REVENUE AND OPERATIONAL IMPACTS OF DEPEAKING FLIGHTS AT HUB AIRPORTS

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LIST OF ABBREVIATIONS

ADA	Airline Deregulation Act
Arr.	Arrival
ASM	Available Seat Miles
BTS	Bureau of Transportation Statistics
CPI	Consumer Price Index
CRS	Computer Reservation System
DB1B	Airline Origin and Destination Survey
Dep.	Departure
DST	Daylight Savings Time
FAA	Federal Aviation Administration
GIS	Geographic Information System
GMT	Greenwich Mean Time
IATA	International Air Transport Association
LCC	Low Cost Carrier
MCT	Minimum Connection Time
MIDT	Marketing Information Data Transfer
MxCT	Maximum Connection Time
NTAD	National Transportation Atlas Database
O&D	Origin and Destination
OAG	Official Airline Guide
PANYNJ	Port Authority of New York and New Jersey
RASM	Revenue per Available Seat Mile
SAS	Statistical Analysis System
SIFL	Standard Industry Fare Level
USDOT	United States Department of Transportation

Note: Airline and Airport codes are listed in Appendix A and Appendix B, respectively.

SUMMARY

Post deregulation, many U.S. airlines created hubs with banked schedules, however, in the past decade these same airlines began to experiment with depeaking their schedules to reduce costs and improve operational performance. To date there has been little research that has investigated revenue and operational shifts associated with depeaked schedules; yet understanding the trade-offs among revenue, costs, and operational performance at a network level is critical before airlines will consider future depeaking and related congestion-management strategies. This study develops data cleaning and analysis methodologies based on publicly available data that are used to quantify airport-level and network-level revenue and operational changes associated with schedule depeaking. These methodologies are applied to six case studies of airline depeaking over the past decade. Results show that depeaking is associated with revenue per available seat mile (RASM) increasing slower than the rest of the network and the industry as a whole. Depeaking is associated with improved operations for both the depeaking airlines and competitors. Airports benefit from increases in non-aeronautical sales associated with connecting passengers spending more time in the terminal. The underlying reasons driving airlines' scheduling decisions during depeaking vary greatly by case. Results from the study provide insights for airlines that are considering depeaking and the airports which are affected. The results suggest that losses in RASM and no improvement in operations could potentially lead an airline to repeak, and that RASM is prone to fall when a strong competitive threat exists.

CHAPTER 1

INTRODUCTION

1.1 Overview

A “depeaked” schedule goes by many names in the airline industry. Some describe it as a rolling hub, because the banks are removed and there are no lulls in activity. It also is described as a continuous schedule, because of the consistent level of operations which occurs throughout the day at the airport. Regardless of name, the depeaking of an airline schedule is a cost-cutting strategy that removes the inefficiencies of a banked, or peaked, schedule. Since the early 2000s, it has been a technique that several major airlines have tried at least once at one of their hubs. The depeaking concept during the early 2000s became one of the biggest experiments in the industry (Mecham, 2004).

In a peaked schedule, aircraft arrive in banks at an airline hub so that short connections are available for passengers. This helps the airline compete against competitors offering non-stop service or service through other hubs. Between the peaks of activity, however, staff and equipment sit idle. In addition, the large number of gates needed to service all the aircraft simultaneously sit empty. Banking, for all the benefits it provides, is an inefficient use of airline resources. Depeaking solves this issue and allows the airline to be more efficient, reducing the cost to operate the schedule.

The benefits of depeaking have been explored in terms of cost savings, operational improvements, and resource usage. These positive effects though come at the expense of a reduction in revenue, as connections are presumed to be broken as the banks are dropped. This study fills this gap in the literature through an exploration into the revenue effects of depeaking. By combining publicly available data, the supply and demand before and after a depeaking event are compared to explore the role these play in airlines' depeaking decision-making processes. In addition, the revenue effect of depeaking a schedule is analyzed so that the change in revenue can be better forecasted.

This dissertation contains five chapters. The first is an introduction to the topic and the motivation behind doing the study. The second chapter describes the literature on topics relevant to depeaking so that the issue can be more fully understood. Chapter three describes the methods used to analyzed depeaking, and chapter four contains the results from this analysis. Chapter five discusses what can be learned from the results, summarizes the conclusions and recommendations, and points out how this study contributes to the industry.

1.2 Context

Many airports are congested, have reached their physical capacity, and cannot expand to meet near-term and long-term demand. Increased traffic is constrained by the level of activity an airport's runways and gates can process. Increased congestion and demand for infrastructure access cause aircraft to experience delays. Airport delays due to congestion can be exacerbated due to a common airline business model: banking flights at hub airports.

The banked schedule, soon after deregulation, became the most common traffic pattern at large airports, with systematic, distinct peaks that resulted from the hub-and-spoke operations of the dominant hub airline (Daniel & Harback, 2008). These banks consist of flights that arrive and depart within a short period of time, allowing airlines to create more connection opportunities and minimize connection times for passengers. Both of these factors are intended to increase airlines' revenue. The more connections an airline can offer in a reasonable time for passengers, the greater the likelihood of a trip on that airline occurring, due to the increased probability that an inbound flight can reach a given outbound flight (Franke, 2004). Some hubs have up to twelve daily banks to allow passengers as many chances to use them to complete their travel at the times they desire (Hirschman, 2004).

Banking flights, however, may result in increased passenger delays because the number of takeoff and landing requests exceeds the available airspace capacity. The massive peaks lead to reduced airside productivity because of the temporary congestion. This is particularly problematic if multiple carriers have banked flight operations at the same hub. Banked flights also constrain the hub airline's ability to recover from irregular operations caused by adverse weather conditions or other events.

