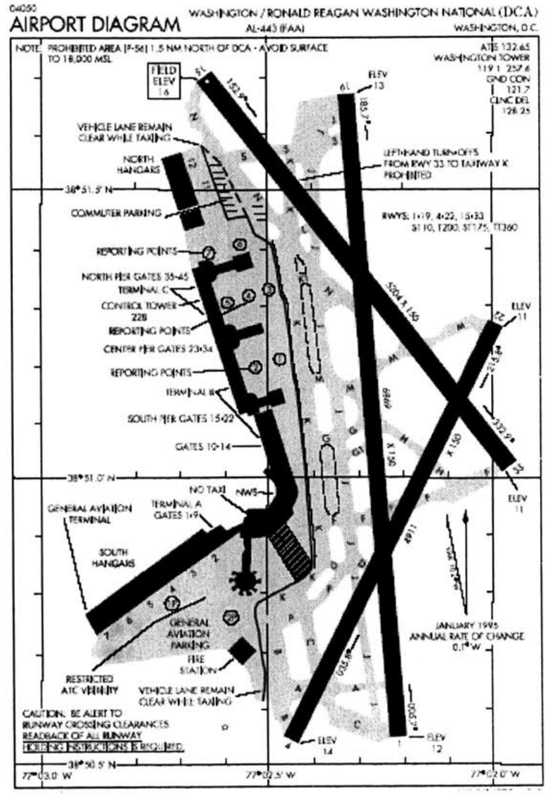
Note: - Core airports in bold characters are emerged core airports

Airport history:

Washington National (DCA) [48,49,29]

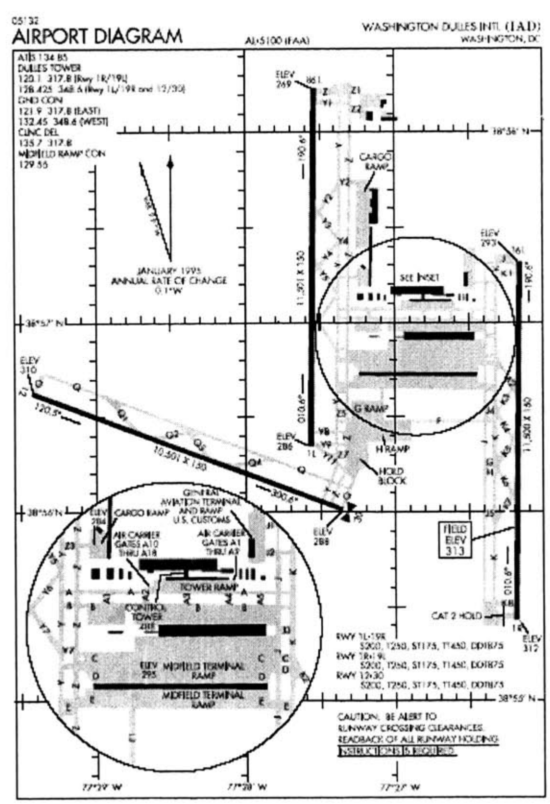
Washington National airport opened on June 16, 1941 as a replacement for Washington-Hoover which was located on the current site of the Pentagon. It was built on mudflats alongside the Potomac River, 4½ mile south of Washington, D.C. From an infrastructure perspective, Terminal A was the original terminal at National Airport. It was expanded over the following years and reached its current size in 1955 with a final expansion phase. By 1979, political factors strongly affected the proper development of

Washington National. This airport along with Dulles Airport, were the only two airports in the United States under government control and the airport faced issues due to increase in traffic and limited funds for expansion since revenues went to federal budgets. In the 1980s, Secretary for Transportation Elizabeth Hanford Dole managed to have the transfer of authority from Congress to the new and independent Metropolitan Washington Airports Authority. The new authority was put in place by President Ronald Reagan in 1987. The benefits of this political battle were reflected in the opening of new Terminal B and C that opened a decade later in 1997. In February 1998, President Bill Clinton signed a legislation changing the airport's name from Washington National Airport to Ronald Reagan Washington National Airport.



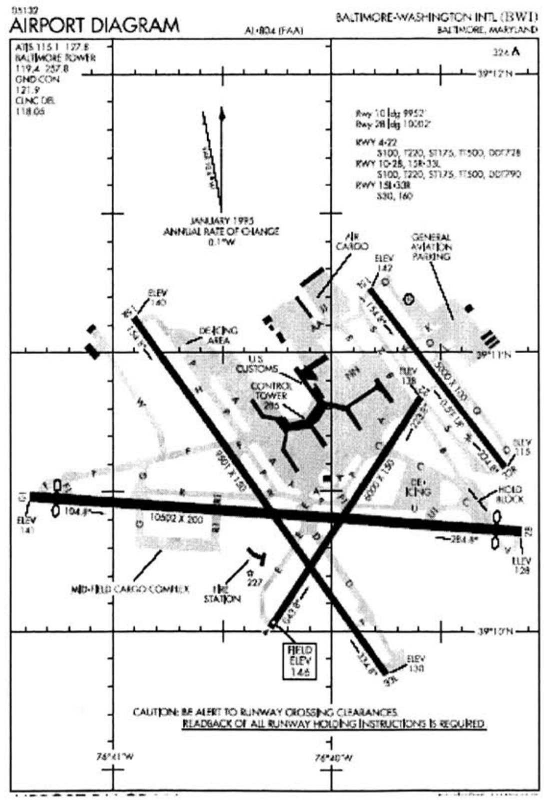
Dulles (IAD) [50,51,29]

After the end of World War II, the need to open a new airport was felt in order to meet the growing demand for air transportation. Congress passed the second Washington Airport Act of 1950 that was amended in 1958. The airport site was selected 26 miles west of Washington, D.C. The construction of the airport started in September 1958 and opened, four years later, in 1962 by President John F. Kennedy and named Washington Dulles airport. Originally, it featured



two north-south parallel runways, each 11,500 feet long and separated by 6,700 feet and a third northwest-southeast runway, 10,000 feet long. The original terminal was a compact, two-level structure; 600 feet long and 200 feet wide. In addition to airport infrastructure, a new access highway as part of the airport development project was constructed providing good ground connectivity. The first expansion was completed in November 1977 with the widening of the jet parking ramp. In 1982, terminal improvements were performed in order to accommodate more passengers. In 1998, the first permanent concourse was completed and a concourse for regional aircraft opened in 1999. In 2001, Dulles airport was the largest airport in the region with 10.3 million enplanements, ahead of Baltimore airport with 8.8 million enplanements and Washington National airport with 7.4 million enplanements.

Baltimore (BWI) [52,29]

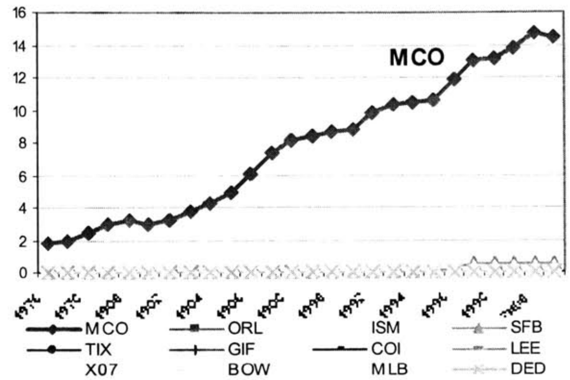


Baltimore airport is located in the state of Maryland, 10 miles south of Baltimore, and 30 miles north of Washington, D.C. It was originally named Friendship Airport when it was dedicated in 1950 by President Harry S Truman. In 1973, it was renamed Baltimore/Washington International Airport. Major infrastructure improvements were performed started in 1974 and were completed in 1979 and included the remodeling of the terminal that more than doubled in size to 635,000 square feet in addition to increasing the number of gates from 20 to 27. In 1980, the airport was connected to the rail network of the Northeast corridor. It became the first airport in the U.S. to have a rail station on airport grounds. From an airport access perspective, the opening of the Interstate I-195 in 1990, connecting the airport to I-95, greatly improved access from both the Washington and Baltimore areas. In 1993, Southwest Airlines selected Baltimore as its first east coast gateway airport which led to record-breaking passenger growth of 40% the first year and 36% the second year. Due to the traffic increase triggering the need to expand the airport, the airfield capacity was boosted with completion of an extension to runway 10-28. In 2000, Baltimore airport started a five-year, $1.8 billion expansion and improvement plan.

Appendix B-4: Orlando Regional Airport System

Overview

The regional airport system surrounding Orlando Airport (MCO) is composed on three core and secondary airports. MCO is considered as the core airport in the region with 95% of the regional passenger traffic. Two secondary airports were found in the region; Orlando Sanford (SFB) that handled 3% of the traffic in 2000 and Melbourne airport (MLB) with a 2% regional traffic share.

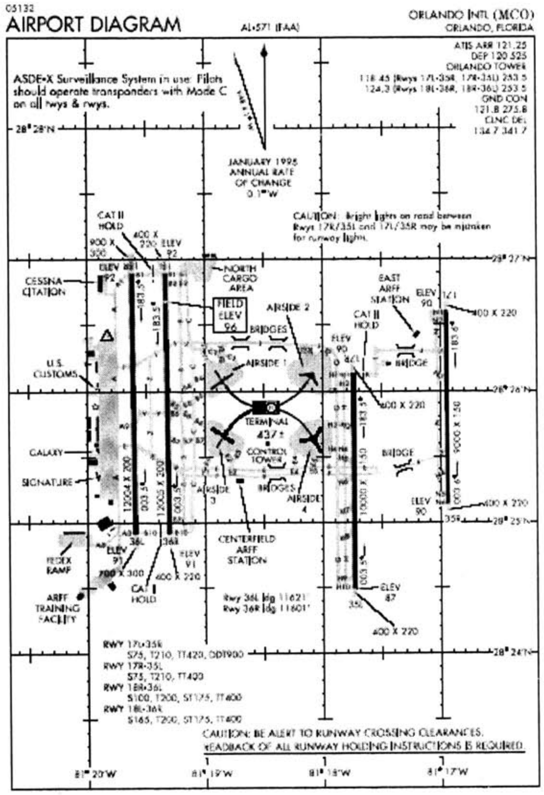


Core airport (Original and Emerged)	Traffic Share	Secondary airport	Traffic Share
Orlando (MCO)	**95%**	Orlando Sanford (SFB)	**3%**
		Melbourne (MLB)	**2%**

Airport history:

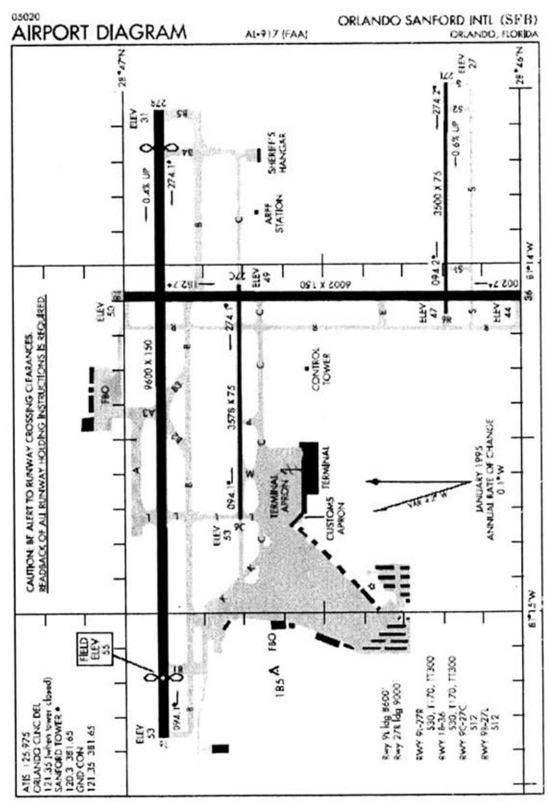
Orlando (MCO) [53,29]

Before 1974, the airport was known as the McCoy Air Force Base. The Air Force Base was closed in 1974, however, Delta airlines, Eastern Airlines, National Airlines, and Southern started scheduled service at the airport in 1970. The airport changed name to Orlando International airport when it gained international airport status in 1976. Eastern Airlines used Orlando as a hub during the 1970s and early 1980s. In 1983, airport improvements were made with the construction of the international concourse that opened a year later in 1984. In 1988, bonds were issued for $430 million for the Phase II Capacity Improvement Program. A third runway was opened in 1989 resulting in the increase of the capacity of the airport. In 1999, the approval for the construction of a fourth runway 17L/35R was received leading to the successful opening of the runway in 2003.