Banked schedules are also a challenge for airports, particularly with respect to manpower planning. Banked flights create peak periods of activity for customer service representatives, baggage handlers, and gate and ground personnel. These large fluctuations come at a time when there is already a high-risk for missed flights due to time critical connections (Franke, 2004), causing high stress to airport staff. Ultimately, this leads to poor punctuality performance. Servicing these peak periods requires hiring more staff and purchasing additional equipment that is not fully utilized when the peaks are over (Kemppainen et al., 2007). This underutilization during the off-peak periods increases the cost per aircraft because more staff is needed than would be necessary if flights were more evenly distributed. Although many airlines have maintained their banked schedules because they believe these banks maximize their revenue opportunities, and fuel the possibility for business growth (McDonald, 2002), other airlines have experimented with depeaked schedules as a way to minimize costs.

Depeaking schedules was one way airlines responded to the high costs they faced throughout the 2000s. By reducing the maximum number of aircraft that depart and arrive at an airport within a period of time, gates, equipment, and personnel can be used more efficiently. Inactivity is reduced as aircraft are constantly being serviced. American Airlines was the first U.S. airline to implement depeaking across parts of its system in order to control for costs. In 2002, American depeaked its hubs in Chicago O'Hare (ORD) and Dallas/Fort Worth (DFW), responding to the economic downturn post-9/11 (Reed, 2006).

Depeaking is not an easy decision for an airline because a more continuous schedule of operations means there are likely fewer connection opportunities, and the average minimum connection time increases. Decreased revenue is thus likely, and an airline needs to assess whether the cost savings associated with depeaking outweigh any revenue losses. Although cost savings are relatively straightforward for an airline to quantify, it is difficult to measure revenue changes. An airline that depeaks its schedule may unintentionally improve operational performance for all carriers at the airport; thus the airline may lose revenue and increase the profitability of its competitors.

1.3 Research Problem

As noted by Stephan Nagel in 2004, Director of Star Alliance's route network operations, "there's no clear answer as to whether the rolling hub is a good hub" (Mecham, 2004).

This gap in knowledge makes it ever more critical to study this topic. The research problem is a lack of understanding about how depeaking affects revenue and operations. Airlines have been implementing depeaking without fully knowing what the effects on revenue the schedule change will have. This problem could put the airline at risk to lose on routes to spoke airports where it once was dominant, as the competition takes advantage of dropped connections at the depeaked hub. It also could cause unforeseen impacts to operations.

The research problem at its core is a lack of information. There has been no formal study to determine how airline revenue is affected by depeaking. Without an analysis performed on what can potentially change when a schedule is depeaked, it is difficult to make an informed decision on the consequences. From the revenue perspective, benefits are often measured indirectly in terms of aircraft utilization and percent of time spent in the air. The operational effect has seen more attention, likely because it is easier to study, but there has yet to be a cross-case comparison on operations due to airline schedule depeaking.

Involved with the problem of a lack of understanding is a lack of measurement for depeaking. Being able to assess depeaking requires a means to say how much of a change occurred and how that relates to the effects. It is an issue that there is not a way to quantify the changes that occur to a schedule during depeaking, or to assess how banked a schedule is compared to a depeaked schedule.

Another part of the problem which has not been studied is with regards to potential connections. There has yet to be a look into how depeaking breaks connections in the schedule. This is important because for a hubbing airline, connections are the key to profitability. By understanding if connections get broken provides either a reason or a factor into revenue potentially decreasing due to depeaking. In addition, even a loss in connections can still be good for revenue, if the decision is made correctly. Figure 1.1 below provides an example of this situation.

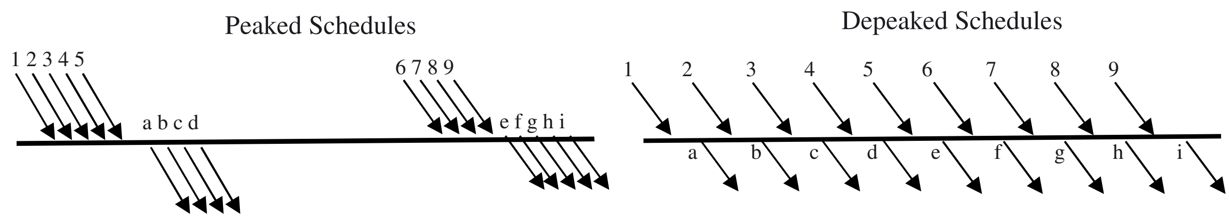

Figure 1.1 Connection opportunities with banked and continuous schedule design.

Under peaked scheduling, flights 1-5 are scheduled to provide connections to flights a-d and flights 6-9 are scheduled to provide connections to flights e-i. Under continuous scheduling, some of these connections (e.g., 3-a and 3-b) are broken, yet additional connections (e.g., 5-e and 5-f) are created. It has been noted that the average passenger volume of the markets which lost connections in depeaking and were removed from the schedule were less than a third than those markets which were maintained (Goedeking & Sala, 2003). The problem is that no mention though was made of the connections that were created in the process. Connections 5-e and 5-f could be much more profitable than the broken connections.

In addition to the lack of information on depeaking, there is no objective determination as to whether depeaking is good or bad for the airport. As described before, there is some information available on depeaking's effects on airlines, especially from the cost side. For airports, however, no statement has been made or studied. The airport may not have a role in the decision, but as an important stakeholder, it is a problem that there is no information for the airport as to how depeaking can affect it.

1.4 Research Question

In order to address the research problem, several research questions were developed to guide the research project. These questions are the ones that will be attempted to be answered through the work of this study, and are purposefully asked to motivate finding solutions to the previously described research problem statements. Each question would build on the body of knowledge for depeaking. The research questions are:

- What are the differences between different airlines' depeaking implementation?
- How did depeaking affect airline revenue?
- How did operations change at the depeaked hub?
- What was the effect on the competition at the depeaked hub?
- How did airlines decide which changes to make in their network when depeaking?
- What is the effect on airport revenue?

1.5 Purpose Statement

Taking a banked schedule and depeaking it certainly comes with risks. The need to, at the least, balance saved cost and lost revenue is important. It is plausible that depeaking negatively affects revenue to such an extent that the saved cost leaves the airline in a worse situation than when it started.

The purpose of this study is to quantitatively and qualitatively examine how depeaking can be used to control cost at an airport hub without hurting revenue and operations to the point where the change does more harm than good. The intent is to help airlines and airports prepare for depeaking, and to be made aware of the risks. Part of this is the objective to compare and contrast depeaking examples to provide a reference for what depeaking is and what it can be reasonably expected to do for an airline. By quantitatively analyzing the network decisions airline’s made in depeaking the airline and airport can be better prepared for deciding to depeak in the future.

To accomplish these overall goals and answer the research questions, the following objectives were developed:

- Identify how past studies have evaluated depeaking and what additional steps can be taken to further their conclusions.
- Understand the background of what gave rise to banked schedules, why depeaking occurred, and what the benefits were discussed as being at the time.
- Develop a methodology to examine revenue and operational impacts of depeaking based on publicly available data. The methodology includes determining how to attribute affiliate airline traffic to parent airlines and developing a heuristic method to identify banks in a schedule.
- Determine if public data sources can be used to identify which airlines depeaked and when they depeaked.
- Develop measures to describe the effectiveness of depeaking.

- Evaluate supply, revenue, and operations changes using a difference-in-difference technique.
- Use multivariate regression model to investigate the decision-making process of airlines depeaking their schedule.
- Measure the relationship between airport profitability and passenger connection time.

1.6 Contributions

This paper contributes to the field of aviation through practical knowledge, methodologies, and relevant conclusions that can be put into practice.

Practically, this paper contributes to the literature by identifying those airlines and airports that depeaked from 2000-2010, a list which is not found elsewhere. It also contributes by determining the context under which each airline depeaked.

Methodologically, this study develops data cleaning and analysis methodologies based on publicly available data that are used to assess revenue impacts associated with schedule depeaking. A new methodology is developed to heuristically identify banks within a peaked schedule, and specifically to determine the number of peaks in the banked schedule, as well as the number of adjacent time periods to define as part of a bank. This study is also unique in that it develops a methodology for recreating historic schedules flown by parent and their affiliate carriers based on combining the On-Time and DB1B ticketing databases available from the Office of Airline Information of the Bureau of Transportation Statistics (BTS).

Lastly, this study contributes to the industry by quantitatively and qualitatively evaluating depeaking. It is the first study to evaluate the revenue impacts of depeaking. In addition, both the revenue and operational impacts are assessed across cases for a broader understanding of depeaking's effects. The study contributes an understanding of the depeaking decision-making process so that in the future airlines can compare their current situation to past cases and assess their best course of action. For airports, this understanding allows them to assess potential future changes in service to other cities that may be cut or added due to depeaking. Lastly, the study formalizes relationships between passenger connection times and airport revenue, which could assist airlines in discussions with airports about the positive benefits of depeaking.

1.7 Note on Naming Conventions

Throughout this dissertation, the official names of airlines, their common-use names, and operating codes are used interchangeably (e.g. Delta Airlines, Delta, and DL). A list of airline operating codes used in this report can be found in Appendix A. Similarly, a list of airport names and airport codes can be found in Appendix B.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Depeaking has received increased interest in the literature since American Airlines depeaked its hub at Chicago O'Hare airport in 2002. As other airlines attempted the strategy at their hubs, research efforts focused on the reasons airlines decided to depeak, defining performance measures to evaluate the effects of depeaking, and evaluating the results of implementing continuous schedules. The following chapter describes how peaked schedules developed during the post-deregulation period, and discusses the history of depeaking and why it arose as a strategy used by legacy airlines a decade and a half later. American Airlines is described in further detail to explain some of the typical results of depeaking.

This chapter also includes background on other areas of significance related to this project. Included in the discussion are sections on how competition is affected by depeaking, peak scheduling in other industries, background on affiliate airlines and how their contracts are structured, and the revenue effects for airports due to the longer transfer times of depeaked schedules.

In the following few sections, the effects of hub-and-spoke networks, flight banks, and depeaked schedules are discussed on how they affected passenger fares and revenue for the airline. The reader will notice that depending on the source, the different network and schedule changes are perceived as increasing or decreasing fares. To make sense of the differing opinions, section 2.4 summarizes the different beliefs, and provides some insight into the different conclusions. One of the goals of this research is to examine depeaking through a more rigorous analysis to gain perspective on these uncertain answers.

2.2 Rise of Banked Schedules

After deregulation, hub-and-spoke networks and banked flight schedules developed around the same time. The shift in 1978 from a highly regulated aviation market to one where airlines could make decisions and operate without government intervention set off a period of innovative practices in the industry. The U.S. aviation business redefined itself in a very short period.

2.2.1 Development of Hub-and-Spoke System

On October 24, 1978, the Airline Deregulation Act (ADA) was signed into law, a decision which was the culmination of nearly three years of congressional hearings. Prior to the enactment of the ADA, experts described what they envisioned the post-deregulation aviation industry to look like. There was very little discussion, however, on the potential for a new route structure under deregulation (Evans & Kessides, 1993), and none of the predictions foresaw the emergence of the hub-and-spoke system (Levine, 1987). Instead, it was expected that airlines would continue to use linear route structures, just as the intrastate airlines, which were never federally regulated, had been using all along.

Prior to deregulation, only Delta and Frontier Airlines operated a hub-and-spoke system, the former out of Atlanta and the latter out of Denver. After deregulation, the hub-and-spoke model was widely adopted by airlines and became the route structure of choice. Many airlines were reluctant to develop such a system under regulation because it required permission to exit a market. In addition, the barriers to entry of a market made it difficult to achieve demand-side benefits associated with networks (Gillen, 2005). Thus the reconfiguration of networks after deregulation got driven by the underlying economics of the industry that were just waiting to be in the driver's seat.