Orlando Sanford (SFB) [54,29]

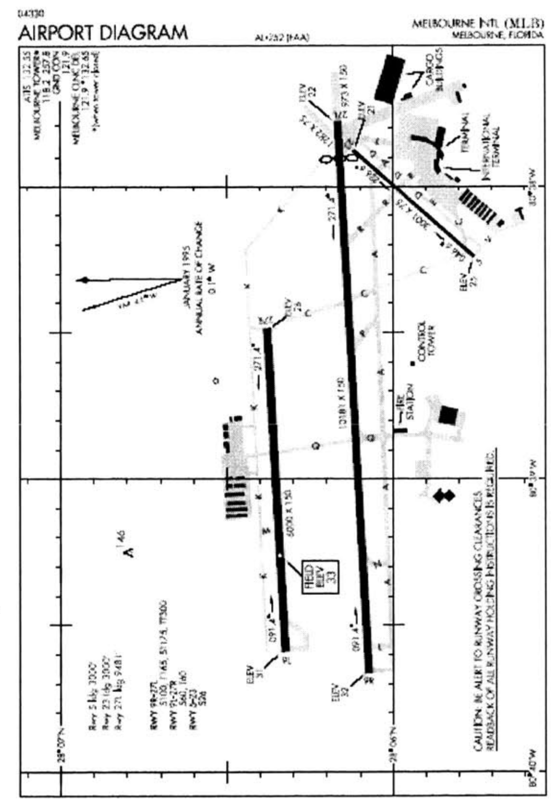
The Orlando Sanford Airport began its history prior to the 1940s as an 865-acre airport equipped with two runways. On June 11, 1942, the City of Sanford deeded the Airport to the U.S. Navy and the Airport became a Naval Air Station. After World War II, the Naval Air Station was decommissioned in 1946. The City of Sanford reacquired the land and the facility was named the Sanford Airport. After the Korean War began in 1951, the Navy once again acquired the airport. The airport operated as a training base for fighter, attack, and reconnaissance aircraft until it closed in June of 1968 and the City of Sanford reacquired the airport and took the operational



control. In 1971, the Sanford Airport Authority was created and became responsible for the operation, maintenance, and development of the airport. A master plan update was completed in January 1995, and revised in 1997 and that included the development of infrastructure such as, a main runway extension, the construction of an international arrivals building, taxiway improvements, and new navigation and approach systems, etc.

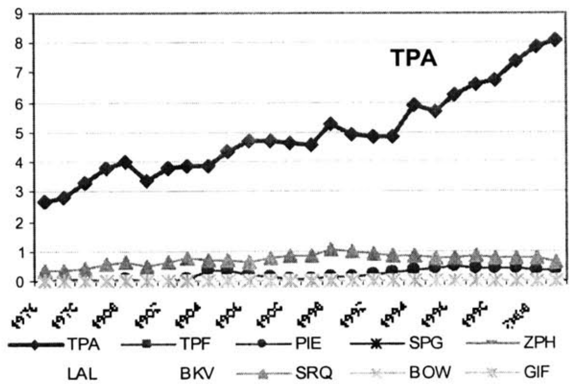
Melbourne (MLB) [55,29]

Melbourne International airport's origin can be traced back to 1928 when it was used as a fuel stop for airmail service. In 1933, the City of Melbourne acquired 160 acres of land in order to develop the airport. Additional developments of the airport were performed when it was operated as a Naval Air Station during World War II. After World War II, the airport returned to the city of Melbourne, in 1947, and was operated as a municipal airport until 1967. The same year, the Melbourne Airport Authority was created with the role of planning, operating, maintaining, and developing the airport. It now features two major parallel runways of which the longest is 10,181 ft long, 8 gates, 7 jet ways, etc. There are plans to increase the length of the main runway to 11,600 ft.



Appendix B-5: Tampa Regional Airport System

Overview:



The Tampa airport system was found to be composed of three airports. Tampa International airport is by far the largest airport in the region with 88% of the regional passenger traffic share in 2000. It is followed by Sarasota airport that accounted for 8% of the regional passenger traffic share. The third airport in terms of size in the region was founded to be St. Petersburg airport that captured 4% of the regional passenger traffic in 2000.

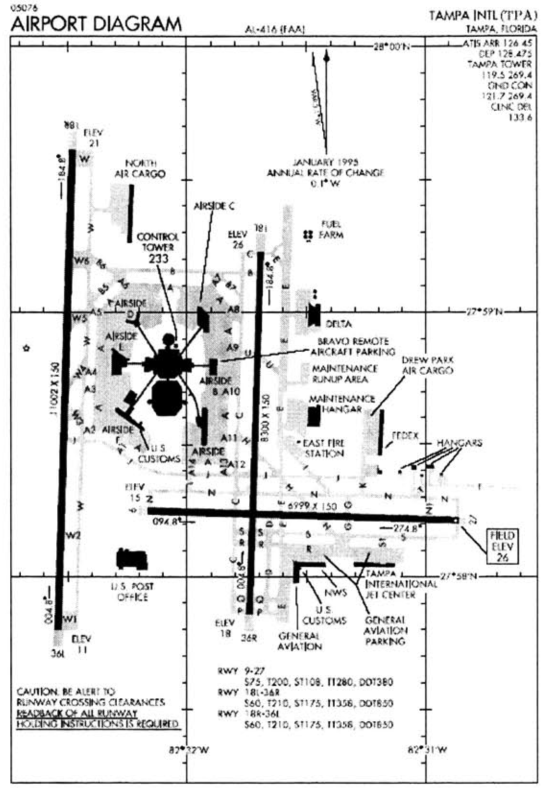
Core airport (Original and Emerged)	Traffic Share	**Secondary** airport	Traffic Share
Tampa (TPA)	**88%**	St Petersburg (PIE)	**4%**
		Sarasota (SRQ)	**8%**

Airport history:

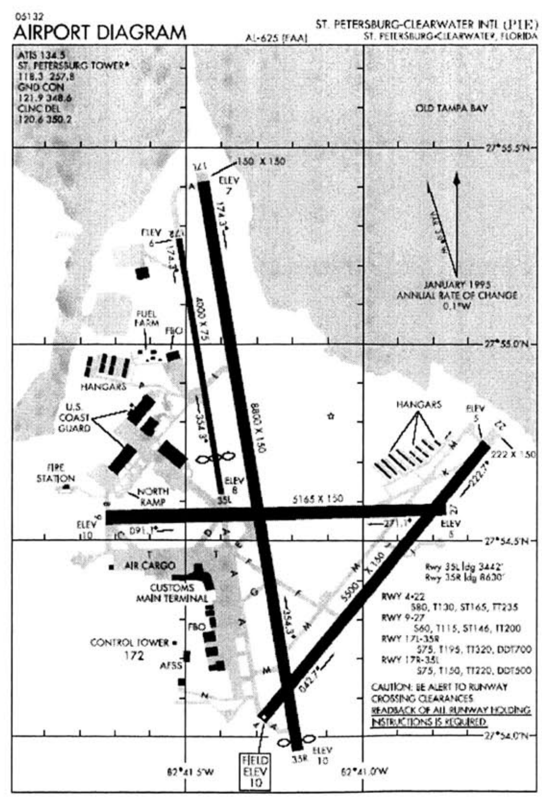
Tampa (TPA) [56,29]

Tampa international airport officially opened on April 15 1971. After its first full year of operations, Tampa international airport reported 4 million passengers. In 1972, infrastructure developments were performed with the construction of a 207-foot control tower, ground level equipment, and radar rooms. In addition, in 1976, the main north-south runway reopened after a $4 million reconstruction project was completed. Two year later it was extended from 8,700 feet to 11,000 feet. The expansion was necessary to accommodate aircraft flying trans-Atlantic routes. In 1981, ground side improvements were made with the construction of terminal parkway system and opened in 1982. In 1985, planning began for the construction of the fifth airside terminal which featured 15 gates. It was dedicated in

1987. Additional improvements were performed in the following years with the new Long Term Parking Garage that opened in 1991, with 4744 additional parking spaces. In 1995, the sixth and latest airside terminal officially opened. It included 235,000 square foot of terminal space and 15 gates, including two specifically designed for commuter aircraft. In 1997, the airport went through a renovation phase with the renovation of its Airside F and its longest runway. These renovations were followed with the beginning of the demolition of Airside E in 2000 and reconstruction which led to the opening of the new Airside E in 2002.

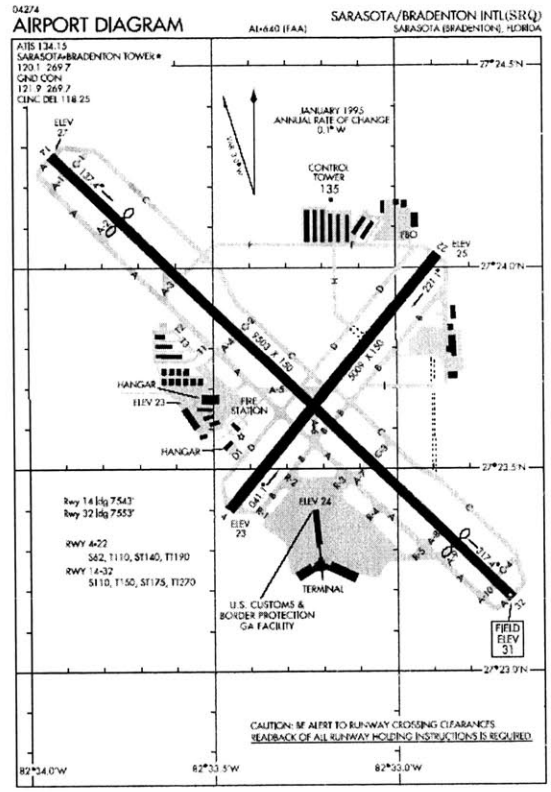


St Petersburg (PIE) [57,29]



St Petersburg airport is located on the west shoreline of Tampa Bay north of St. Petersburg. Even though the origin of commercial air transportation on the area can be traced back to 1914, with the air service provided by St. Petersburg-Tampa Airboat Line, the construction of the St. Petersburg-Clearwater International airport at its present site started in March 1941. It started as a military flight-training base. Since the 1940s, the airport went through several phases of expansion and improvements. The airport now features three intersecting runways of 8800 ft, 5500 ft and 5165 ft long and is spread over 2000 acres of land which are designated as a Foreign Trade Zone

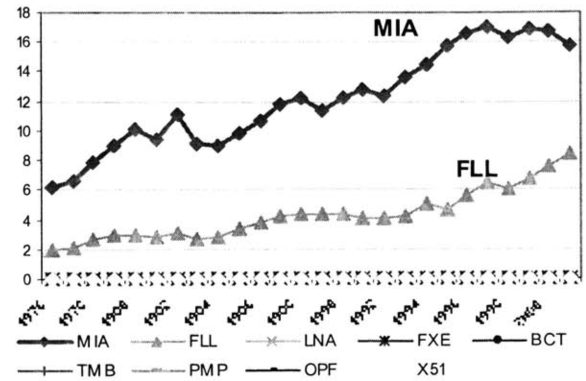
Sarasota (SRQ) [58,29]



Sarasota airport beginnings can be traced back to 1939 when government and business leaders from Sarasota and Manatee counties agreed to construct an airport together, designed to serve the aviation needs of the two-county area. A 620-acre site was selected on the Sarasota-Manatee County line. In 1941, the airport was named Sarasota Bradenton Airport and the construction was completed by early 1942. The Army Air Corps used the airport as a fighter pilot training base during World War II and then returned it to the authority in 1947. In 1955, the Florida Legislature passed the Sarasota Manatee Airport Authority Act that gave authority to maintain and improve the facilities as necessary, adopt bylaws, policies, and procedures to operate the airport, etc. Several improvements were made to the airport following the Sarasota Manatee Airport Authority Act, such as the opening of a new terminal building in 1959, parallel taxiway and runway overlay construction in 1963, and a runway extension in the early 1970s. The main runway was extended to its actual length in 2002. In 2000, the airport handled 760,000 enplanements over the year, accounting for 8% of the overall Tampa regional passenger traffic.

Appendix B-6: Miami Regional Airport System

Overview

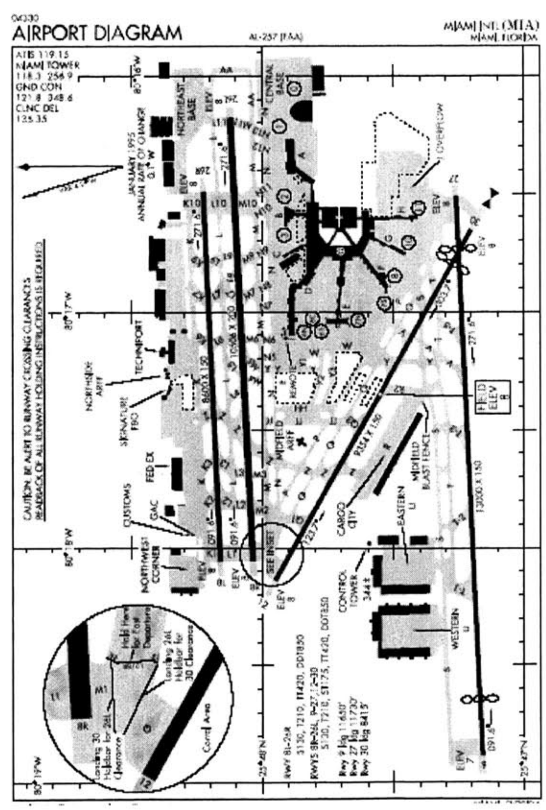


The Miami airport system is composed of two key airports. Miami International airport is considered as the core airport in the region with 69% of the passenger traffic share in the region. North of Mimia, Fort Lauderdale airport is the secondary airport in the region with 31% of the regional airport traffic.