The economics that drove the development of the hub-and-spoke system in the industry are described by Gillen (2005) to be two primary network effects: (1) the compatibility of flights in each market and (2) the internalization of externalities in using spokes as feeder traffic for trunk routes. Gillen describes that in a linear connected network, direct flights achieve direct density economies, such that the presence of a non-stop flight in a market attracts more demand than having a connection in between. Thus, a non-stop flight is preferable to a connection for the airline, all other variables aside, because it attracts passengers.

The linear network with many direct flights, however, is not cost effective and does not optimize profit. The combination of high frequencies and larger aircraft are simply not possible in a system served by non-stop flights (Kanafani & Ghobrial, 1985). A hub-and-spoke network allows more flights for a given traffic density on the spokes, and cost levels can be reduced by ensuring a compatibility of flights to these markets (Gillen, 2005). By matching smaller aircraft to smaller markets, these aircraft can work as feeder services to larger trunk routes through the hub connection. Large trunk routes can fly large intercontinental aircraft long distances, at the same frequency of the small market. This internalizes the externalities of the system by pricing tickets so that the feeder spokes can offer higher frequencies and be more cost efficient, while pricing trunk routes to have heavier traffic with demand created throughout the system. Airlines thus consolidate flights to a few hub airports to take advantage of the higher volumes which are a result of the change (Kanafani & Ghobrial, 1985), using large aircraft to service those demands and taking advantage of the economies of large aircraft size. It is then also possible to increase service frequency as well, a benefit to passengers which slightly offsets the increase in travel time due to transferring.

The hub-and-spoke model was preferred by deregulated airlines for a number of reasons. First, by developing a network focused on a hub the airlines were able to keep costs down and reduce fares (Button, 2002; Evans & Kessides, 1993; Levine, 1987). These goals in some part were achieved through increased load factors. This increase reduced the cost per passenger mile on traffic to the spokes in the network and also helped reduce fares in the hub-spoke markets (Evans & Kessides, 1993; Siegmund, 1990). In addition, the hub-and-spoke model allowed for airlines to keep aircraft in the air longer than a linear network and enabled airlines to coordinate aircraft maintenance, both aiding in the reduction of cost relative to revenue (Button, 2002).

The second reason for the shift by deregulated airlines to a hub-and-spoke network was it allowed an overall increase in the scope of their operations (Evans & Kessides, 1993), both in breadth of markets and service frequency. By reducing the number of direct flights offered in the overall network, the airline repurposed aircraft to serve hub-spoke routes continuously. By aggregating their traffic from a variety of origins and making passengers connect through a hub, the airlines increased their number of city-pair routes (Evans & Kessides, 1993; Levine, 1987). This aggregation of passengers at the hub allowed for medium and small markets to get service to destinations across the system, when typically no service would be available at all because the traffic density would not support it. As described by Levine (1987), each additional spoke adds to the system such that there is a geometric expansion in the number of markets being served. As described by Franke (2004), the system accomplished a disproportional increase in connections at just an incremental cost.

To the surprise of those who thought service frequency would decrease after deregulation, service frequency among markets increased because of the rise of the hub-and-spoke network. The increase occurred because each additional aircraft departure to an additional spoke provides many alternatives for connecting flights (Winston, 1998). Increased service frequency also was beneficial for the airline because it satisfied the needs of the high yield business customer (Gillen, 2005). Airlines preferred this network type because it positioned them to capture higher fares from customers desiring a broad range of destinations at high frequencies. A final advantage of the increase in schedule frequency is that it gave the airline a prominent share of the market (Kanafani & Ghobrial, 1985), which in turn provided increased returns on market share.

The final reason airlines turned to hub-and-spoke networks was the market power it provided and the savings generated from economies of scale. The hub-and-spoke model kept concerned airlines reassured that they could survive deregulation because it provided protection from new airlines entering their hub (Levine, 1987). With one airline having strong market power at a hub, other airlines did not enter that hub unless providing service to and from their own strong hubs. A hub’s market power also extended to reservation systems. The hubbing airline dominated the Computer Reservation System

(CRS) at the hub, and with their large volumes and variety of flights, it could create more effective CRS override programs, such as incentives for travel agents to encourage them to sell seats on the hubbing airline (Levine, 1987). Agents were exposed to more information from the dominant hub airline, and thus sold more tickets for it than competitors (Siegmund, 1990). Even the distribution of information to consumers gave the hub airline an advantage. A dominant hub airline could afford the costs of developing and communicating information about schedules, seat availability, service features, and prices to consumers (Levine, 1987). These consumers, exposed to a greater concentration of information about one airline than others in a market, would choose the same hub airline continuously for future travel.

Being in control of an airport also gives the airline an advantage in setting fares in markets. Through operating a large percentage of the available gates, the airline has the ability to increase fares in markets since they likely have greater frequency of service and exposure to the customers (Siegmund, 1990). Hanlon (1996) describes how the average fare to and from hubs are much greater than the average fares on other routes provided by the airline; a premium for traveling to and from the hub. This fare increase becomes accentuated when competition is reduced on these hub routes, and the hub airline can increase fares further. The hub airline's control of an airport also garners it cost savings from economies of scale due to the centralizing of maintenance, reservations, sales, and general traffic services. Lastly, even though the average cost per passenger does not decrease as passenger volume increases (Kanafani & Ghobrial, 1985), with a hub, the incremental cost of adding a passenger is much lower than the incremental revenue that passenger brings to the system (Levine, 1987).

2.2.2 Banked Schedules at the New Hubs

Once a hub-and-spoke system was implemented, the preferred scheduling design post-deregulation was a banked schedule. Coordinating the arrival and departure of aircraft became ever more important as competition increased at major airports (Hanlon, 1996). Flight banks occurring repeatedly throughout the day gave passengers many options for service, reasonable travel times, and lower fares. Airlines claimed that a banked wave structure was designed to meet passenger expectations, particularly convenient access to many destinations, based on responses they received from travelers over time (Button, 2002; Kemppainen et al., 2007). Airlines felt safe to assume that passengers desired to minimize their total elapsed time, creating banks to achieve this goal (Theis et al., 2006).

The key aspect of a banked schedule was that all aircraft would arrive and depart in a short period of time. In this system, it was necessary to schedule all arriving flights ahead of any departing flights. This allowed passengers to make transfers between all aircraft, and maximize the number of origins and destinations pairs they could travel between (Kanafani & Ghobrial, 1985; Daniel, 1995). Maximizing the amplitude of each bank only further increased the potential benefits (Hanlon, 1996). The time for these transfers needed be long enough to permit passengers to get between any aircraft in the arrival and departure banks. The quick turnarounds also kept aircraft in the air longer than in a linear network, keeping fares low and attracting more passengers to the system (Button, 2002). More importantly, though, is that banked schedules provided more choices of service for passengers (Button, 2002; Gillen, 2005; Siegmund, 1990). Airlines accomplished this by providing many gates close together in a single terminal to handle the peak flow of passengers. More options opened up to the passenger because of the simultaneous arrival of many flights going to dozens of destinations.

Banked schedules were favorable for airlines because they retained a reasonable travel time as compared to a direct flight. A fast connection kept the airline's offering for a given market competitive. By having flights arrive in a bank, passengers were able to connect quickly and not be burdened by dwelling in a terminal for a longer period (Button, 2002; Dennis, 2001; Siegmund, 1990). Passengers value both their time in the air and on the ground. Reducing overall elapsed time in the schedule made it more convenient for a connecting traveler (Levine, 1987). Although a nonstop flight was superior in total elapsed travel time, a connecting flight could be cheaper at the expense of time, but not too much longer to not be competitive.

Having flights arrive at the airport and requiring servicing simultaneously is the major drawback of banked schedules. It is acknowledged that when complex hubs coordinate all arrivals into banks, it poorly utilizes labor and equipment which sit idle in between banks (Button, 2002; Gillen, 2005). This drawback, however, can often be minimized with careful staff scheduling.

Hub-and-spoke networks are a successful innovation in their own right, but banked scheduling amplified their success. At a given airport, banked schedules increased the dominance of the airline hubbing there (Dennis, 2001), further amplifying the airline's market power.

2.2.3 Adding to Banked Schedules

The growth of passenger traffic in the aviation industry has resulted in airlines having to prepare for additional travelers in their schedules. Simultaneously, airlines in periods of good growth aim to add new destinations from their hub to reap the geometric effects on revenue each connection contributes to the network. Dennis (2001) discusses how airlines have two options for these new flights: (1) add new banks to the schedule, or (2) add to the edges of existing banks. Both of these have their share of complexities. The first requires moving flights from other banks to create a new bank of flights, or adding additional daily flights to a destination to fill the new bank. The second option has the potential to add to a passenger's waiting time, which risks pushing the passenger to a competitor or to not fly at all. The second option though has the potential to be favorable over the first option, because adding to the periphery of the banks could have multiplicative benefits.

In order to explore the multiplicative effect of adding to a bank, Dennis (2001) examines the relationship between the number of flights in a bank, the necessary connection time, and the amount of potential connections that can occur. Using as an assumption an airport that has the runway capacity to handle 60 arrivals and departures per hour and a minimum connection time of 30 minutes, Dennis finds the optimal size of a bank is 50 aircraft, as seen in Figure 2.1. As banks become too long, due to a limited capacity for runways to process arrivals and departures, the waiting times for passengers become extended. Any additional connections created by placing a flight at the outskirts of the bank act to only increase average waiting times, thus marginal waiting time increases with each additional flight in the bank.

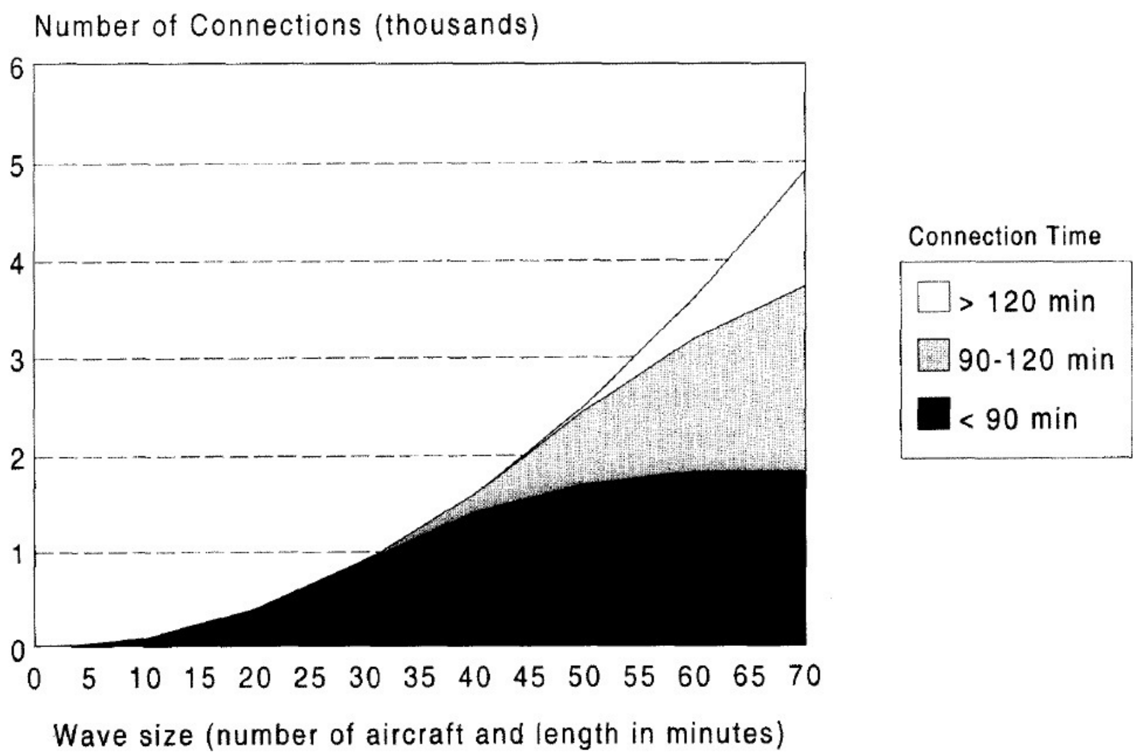

Figure 2.1 Increase in connections with respect to bank (wave) size (based on 60 arrivals/departures per hour and 30 minute minimum connection time). ***Source: Dennis (2001)***

Because adding to a bank can have negative effects after a certain point, airlines have historically gone in the direction of adding more banks throughout the day. This had the added benefit of increased flight frequency which was attractive to travelers. Airlines at busy airports, like American at DFW and Delta at ATL, had as many as 11 and 10 banks a day, respectively. They maintained a disciplined series of arrivals and departures that squeezed as much revenue out of the airports' runway capacities (Dennis, 2001).