Core airport **(Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
Miami (MIA)	**69%**	Fort Lauderdale (FLL)	**31%**

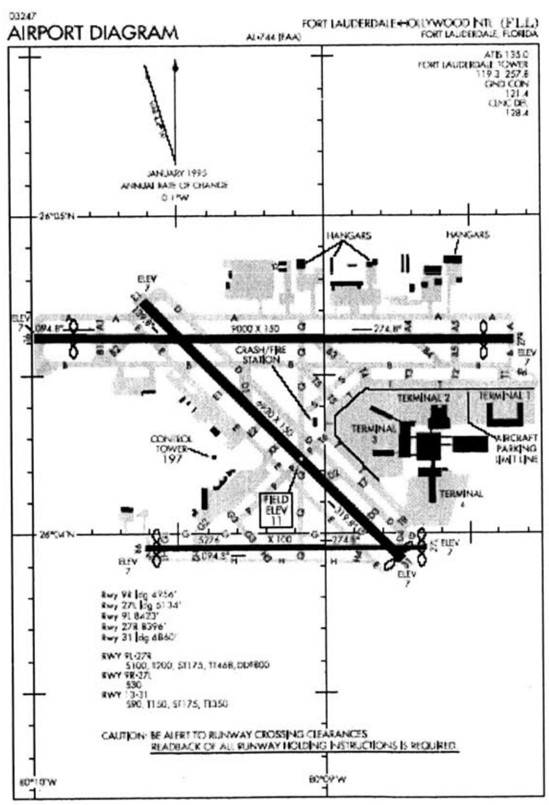
Airport history

Miami (MIA) [59,29]



Miami International Airport is located in Miami, Florida between the suburbs of Hialeah, Doral, Fontainbleau, and Miami Springs. The airport was originally the base of Pan Am's flights to Cuba. The airport fell into disuse when the airline switched to seaplanes in the mid-1930s. The airport was then reutilized after the entry into service of Eastern Airlines in 1934, followed by National Airlines in 1937. In 1945, the City of Miami established a Port Authority and raised bond revenue to purchase the airport from Pan Am. Expansion of the airport was the result of a merger with an adjoining Army airfield in 1949. Pan Am and Eastern remained Miami's main tenants until 1991, when both carriers went bankrupt. Their hubs were taken over by United Airlines and American Airlines. After the slow retreat of United through the 1990s, leading to its departure from MIA, American was left with the largest market share at MIA and a strong hub connecting routes to the Latin America. The airport is currently a hub of American Airlines, American Eagle, cargo airline Fine Air, and charter airline Miami Air. In 2000, Miami International airport handled 16.8 million enplanements accounting for 69% of the regional commercial passenger traffic.

Fort Lauderdale (FLL) [60,29]

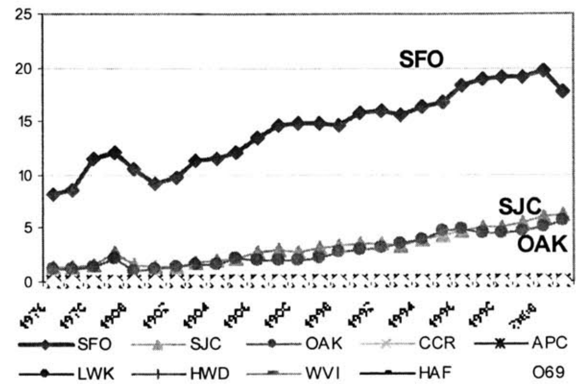


Fort Lauderdale International Airport is located in Dania Beach, Florida between the cities of Fort Lauderdale and Hollywood, 21 miles north of Miami. It was opened in May 1929, under the name of Merle Fogg Airport. At the start of World War II, it was commissioned by the United States Navy and renamed NAS Fort Lauderdale. The base was initially used for refitting civil airliners and was later used as a main training base for naval aviators. After the end of World War II, Broward County purchased the Naval Air Station in order to develop the airport as a commercial airport. First commercial flights to Nassau began in June 1953, and domestic flights began in 1958, operated by Eastern Airlines, National Airlines, and Northeast Airlines. Traffic at the airport grew slowly until low-cost carrier entries - Southwest in 1996, Spirit in 1999, and jetBlue in 2001- stimulated the growth of the airport.

Appendix B-7: San Francisco Regional Airport System

Overview

San Francisco airport system is composed of three key airports. San Francisco International airport is the core airport in the region capturing 64% of the regional passenger. The second largest airport is Norman Mineta San Jose airport, that captured 20% of the regional airport traffic in 2000. The third key airport in the region, comparable in terms of traffic to San Jose airport, is Oakland airport. The airport is located east of San Francisco city on the opposite side of the San Francisco bay. This airport captured 17% of the regional passenger traffic in 2000



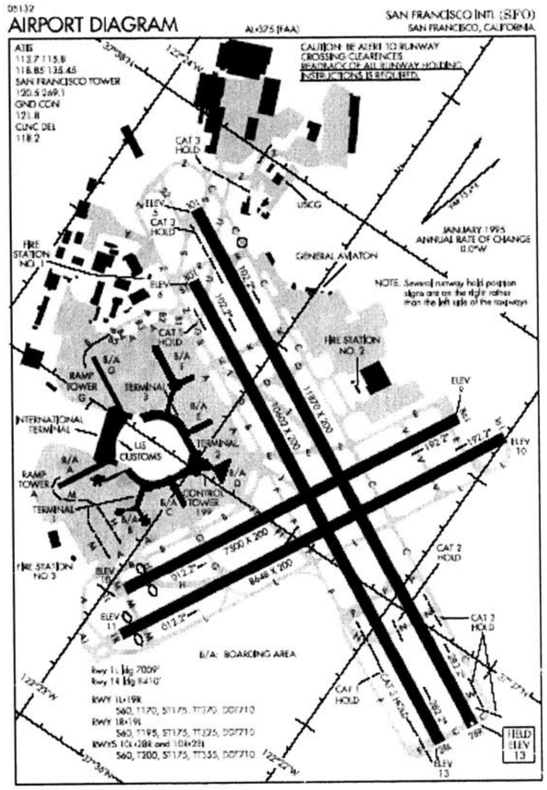
Core airport (Original and Emerged)	Traffic Share	**Secondary** airport	Traffic Share
San Francisco (SFO)	**64%**	Oakland (OAK)	**17%**
		San Jose (SJC)	**20%**

Airport history

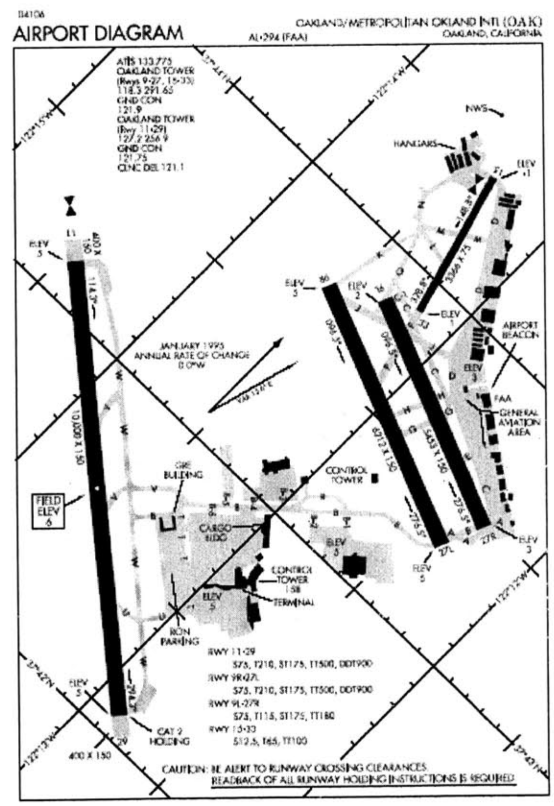
San Francisco (SFO) [61,29]

San Francisco airport was opened in May 1927 and was utilized after 1935 by Pan American World Airways who used the facility as the terminal for its "China Clipper" flying boat service across the Pacific Ocean. During World War II, the domestic traffic from Oakland airport was moved to San Francisco when the airport was taken over by military. United Airlines entered service at San Francisco airport after the war. Major airport improvements were made in the 1950s with the construction of a central passenger terminal. Airport expansion and improvements continued during the 1970s with the construction of a new terminal dedicated to domestic flights. The older terminal was then used for international flights. More recently, a new international terminal opened in

December 2000. In 2000, the airport handled 19.7 million enplanements that accounted for 64% of the regional passenger traffic.

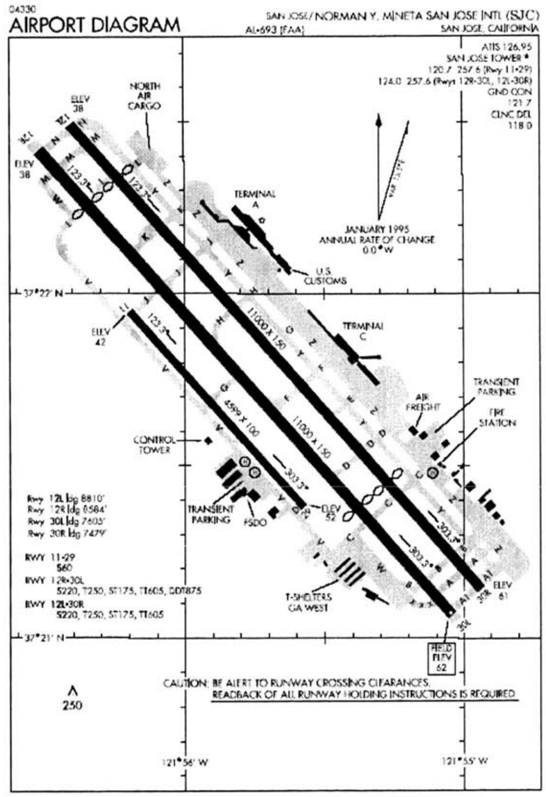


Oakland (OAK) [62,29]



Oakland airport is located in Oakland, California and serves the San Francisco Bay Area metro region. The construction of the airport dates back to 1927. By 1929, a passenger terminal, administrative offices and five hangars are built. In 1937, the airport gains a connection with the east coast with United Air Lines introduction to service of DC-3 between Oakland and New York. Commercial flights were diverted to San Francisco Municipal airport in 1943 when the airport was taken over for military purposes. A new 6,200-foot runway was built in 1945. Additional improvements were made to the airport in the 1960s with the construction of a 10,000 foot runway and a new passenger terminal topped with a 10-story control tower. The airport was also developed in the 1970s with the opening of a 16,000 square foot International Arrivals Building. In 2000, Oakland airport handled 5 million enplanements, accounting for 17% of the total regional passenger traffic.

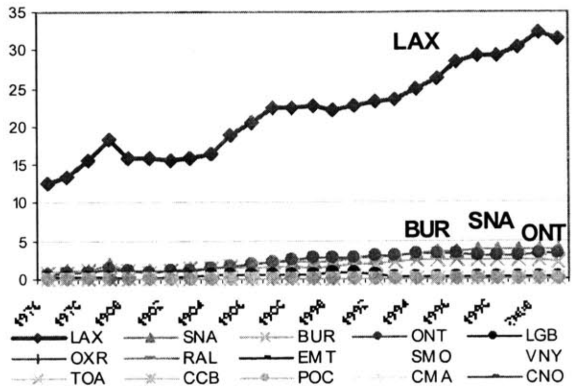
San Jose (SJC) [63,29]



San Jose airport, also named Norman Y. Mineta San José International Airport is located at the north end of the San Jose city. In 1988, American Airlines entered service at San Jose airport. American Airlines is the second largest scheduled airline after Southwest Airlines. The airport was renamed "Norman Mineta San José International Airport" in 2001. The airport features three runways, two 11,000 foot runways and a third runway 4599 feet long. In 2000, the airport handled 6 million enplanements which made it the second largest airport in the region with 20% of the regional passenger traffic.

Appendix B-8: Los Angeles Regional Airport System

Overview

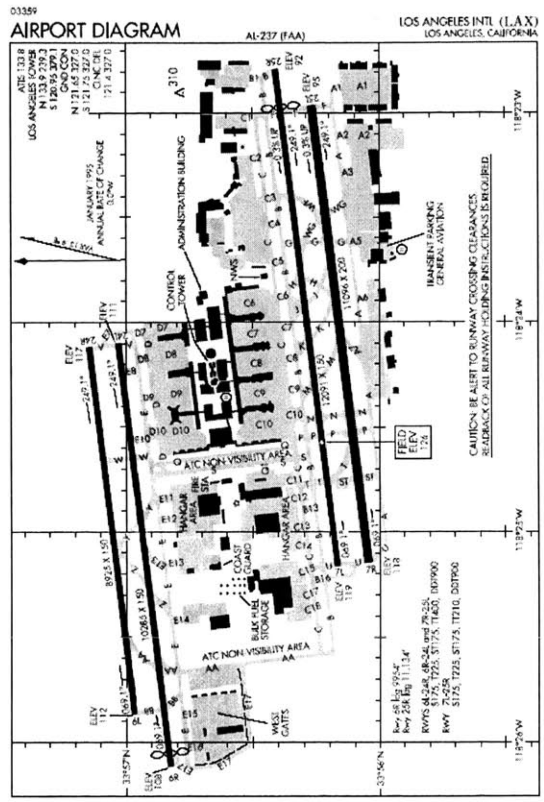


The Los Angeles regional airport is the multi-airport system that has the largest number of airports in the United States. It is composed of one core airport and four secondary airports. The largest airport is Los Angeles International airport about 15 miles southwest of downtown Los Angeles. This airport handled 77% of the regional passenger traffic in 2000. Orange county airport follows with 9%. There are two other secondary airports with similar sizes; Ontario airport in the east part of the metropolitan area region with 8% of the traffic and Burbank airport with 6% of the regional passenger traffic. Long Beach airport is the smallest secondary airport in terms of volume of passenger traffic, with 1% of the regional passenger traffic.