Whether adding banks or to the periphery of banks, airlines must consider a number of variables (Hanlon, 1996). First, the airport and the airspace have limited capacity, perhaps the most important factor when determining changes to a schedule. If the infrastructure and travel patterns cannot handle an increase, it cannot be forced through. Second, flight safety needs to be considered, so that passengers and crew are not put at risk due to the intensity of operations. Lastly, rostering for crew and aircraft allocation has to be considered carefully so that work limits are not exceeded and maintenance schedules are still met.

2.2.4 Looking for Another Option

The results from the 2001 study by Dennis showed that there is an upper bound for the potential of banks in a schedule. Banks can only get so large before more banks need to be added and the bank size reduced. The probability of capacity getting increased, such as adding additional runways, is low in the short time-frames airlines have to adjust their schedules. When airports are congested and nearly a dozen banks are operating daily for an airline, there are few options left.

As just mentioned, an expensive capacity increase is likely not plausible to solve an airline's connection time issue within its banks. One option has been for airports to make investments to reduce the minimum connection time for passengers by rearranging terminal and gate assignments (Dennis, 2001). This is not always possible, however, as the airport has contracts with many airlines, and it could involve coordinating with competitors, with the hubbing airline likely being the only one to reap the benefits.

Searching for an option that is within an airline's own power to control, airlines looked toward depeaking their schedules. Depeaking, however, is a major challenge in itself, and similar to the rise of hub-and-spoke systems, a strong stimulus was needed to convince airlines it was a good path to explore.

As described earlier, the rise of hub-and-spoke airline systems and thus the emergence of banked schedules occurred during a volatile period in U.S. aviation history. These characteristics developed just as the industry was suddenly expanding due to deregulation, and subsequently contracting domestically as airlines merged and went bankrupt in the free market environment where fares were not set by the government (Evans & Kessides, 1993). During this time of change, innovative practices flourished. Over two decades later, the events of 9/11 changed the airline industry, and from this volatile change, the innovative practice of depeaking emerged.

2.3 The Switch to Depeaked Schedules

The airline industry is always changing and adapting, keeping itself at the frontlines of operations research and developing new concepts. Depeaking, a term to describe an airline implementing a continuous or rolling schedule at a hub, arose in the early 2000s as a viable option to solve rising costs in the system. The central premise is that one can save more cost from being efficient with labor, equipment, and real estate than from lost revenue by connections becoming too long or too short.

Taking a banked schedule and depeaking it certainly comes with risks. The need to, at the least, balance saved cost and lost revenue is important. It is plausible that depeaking negatively affects revenue to such an extent that the saved cost leaves the airline in a worse situation than when it started. In addition, the belief held by Button (2002) is still applicable in many situations: that the loss due to spreading out of services to better make use of landside staff and facilities is more than offset by the additional passenger benefits which come from convenient connections amassed in a bank.

The following subsections describe the problems with banked schedules and how these problems results in a need for depeaking, what the business climate was like in the early 2000s that led to the depeaking trend, and the decision points airlines have to consider before depeaking.

2.3.1 Depeaking's Need - Problems with Banked Schedules

Banked schedules, as described previously, had many benefits that led to their rise post-deregulation. As both airport airside and landside congestion increased over the decades, having aircraft from the majority of spokes arriving in a short time period became a problem (Gillen, 2005). With large numbers of aircraft and passengers congregating at the hub during each bank, problems arose simply from the facilities being used near or at their capacity (Button, 2002). Banks simply required more capacity per unit of traffic served than a non-banked schedule (Kanafani & Ghobrial, 1985). The temporary congestion caused by the massive peaks reduced airside productivity such that large queues formed for the runways (Franke, 2004), and became an issue for aircraft that needed to turn around and meet schedules. Overall, punctuality for the aircraft decreased in an environment where there were time critical connections. Passengers also had to deal with transferring in a crowded terminal, under a very short time window.

The congestion issues decreased the quality of service for a connecting passenger. It has also been seen that passengers were not willing to pay the premiums that once supported a wide array of opportunities for having convenient connections. Customers were willing to give up time in their schedule in order to fly on lower priced tickets (Mecham, 2004). Ultimately, passengers never preferred unconditionally the shortest possible connection, but rather the shortest connection which they know they can successfully make (Theis et al., 2006). Passengers are both risk averse and rush averse. If passengers have this flexibility in their travel time, and are glad to have a connection which does not require high stress, legacy carriers do not have to focus on maximizing scheduling connections and minimizing connection times. The presence of a large of group of customers who are non-time-sensitive encourages major airlines to depeak.

A second issue with banked schedules is the inefficient usage of airport infrastructure and airline resources. The airline needed to have its aircraft arrive simultaneously to provide a multitude of short connection opportunities, setting the upper limit for resources during this time period. The airport must have enough gates for all arriving aircraft, and the airline must have enough staff, crew, and equipment. Having enough of all of these resources on hand to serve the peak is inefficient (Dennis, 2001; Theis et al., 2006), because during the periods between banks, the staff, gates, and equipment sat idle. These inefficiencies cost the airline because they needed excess resources to handle only the maximum activity, and be ready to serve the sharp surges in activity (Hanlon, 1996). By reducing the peak labor needs, there is an increase in productivity in the workforce and cost is reduced as services are spread through the day (Abeyratne, 2000; Gillen, 2005; Mecham, 2004). The minimizing of connection time, however, should only put into place if the anticipated revenue that would be gained would be larger than the additional operating costs that would result (Theis et al., 2006). It is the hope of the airline that a peaked schedule would be more attractive to the connecting passenger, so that revenues increase to a great enough degree.

A final issue with banking is the effect it has on aircraft operations. The traffic pattern during the banks is dominated by the hub airline's aircraft, and these peaks every few hours exceed the airport service rate (Daniel & Harback, 2008). As a result, queuing delays increase and add cost to the airline. Runway congestion from the bank of flights, along with the potential to have to wait for passengers who are running to make their connection, increase the delay for aircraft movements (Hanlon, 1996; Theis et al., 2006), even when the individual aircraft and its crew are performing at their best. The arrival rates peak less severely than departure rates, because arrival queues are more costly than departure queues (Daniel, 1995), but both are at risk for added cost. Banked schedules are also at greater risk to weather events, as a single weather delay can affect all of an airline's flights and cause disruptions throughout the airline's network (Hanlon, 1996). The banked schedule also incurs a high cost because aircraft dwell at the hub for a long period of time waiting for feeder flights to arrive into the bank (Daniel, 1995). The earliest arriving aircraft and latest departing aircraft have the greatest layover costs as these aircraft sit and wait for all other aircraft to arrive and/or depart. By reducing aircraft delay through depeaking, Daniel reports in 1995 that Minneapolis-St. Paul, as an example, could accommodate 30% more traffic per day.

The peaked schedule is great at maximizing the number of connections between airports in the system. Not all connections, however, are profitable ones (Hanlon, 1996). Often times flights into and out of the hub are only there to ensure there is an aircraft waiting at the spoke for passengers (Theis et al., 2006). Aircraft are kept at the hub with lengthy and expensive waits for connections to all be made. Hanlon discusses that instead of maximizing connections, airlines should aim to maximize profitable connections. With careful network planning, airlines can reduce redundant connections and ensure that useful connections are prioritized in scheduling. Connectivity can still be emphasized, but not at the expense of profitable connections between critical cities.

Switching from the hub-and-spoke banked model to a hub-and-spoke model that still emphasizes connectivity can solve many of the issues hub airlines have with banked schedules. Many airlines have experienced these changes post-9/11 by experimenting with a more continuous flow of flights (Gillen, 2005). By depeaking schedules, airlines expect to accomplish the following (Kemppainen et al., 2007):

- Reduce the congestion at the gates and overall number of gates
- Reduce congestion at the runway during peak periods
- Decrease the number of aircraft needed to fly on specific routes
- Decrease their airside and landside airport staff size
- Improve the reliability of their schedule

These positive benefits are the key aspects of depeaking which allow cost to be saved. The benefits are achieved by tackling the biggest issues with banked schedules: airport congestion and inefficient usage of infrastructure. In the next subsection, however, the opposite argument, to stay peaked, is discussed.

2.3.2 Why Not Depeak?

Despite the cost benefits of depeaking, there are risks involved with depeaking that could dissuade an airline not to depeak. First and foremost, there is a large risk to an airline's revenue. Depeaking is expected to reduce ticket revenue because of extended connection times that become undesirable for passengers (Luethi, Kisseleff, & Nash, 2009; Mecham, 2004). In addition, some connections become so long that they are no longer marketed. The longer elapsed time is associated with a reduction in service quality (Gillen, 2005); passengers are then willing to pay less for this lower service level. Overall, there would be loss of traffic in many local markets, putting some at risk for service because the number of passengers needed to maintain a link is reduced too much.

Dissent towards depeaking has also been brought up in reference to its effect on operations. Although many studies tout depeaking's positive effect on on-time operations and reduced congestion risk (Flint, 2002; Goedeking & Sala, 2003; Jiang, 2006; Kemppainen et al., 2007), a recent study contends that depeaking contributes to delays when they hurt the most (Jenkins, Marks, & Miller, 2012). A depeaked airport is more susceptible to bad weather because the valleys between the banks are no longer present to allow for recovery in the system. The authors do not dispute that depeaking is an effective cost fix, and note that in normal weather depeaking is more efficient at using the gate areas, ramps, equipment, and staff. Their concern arises during irregular operations when a depeaked schedule has the potential to contribute to flight delays. The authors find that airports with the most peaked schedules have the lowest observed aggregate delay rates, although no statistical correlation exists. They also point to an increase in aircraft turn times since the depeaking trend began.

2.3.3 Difference from Low Cost Carrier Scheduling

Continuous scheduling has been used for a longer period of time than the short period in which full-service carriers have been operating with depeaked schedules. Low cost carriers, particularly Southwest, have been using continuous schedules at the airlines' focus cities. It is not uncommon for legacy airlines to look towards Southwest to gain perspective on how to increase market capitalization (Bogusch, 2003). American Airlines used Southwest as a model in looking at how the airline operated such a schedule, particularly in how turnaround times can be reduced with the effective use of manpower (Ott, 2002, 2003). Bogusch (2003) examines the American Airlines schedule from after its depeaking, and describes it to be emulating the Southwest schedule.

Southwest does not particularly schedule connection opportunities at its focus cities, but allows them to occur naturally if two flights are within a certain time window in the schedule. By having a sufficient number of services available, they are able to combine flows necessary to operate into new markets (Dennis, 2001). Although flights are not scheduled into banks, passengers are still willing to put up with a longer wait time in order to save money on their fare. The low cost carriers (LCCs) also use the continuous schedule to spread out their staffing, ground handling, maintenance, and gate needs to achieve savings (Gillen, 2005), a model some of the full-service carriers have looked to follow.