Core airport **(Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
Los Angeles (LAX)	**77%**	Burbank (BUR)	**6%**
		Ontario (ONT)	**8%**
		Orange county (SNA)	**9%**
		Long Beach (LGB)	**1%**

Airport history

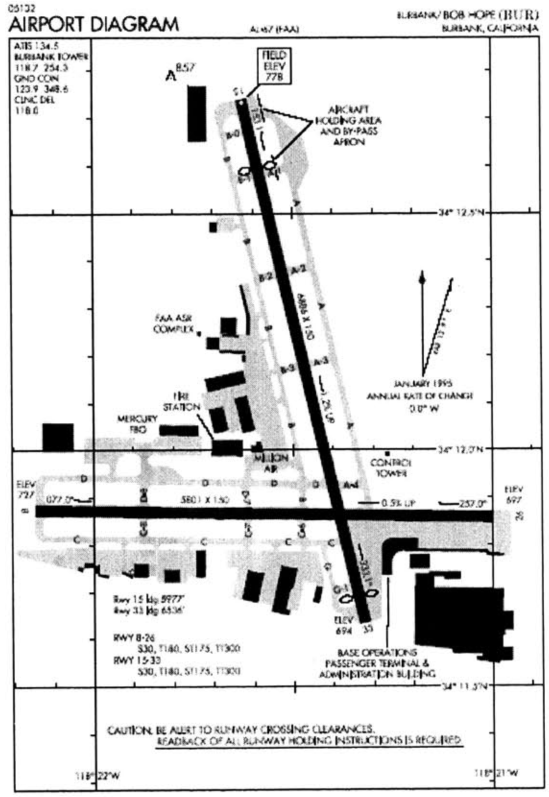
Los Angeles (LAX) [64,65,29]



Los Angeles International airport located on the Pacific coast, about 15 miles southwest of downtown Los Angeles. Its history can be traced back to 1928 when the Los Angeles City Council selected a 640 acre site in order to construct the airport. It was originally named Mines Field. The first airport groundside structure (Hangar No. 1) was constructed in 1929. The airport was officially opened in 1930, and the city purchased it to be a municipal airfield in 1937. In the 1930s several aircraft manufacturing centers were established at the airport (Douglas, Northrop and North American) which assured the airport survival despite the depression years. The airport was renamed in 1949 as Los Angeles International Airport (LAX). In the 1950s the airport was expanded westward towards the Pacific Ocean. In 1959, the airport hosted the new generation of commercial jet aircraft that were flown between New York and Los Angeles. This route was later, in 1970, operated TWA using wide-bodied jets (Boeing 747). The increased passenger traffic generated by the new jet aircraft fostered the need to expand the ground side infrastructure. In the early 1980s, a new international terminal was built.

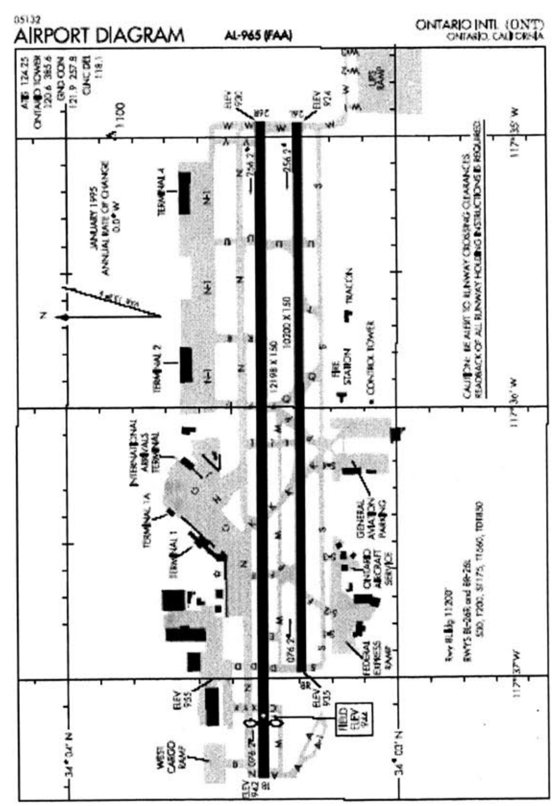
Burbank (BUR) [66,29]

Bob Hope Airport, formerly known as the Burbank-Glendale-Pasadena Airport, is located in Burbank, California. It officially opened in 1930. In 1940, as World War II approached, the airport was purchased by Lockheed who began expanding its facilities on land adjacent to the airport's runways in support of the war effort. As a result the name of the airport was changed to Lockheed Air Terminal and continued to operate it as a commercial airport even though military aircraft were built on the airport. After 1945, all the major carriers moved to Los Angeles Municipal Airport. Airline reentered the Burbank airport in the 1960s were jet airliners capable of using the airport short runways were available. The airport was renamed in honor of legendary entertainer Bob Hope in December, 2003. In 2000, the Burbank airport handled 2.4 million enplanements, accounting for 6% of the regional passenger traffic, which makes it the fourth largest airport in the region after Los Angeles International (LAX), Orange County (SNA) and Ontario (ONT).



Ontario (ONT) [67,29]

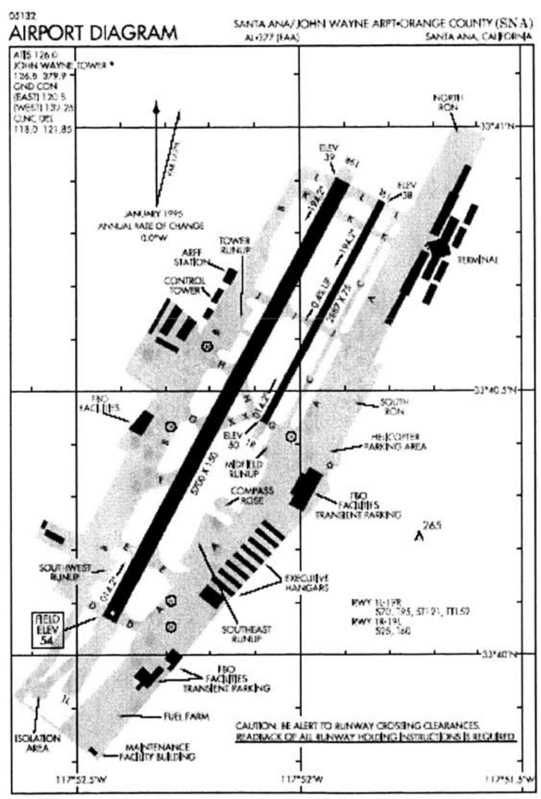
The history of Ontario Airport can be traced back to 1923 when the airport (airstrip at the time) was called Latimer Field and was later, around the 1930s, refer to as the Ontario Airfield. In the early 1940s, due to the military needs during World War II, the airport was transformed from the dirt field of the 1930s to a modern airfield with concrete runways. In addition, air traffic control tower and instrument landing systems were added to the airport. Two new runways were constructed in 1942; a 6200 ft east/west runway and a 4,700 ft



northeast/southwest runway. In 1946, the airport was designated as an international airport. In the 1950s Ontario International Airport the airport grew, enjoying the postwar prosperity.

Today the airport features two parallel runways 12,298 and 10,200 feet long, four main terminals in addition to several cargo and general aviation buildings. In 2000, the airport handled 3.1 million enplanements accounting for 8% of the regional passenger traffic.

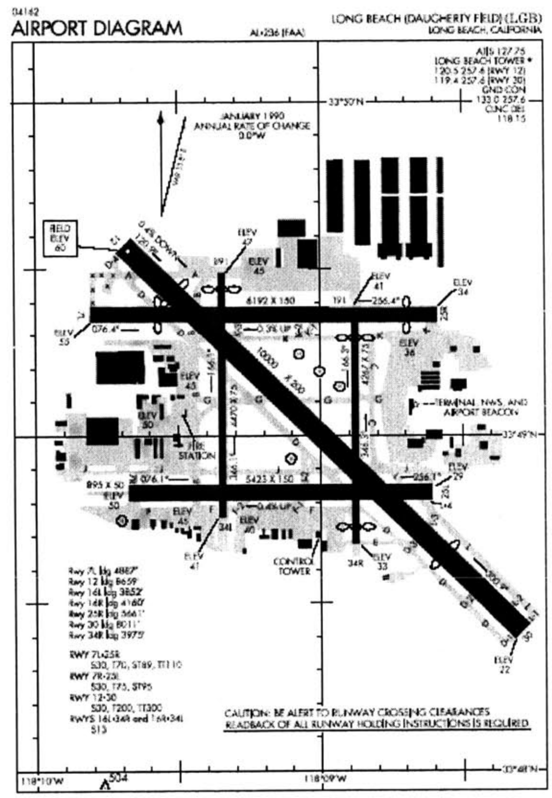
Orange County (SNA) [68,29]



The origin of Orange County airport also called John Wayne airport can be traced back to the 1920s. At the time it was a private airfield. The airport became publicly owned in 1939. After serving as a military base during World War II, it was returned by the federal government to the County. Major airport improvements were made in the 1960s with the opening of a new 22,000 square foot terminal and that could accommodate 400,000 passengers annually. Several other improvements were made in the 1970s and 1980s with a new baggage claim area and a terminal annex building. On June 1979, the airport was renamed John Wayne airport. In 1985, a Federal Court settlement was signed in order to formalize a consensus reached between the County of Orange and the local communities on the nature and extent of airport improvements. In 1987, a general aviation parking area was built and a new terminal was opened in 1990. This new terminal replaced the original terminal built in 1960s which was demolished in 1994. In 2000, Orange County airport (John Wayne airport) handled 3.9

million enplanements accounting for 9% of the regional passenger traffic which made it the second largest airport in the region –in terms of passenger traffic- after Los Angeles (LAX).

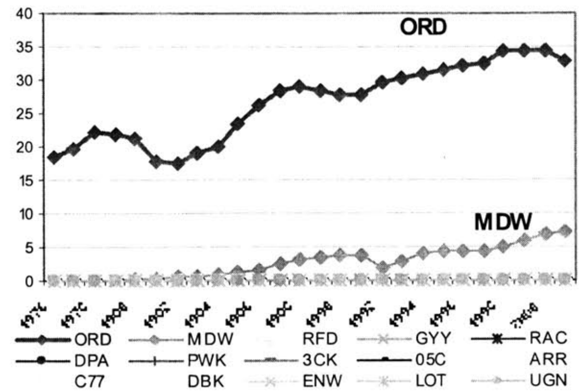
Long Beach (LGB) [69,70,71,29]



Long Beach Municipal Airport (LGB) is located in Long Beach, California. The historical beginning of Long Beach Municipal Airport can be traced back the 1920s. At the time, the Naval Reserve Air Base (NRAB) was located at the airport and then moved to a military field in May 1928. The airport received two runways in the mid 1930s and in 1936 the Civil Aeronautics Authority formally activated a control tower. During the 1970s, Douglas also consolidated its operations at the Long Beach Airport. On the commercial traffic side, due to the use of larger aircraft (Boeing 737 and Douglas DC-9) and increased traffic, the Long Beach terminal was improvement and a new concourse opened in 1984. Currently, Long Beach Airport covers 1,166 acres and has five runways, the longest being 10,000 feet. In 2000, the airport handled only 340,000 enplanements accounting for 1% of the regional traffic. The low level of passenger traffic is mainly due to ordinances adopted to minimize noise in the residential neighborhoods surrounding the airport. In fact, the airport is restricted with only 41 slots are available each day for commercial passengers' flights and cargo. As of March 7, 2003, the agreement between Long Beach airport, and air carriers, stated the allocation of slots to carriers; Jet Blue (22), American (7), America West (5), Alaska (2), UPS (2), FedEx (2) and Airborne Express (1).

Appendix B-9: Chicago Regional Airport System

Overview



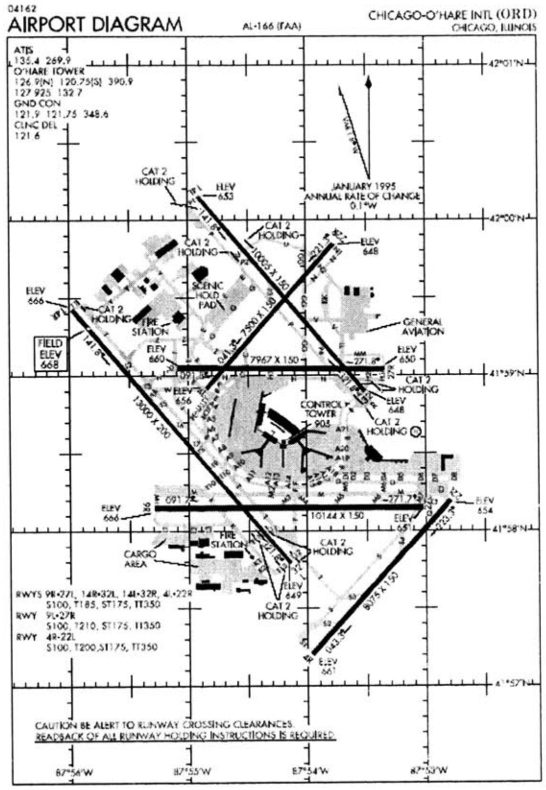
The Chicago airport system is composed of two key airports. The current core airport (an emerged core airport) Chicago O'Hare airport captured 83% of the total passenger enplanements at the regional level. This airport is 17 miles northwest of the Chicago Loop. Chicago Midway airport was identified as the secondary airport in the regional airport system. This airport is located closer to the center of Chicago City since it is located on Chicago City's southwest side, 10 miles from downtown. This airport was the original airport in the region but it was constrained by its infrastructure in the era of the first generation of commercial jet aircraft that required longer runways. Chicago O'Hare became competitive for hosting this new traffic and flights were transferred from Midway to O'Hare in 1962. Midway re-emerged as a key airport due to its location advantage and the service offered by low-cost carriers.

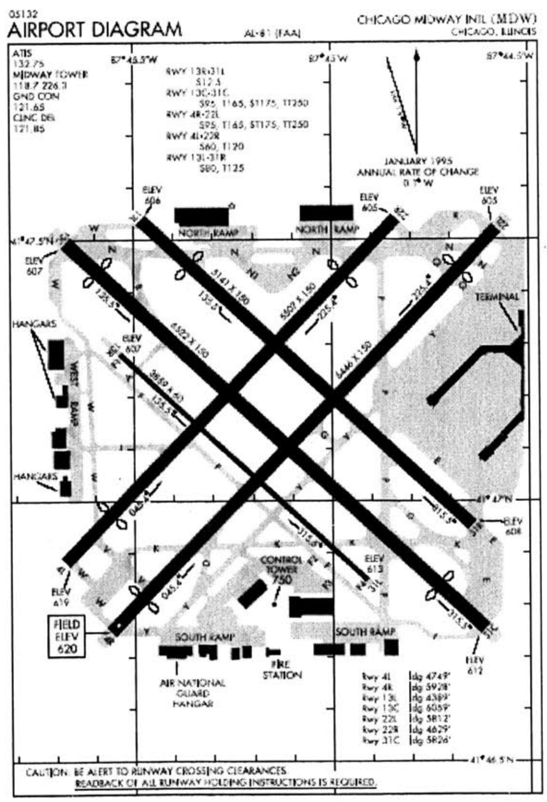
Core airport **(Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
Chicago O'Hare (ORD)	**83%**	*Chicago Midway (MDW)*	**17%**

Airport history

Chicago O'Hare (ORD) [72,73,29]

Chicago O'Hare International Airport is located in Chicago, Illinois, 17 miles northwest of the Chicago Loop. The airport was constructed in 1942 as Douglas aircraft manufacturing plant during World War II. The site was chosen for its proximity to the city and transportation. Douglas Aircraft Company's contract ended in 1945, and though plans were proposed to build commercial aircraft, the company ultimately chose to concentrate production on the west coast. Chicago Midway airport, located closer to the City of Chicago center was the original core airport in the region and served the demand for commercial traffic of the region since 1931. However, by the mid 1940s, Midway reached saturation. In the 1950s, it was also constrained by its infrastructure – runways to short- did not allow the airport to host the first generation of jet airplanes. At the same time the City of Chicago and FAA began to develop O'Hare as the next core airport in the region. The first commercial passenger flights were started there in 1955. The international terminal was built in 1958, but the majority of domestic traffic did not move from Midway until completion of a 1962 expansion of O'Hare. With the traffic transferred from Midway, Chicago O'Hare soon became the World's Busiest Airport. Today, the airport is the headquarters of United Airlines and the second-largest hub of American Airlines. In 2000, it handled almost 35 million enplanements accounting for 83% of the passenger traffic in the region.



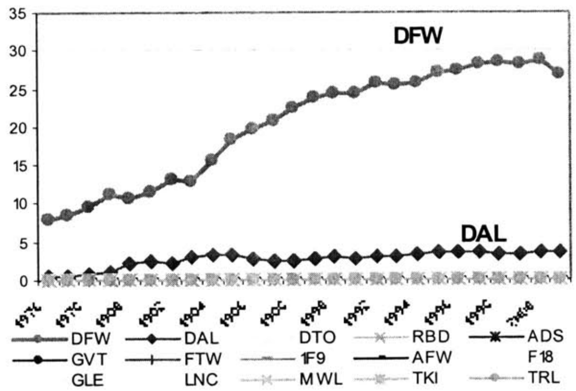


Chicago Midway (MDW) [74,75]

Chicago Midway airport history can be traced back to the early 1920s. The airport is located on Chicago City's southwest side, 10 miles from downtown. Originally built in 1923 as the Chicago Air Park, the airport was mainly used by airmail contractors. The airport was dedicated as Chicago Municipal Airport in 1927. Before the emergence of Chicago O'Hare airport as a core airport in the region in 1962, Chicago Midway held the position of the busiest airport in the world during three decades. After the World War II Battle of Midway, the airport was renamed Chicago Midway Airport in 1949. Constrained by its short runways leading to its inability to host the first generation of jets, Midway was handicapped and could not compete with O'Hare. Chicago O'Hare had longer runways and could accommodate larger aircraft. In the 1960s and the 1970s passenger declined significantly, and ultimately reached less than 25,000 enplanements in 1977. In 1979, Midway Airlines became the first major airline formed after deregulation. Together with Southwest Airlines, they are credited with revitalizing the airport and giving the southwest side an economic boost in the 1980s. Midway Airlines ceased operations in 1991. Southwest Airlines and American Trans Air quickly replaced Midway Airlines and the airport went through significant growth in the 1990s. With the merger of Southwest and ATA, Chicago Midway shows an enormous presence of low-cost carriers compared to Chicago O'Hare which remains a large hub for both United and American. In 2000, Chicago Midway airport handled almost 7 million enplanements accounting for 17% of the regional passenger traffic.

Appendix B-10: Dallas Regional Airport System

Overview



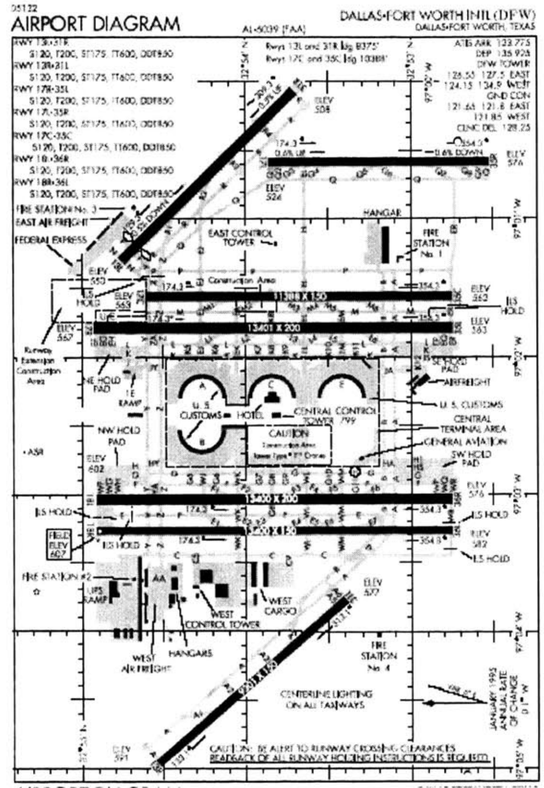
The Dallas regional airport system is composed of two key airports. The core airport, which is an emerged core airport, is Dallas Fort-Worth. The airport is located at equal distance between the City of Dallas and the City of Fort-Worth. This airport is clearly the dominant airport in the region with 89% of the regional passenger traffic. The second key airport in the region is Dallas Love Field located closer to the City of Dallas. This airport was the original major airport in the region before DFW was built. Due to capacity problems and expansion constraints, Dallas Fort-Worth was built and commercial traffic was transferred from Love Field to Dallas Fort-Worth, at the exception of flights operated by Southwest Airlines. In 2000, Dallas Love Field accounted for 11% of the regional passenger traffic.

Core airport **(Original and Emerged)**	Traffic Share	**Secondary** airport	Traffic Share
Dallas Fort Worth (DFW)	**89%**	*Dallas (DAL)*	**11%**

Airports history

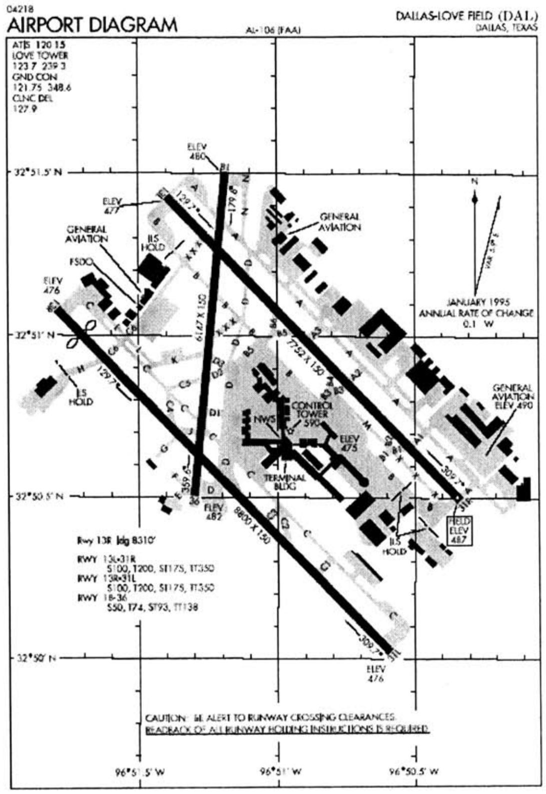
Dallas-Fort Worth (DFW) [76,77,29]

Dallas-Fort Worth International Airport is located between the cities of Dallas and Fort Worth in Texas. The origin of the airport can be traced back to 1966 when the land of the airport was purchased. Construction began in 1969 and the airport was opened for commercial service in January 1974. Before 1974, the cities of Dallas and Fort Worth had their own airport; Dallas Love Field closer to the City of Dallas and Meacham Field was serving the Fort Worth demand. After 1945, Fort-Worth transferred its flights from Meacham Field to Amon Carter Field located 12 miles from Dallas Love Field. However the attempt of Fort-Worth to compete with Dallas airport (Dallas Love Field) was not successful and Love Field remained the major airport in the region. The origins of a common airport between the two cities can be traced back to 1927, when a first attempt to build a common airport failed. Other attempts were made in the 1940s but eventually failed because of disagreements over its construction. Due to both the refusal of the FAA to invest in separate airport and the congestion of Dallas Love Field, Dallas and Fort-Worth cities agreed on the location (between the two cities) of a common airport. In 1979, the Wright Amendment was passed. Its purpose was to transfer all remaining long-distance flights from Dallas Love Field to DFW by banning those flights from Love Field. In the early 1980s, the airport became a major hub for American Airlines and Delta Airlines. In the late 1980s, the airport authority announced plans to rebuild the existing terminals and construct two new runways. DFW's seventh runway was opened in 1996.



Dallas (DAL) [78,29]

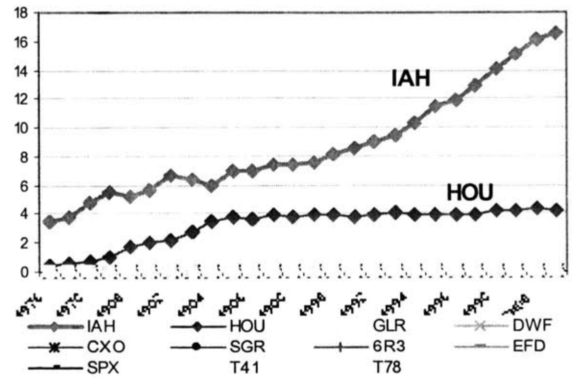
The origin of Dallas Love Field can be traced back to 1917. It was opened to civilian use in 1927. Braniff Airways moved its headquarters to Love Field in 1936 and the airport remained Dallas primary airport until the opening of Dallas Fort Worth in 1974 after both cities agreed on the location of a common airport in the 1960s. Due to its better location than the new DFW airport, Dallas Love Field remained competitive even with its limited infrastructure. Southwest airlines, founded in 1971, exploited the location advantage of Love Field by offering short haul services between Dallas, Houston, and San Antonio. In 1973, Southwest Airlines managed to remain at Love Field after it was granted by the courts the right to continue to operate intrastate service out of Love Field. After the opening of DFW Southwest airlines was the only carrier operating at Love Field. After 1978, Southwest Airlines had plans to start offering flights to destination outside the state of Texas. In order to keep Fort Worth attractive by limiting the competition with Love Field, Congressman Wright from Fort-Worth, helped pass a law in Congress that restricted air service at Love Field. The Wright Amendment restricted flights out of Love Field to destination in four neighboring states; Louisiana, Arkansas, Oklahoma, and New Mexico. Southwest continued to grow by offering flights that complied with the Wright Amendment. As a result of Southwest Airlines success, other airlines showed their interest in providing service out of Love Field. In 1985, court battles were started over the interpretation of the Wright Amendment. In 1997, the Shelby Amendment successfully passed through Congress, which amended the Wright Amendment. It extended the number of neighboring states accessible from Love Field from four to seven, adding Kansas, Mississippi and Alabama. In 1998, Continental Express became the first major airline other than Southwest to fly out of Love Field since 1974. American Airlines followed the entry of Continental but was still battling against the Shelby Amendment, in order to restrict traffic out of Love Field and keep DFW competitive.



Appendix B-11: Houston Regional Airport System

Overview

The Houston regional airport is composed of two key airports. Following an identical regional airport system evolution model as Chicago and Dallas airport systems, Houston has one emerged core airport and a secondary airport that is re-emerged from an original airport. Houston Bush International airport is the core airport in the region with 79% of the regional passenger traffic share in 2000. Houston Hobby airport was built in the 1930s and remained the major airport in the region until 1969 when commercial traffic was transferred to the newly opened Houston International airport. The airport reopened in 1971 and regained traffic. It reached 4 million enplanements in 2000 accounting for 21% of the regional passenger traffic.

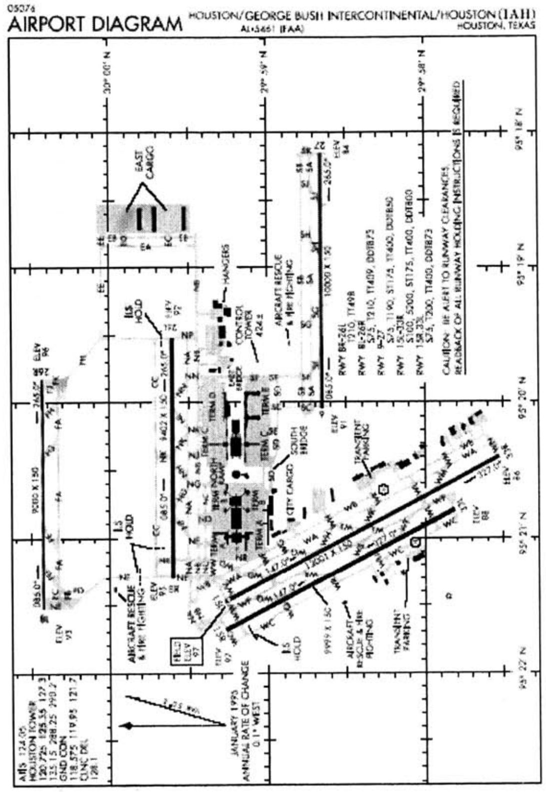


Core airport (Original and Emerged)	Traffic Share	Secondary airport	Traffic Share
Houston International (IAH)	**79%**	*Houston Hobby (HOU)*	**21%**

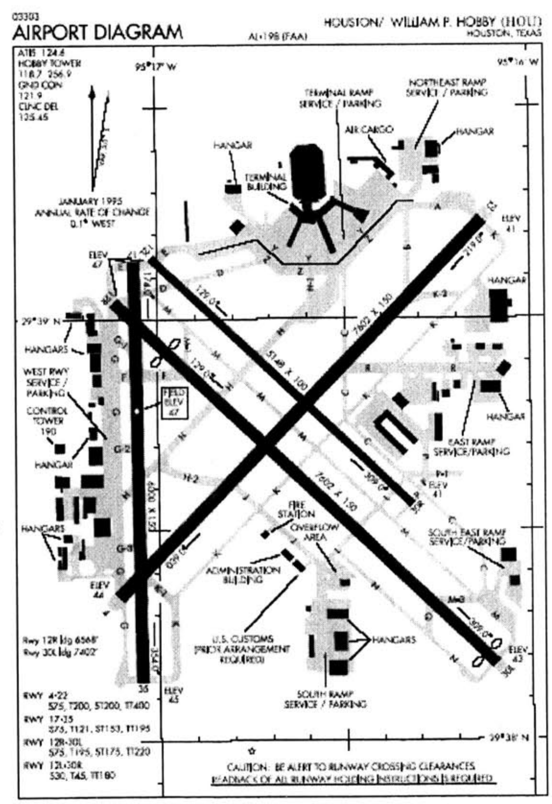
Airport history

Houston International (IAH) [79,29]

George Bush Intercontinental Airport is located twenty miles north of downtown Houston, Texas. In the 1960s, the construction of this airport was motivated by the land limitations at Houston Hobby, the first commercial airport in the region. The airport was opened in 1969 as Houston Intercontinental Airport. All passenger air carriers moved from Hobby Airport to the new airport. Originally, Terminals A and B were built. With the growth of traffic, new facilities were added in the 1980s (Terminal C) and the early 1990s with the opening of the Mickey Leland International Airlines Building. The airport ultimately changed in 1997, and was renamed Houston Intercontinental Airport.

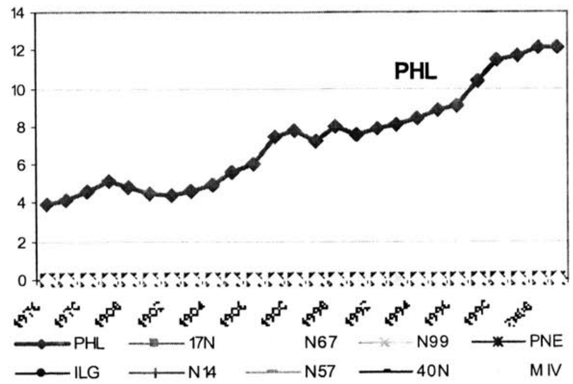


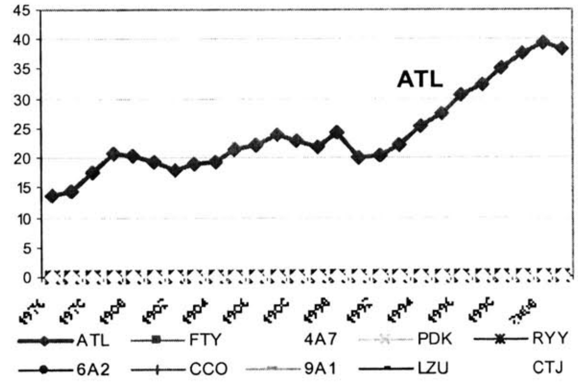
Houston Hobby (HOU) [80,81,29]

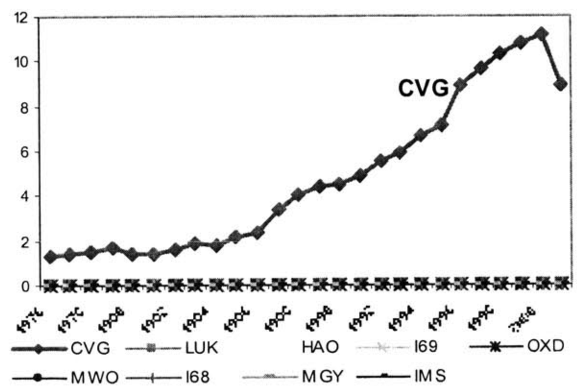


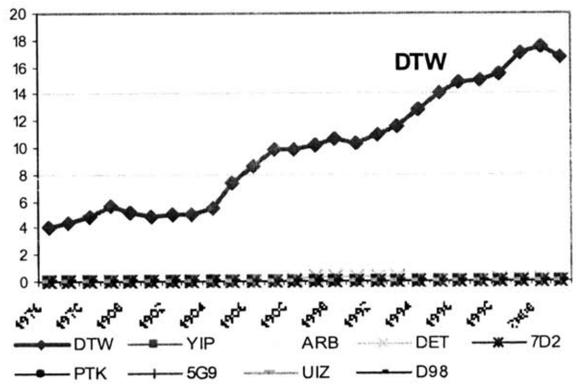
William P. Hobby Airport origins can be traced back to 1937, when the airport was called Houston Municipal Airport and was the first public airport of the City of Houston. At the end of the 1930s, the airport was also the early base of operation of Howard R. Hughes. In the early 1940s the airport's first concrete paved runways and taxiways were completed. At this time, Braniff and Eastern were the only two airlines serving the airport. After the end of World War II, four additional airlines were serving the city from Houston Municipal Airport. Following the entry Pan Am in 1950 and the first flight out of the United States, the name was changed to Houston International Airport, in 1954. Many airport facility improvements were made in the 1950s such as, terminal expansion, the reconstruction of runways 17/35, 4/22 and 13/31, etc. By the end of the 1950s, even though runways were reconstructed, there was the need to lengthen them in order to host the first generation of jet aircraft. After the construction of Houston Intercontinental Airport (IAH), in 1969, all commercial traffic was moved from Hobby to Houston Intercontinental. Hobby was reopened to commercial aviation in 1971 and Southwest initiated service with Dallas Love Field. Several other airlines followed the entry of Southwest, including Braniff and Texas International Airlines. Due to its location advantage Hobby has remained competitive with Houston Bush Intercontinental.

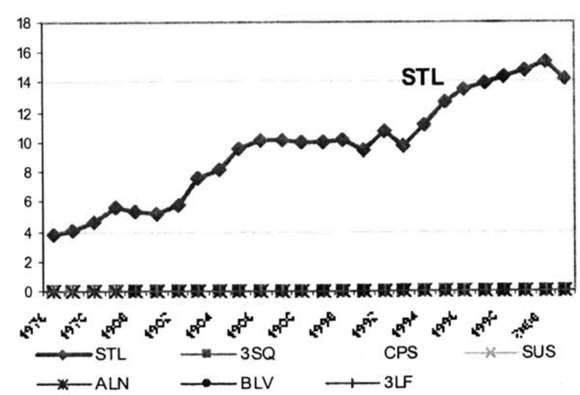
Appendix C: Traffic patterns of single airport systems

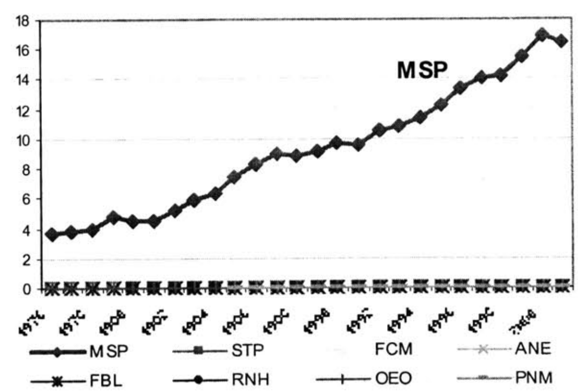


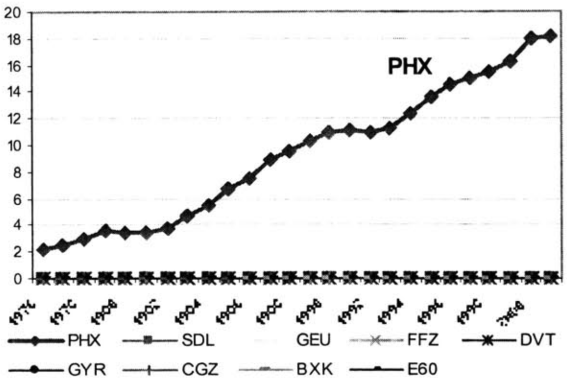


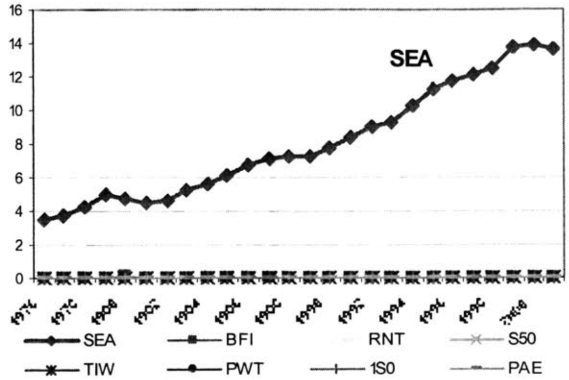


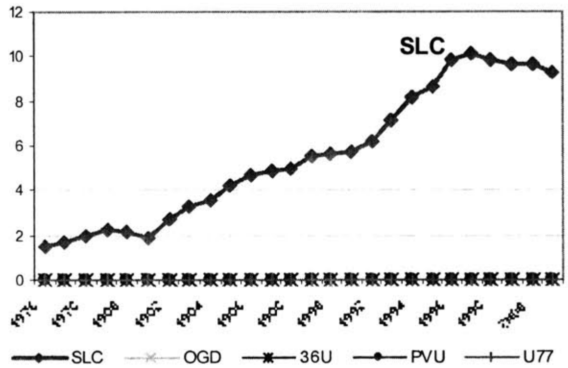


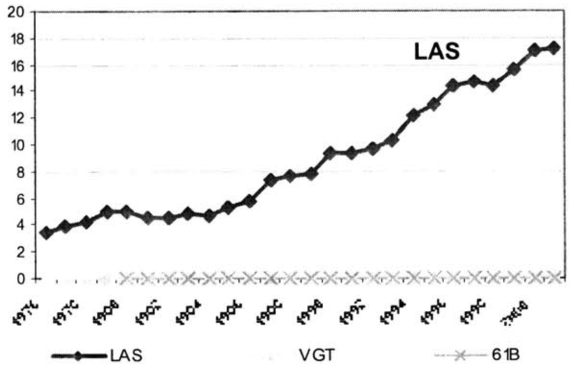


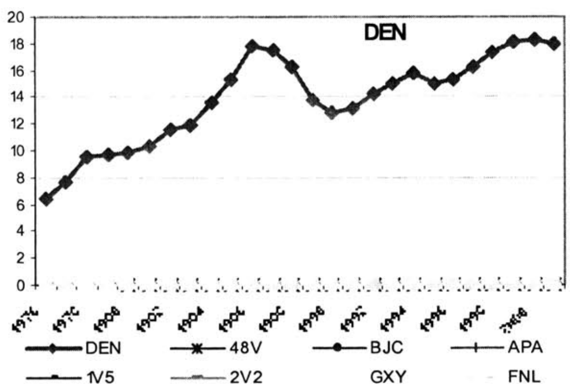


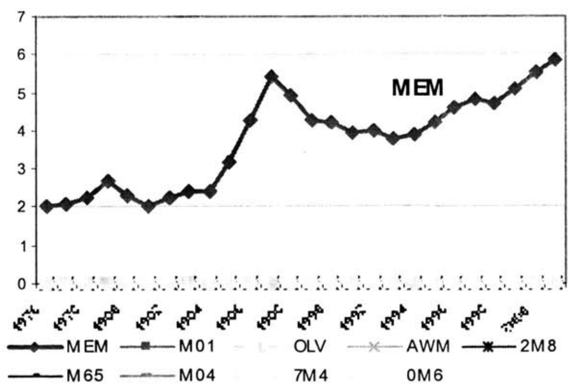

PHX
PHX
SDL
GEU
FFZ
DVT
GYR
CGZ
BXK
E60

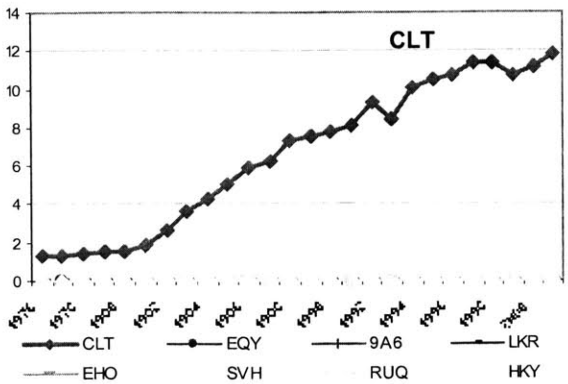

SEA
SEA
BFI
RNT
S50
TIW
PWT
1S0
PAE

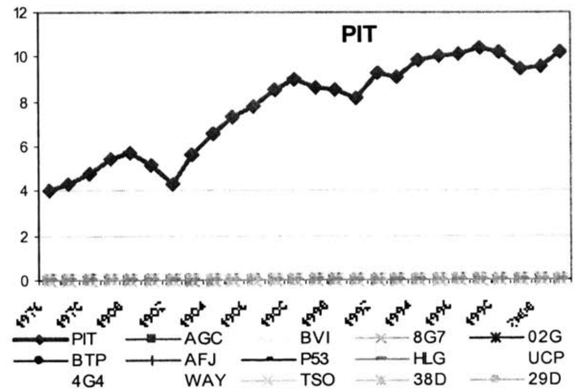

SLC
SLC
OGD
36U
PVU
U77

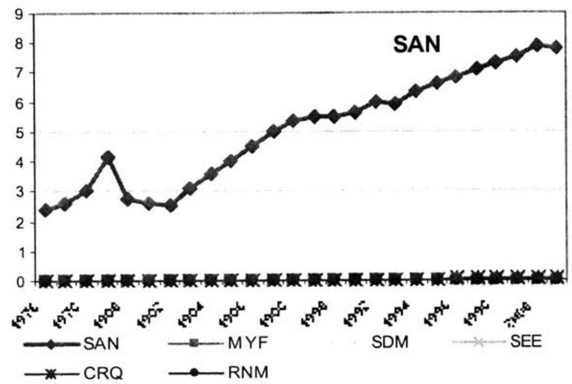

LAS
LAS
VGT
61B


DEN
DEN
48V
BJC
APA
1V5
2V2
GXY
FNL


MEM
MEM
M01
OLV
AWM
2M8
M65
M04
7M4
0M6

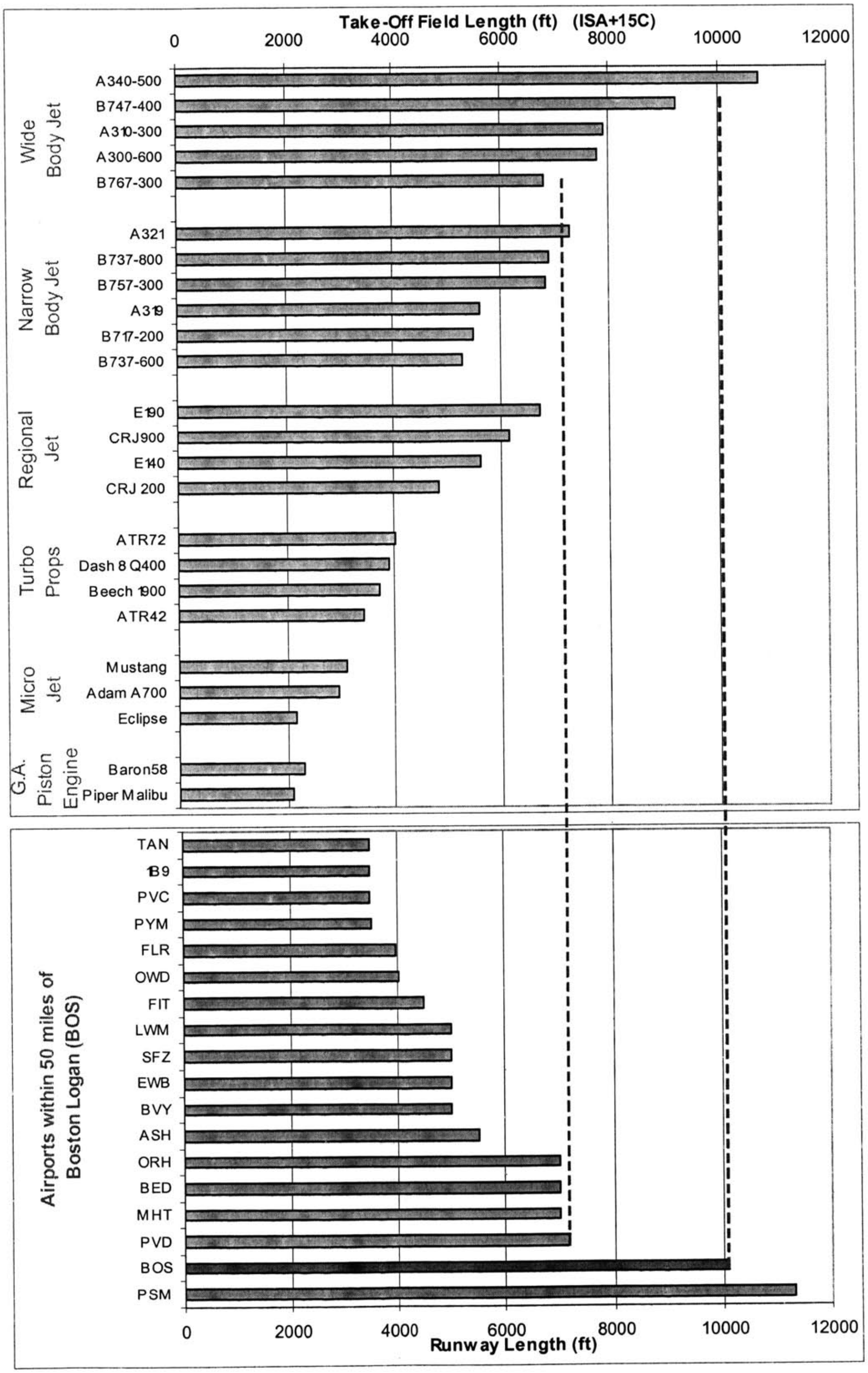

CLT
CLT
EQY
9A6
LKR
EHO
SVH
RUQ
HKY


PIT
PIT
AGC
BVI
8G7
02G
BTP
AFJ
P53
HLG
UCP
4G4
WAY
TSO
38D
29D

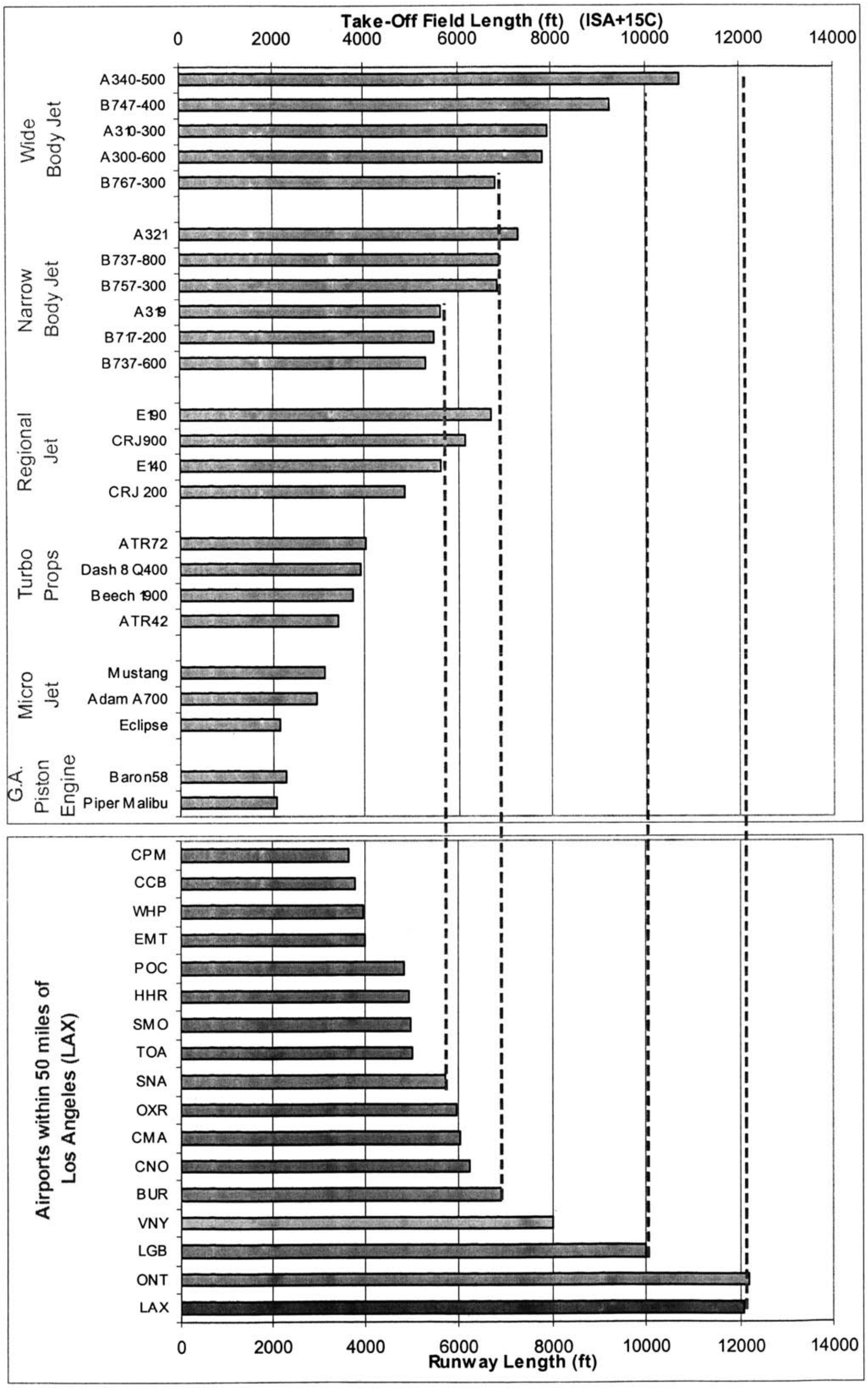

SAN
SAN
MYF
SDM
SEE
CRQ
RNM

Appendix D: Maximum Airport Runway Length and Aircraft Requirements

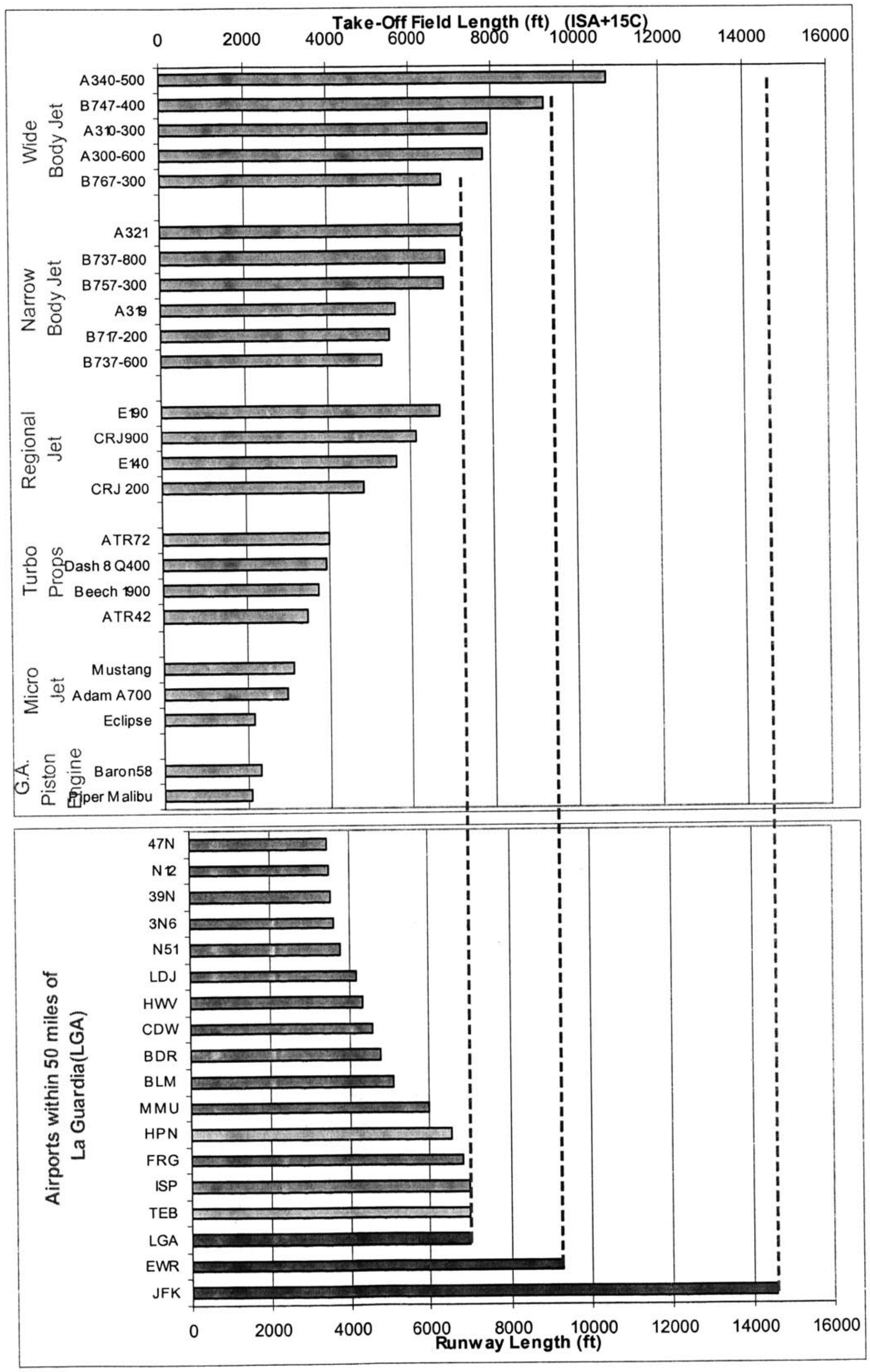
Appendix D-1: Boston Regional Airport System



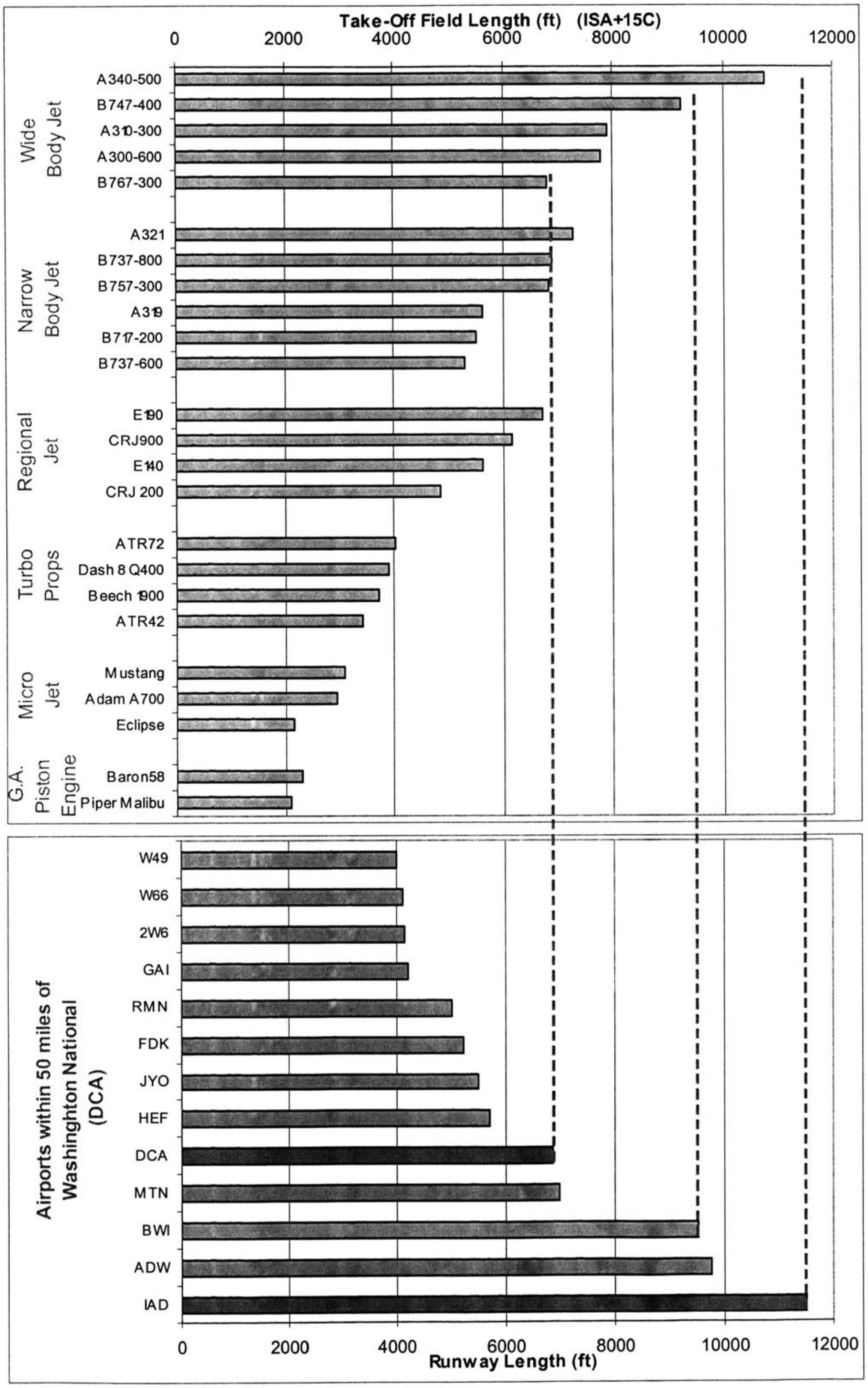
Appendix D-2: Los Angeles Regional Airport System



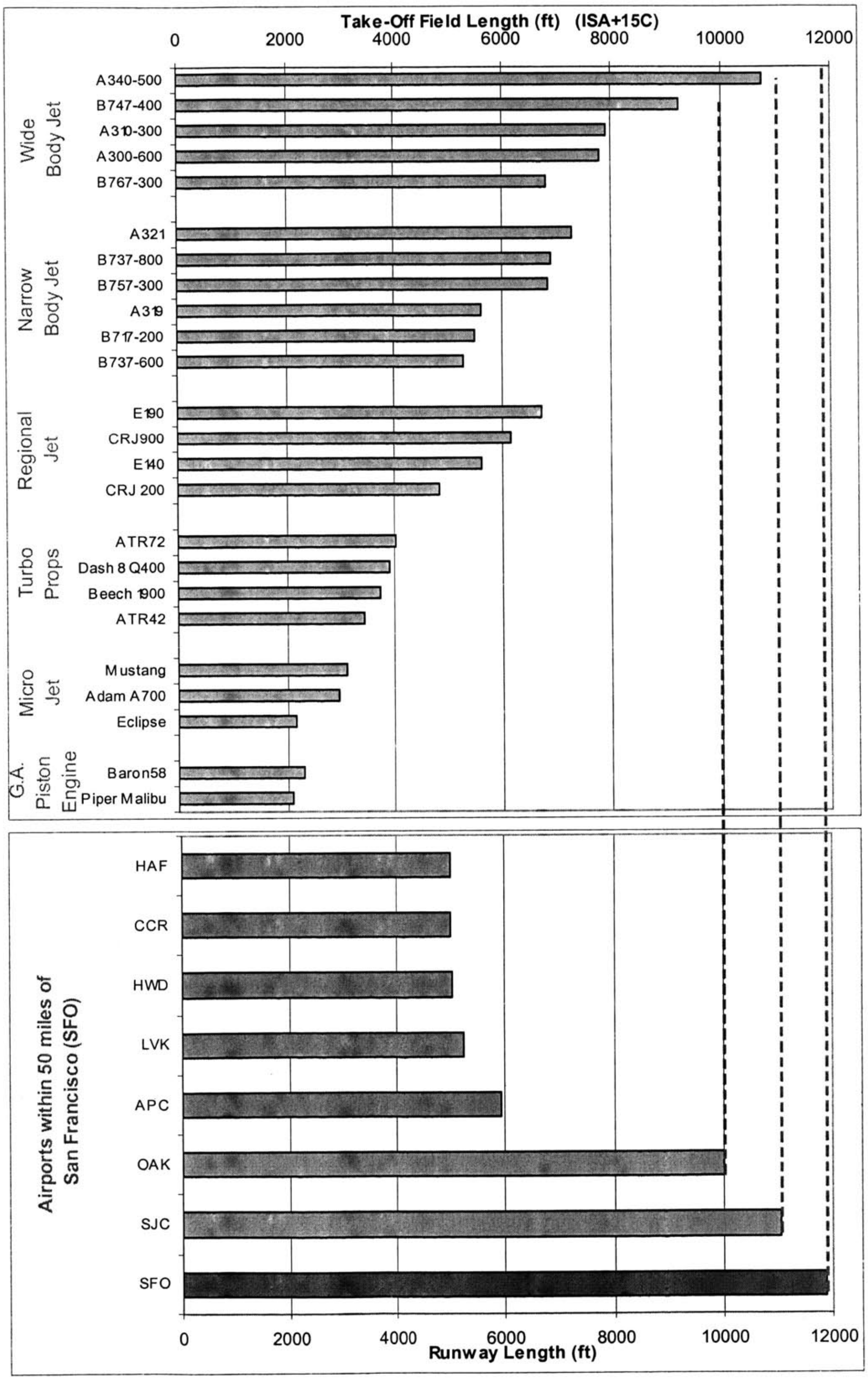
Appendix D-3: New York Regional Airport System



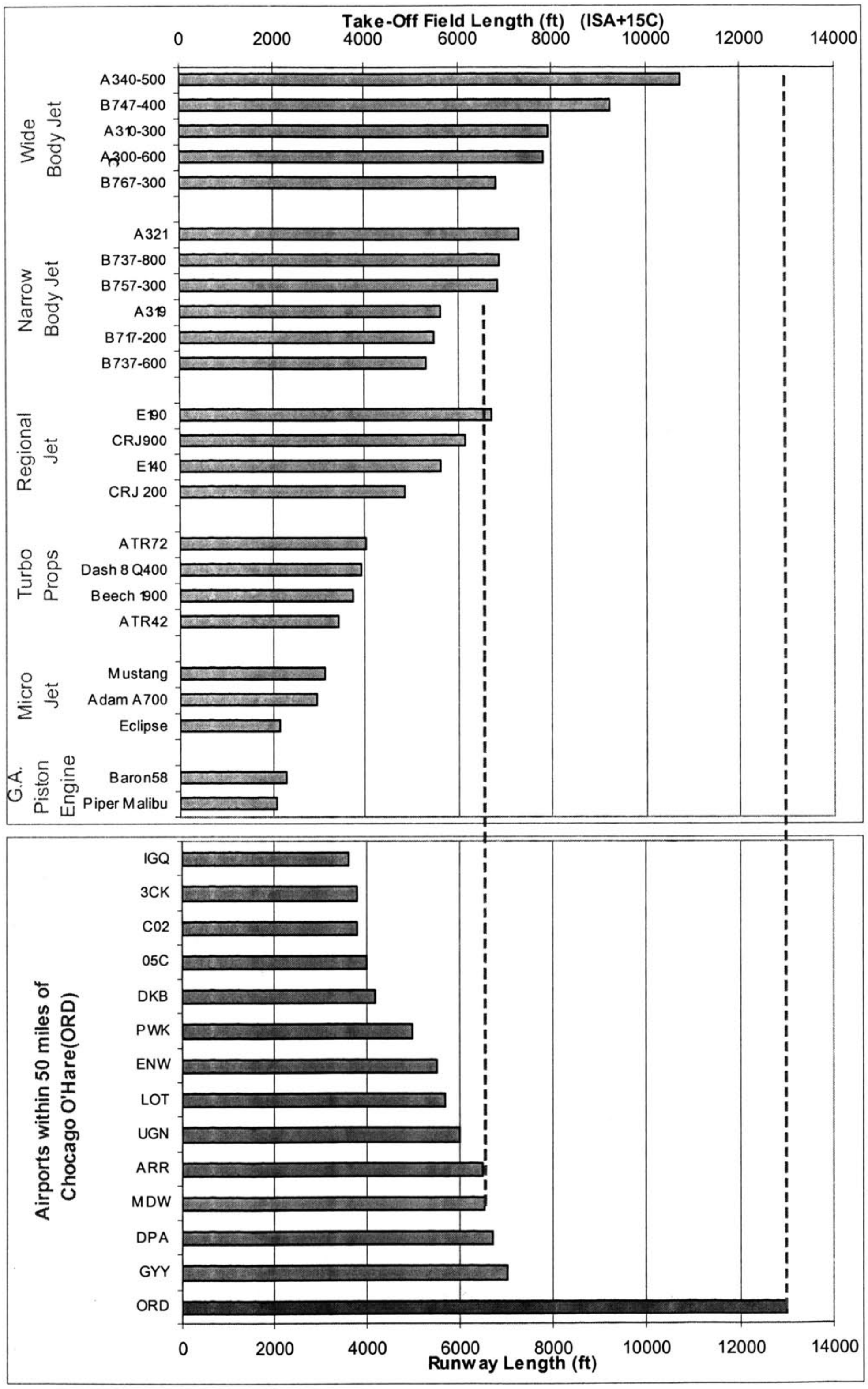
Appendix D-4: Washington Regional Airport System



Appendix D-5: San-Francisco Regional Airport System



Appendix D-6: Chicago Regional Airport System



Appendix D-7: Miami Regional Airport System