The flexibility on the passenger's part to have longer connections, the ability to still have connections in a continuous schedule, and the savings associated with staff and other services, provides a motivation for a legacy carrier to depeak. The difference is that connections with the hubbed legacy airline are purposeful and planned. Although banks no longer exist, the hub-and-spoke system still does, and connections are critical to survival of the airline. A balance must be struck between preserving connections with high revenue potential, and smoothing the schedule so resources can be used more efficiently. Gillen (2005) believes though that the depeaked hub-and-spoke model will soon be the dominant network structure and represents a convergence of the legacy carrier and LCC network types.

2.3.4 Climate for Depeaking

Although the hub-and-spoke model has been described "on its face to be the natural method of structuring airline networks" (Evans & Kessides, 1993), the past decade has seen a wide array of changes in the airline industry. Depeaked schedules arose from the challenges airlines faced, and several airlines saw an opportunity to respond to changing markets. Thus what once was thought as the natural way of the airline industry has been reinvented to respond to changing conditions.

The events of 9/11 caused an economic downturn that particularly affected the airline industry due to the terrorist attack's connection to aviation. Many airlines spent the final quarter of 2001 and the beginning of 2002 evaluating their business practices, and struggling to make it through low passenger volumes (Bogusch, 2003). In order to survive, United Airlines and US Airways filed for bankruptcy. These challenges, however, were seen by American as an opportunity to reform its business processes, and American began to experiment with introducing more continuous arrival flows at some hub airports.

The rise of the Internet ticket booking era also aided in the ability for airlines to depeak schedules because the Internet changed how customers identified and compared flight options. Previously, travel agents played a large role in what flights customers were made aware of. Travel agents relied on terminals linked to a CRS for flight information. Travel agents tended to sell passengers tickets from the first page of results in the CRS for a given origin and destination (O&D) search (Flint, 2002). The CRS page results were ordered by shortest travel time, and thus a short connection at a hub airport was more likely to be booked by a potential passenger because these connections appeared at the top of the screen (Theis et al., 2006). Travel agents booked 80 percent of tickets from the first display page, and 50 percent from the first line of the display (House of Lords, 1998). It was critical for an airline to have its flight make it onto the first page in order to get travel agents to book passengers on the flight. As a result, airlines focused their flight planning on short connections. A banked system was the strategy that best met this goal. Today, most airlines' online booking displays prioritize flights by fare, and it is no longer critical for airlines to offer the shortest connection in the market in order to garner bookings (Jiang, 2006). There is no regulation on display order for Internet sites (Theis et al., 2006). The Internet has made banked schedules less important because it has reduced the importance of short connection times for booking purposes.

The combination of an era of tight finances and the rise of the Internet made the climate ripe for airlines to choose to depeak their hubs. American was the first to recognize and act upon this change, but others would soon test the waters as well.

2.3.5 Choosing to Depeak a Specific Airport

Part of the decision to depeak an airline is beyond a motivation to cut cost, and lies with the airline's scale of operations at the hub and geographic realities of connecting flights. Large hubs are the best candidates for depeaking because the high number of connections on profitable main routes can still be maintained, due to high flight frequencies, and aid in minimizing any revenue loss that depeaking will cause (Luethi et al., 2009; Mecham, 2004). Even midsize airline hubs are difficult to depeak because there are not enough flights to allow depeaking while maintaining a profitable level of connections. In addition, hubs are typically the connection point for larger international aircraft. Large hubs that serve a large number of smaller spoke cities are best suited for filling seats on these larger aircraft, because they are able to combine many passengers from a variety of origins (Franke, 2004). Another important factor is for there to be a high level of domestic traffic, such that the level of international flights is small relative to shorter domestic flights (Goedeking & Sala, 2003). The economies of scale thus give large hubs the greatest likelihood for depeaking success.

The geographical location of an airline hub plays a role in determining the success of a depeaked hub. A continuous schedule works best if there is directionality in the connecting traffic (Goedeking & Sala, 2003). DFW and ORD are great targets for depeaking because there traffic is primarily heading east-west, with very little traffic north-south. Goedeking and Sala describe how American chose to maintain banks of flights coming in from one half of the country, but arrivals from the other half were spread out in a constant flow pattern irrespective of connection opportunities. A hub which has omnidirectionality, with flights coming in from all around, has a reduced ability to create a pattern for its operations. In fact, a major reason that high levels of international traffic are bad for a depeaked hub is because of its need for an omnidirectional source of connections. For these reasons, MIA is not a suitable airport to depeak. It is a good example of a hub that is geographically challenged and has little directionality to its traffic (Zhang et al., 2004); still American depeaked it in 2004. A summary table on the factors that could play into a decision to depeak an airport is listed in Table 2.1.

Table 2.1 Depeak or Don't Depeak? Factors for Consideration *Source: Goedeking & Sala, 2003*

De-peaking	Traditional Hub System
High directionality	High multi-directionality
Little long-haul	High number of long-haul flights
High volumes	High dependence on connectivity
Limited airport capacity	

2.4 Uncertainty in Effects of Depeaking

Revenue implications of different schedules have been unclear as far back as deregulation. Hub-and-spoke systems and peaked schedules have been described by researchers at different times to either increase or decrease passenger fares, and affect revenue accordingly. As revenue implications of depeaking are a major focus of this study, it seemed prudent to discuss the differing views on how fares and revenue change due to these structural schedule changes. All sources mentioned here were previously mentioned in the last three subsections.

2.4.1 Hubbing and Price

Hub-and-spoke networks are described as being able to reduce fares because the network structure reduces cost for the airline, and thus reduce the cost per passenger (Button, 2002; Evans & Kessides, 1993; Levine, 1987; Siegmund, 1990). The cost per passenger is reduced because higher load factors are achieved through the consolidation of flights at the hub, keeping planes in the air longer than in a linear network, and coordinating maintenance. These authors perceive the airlines as passing the cost savings on to the passengers' fares.

Experience in the hub-and-spoke network, however, has shown that hubbing increases fares for flights traveling to and from the hub. Siegmund (1990) provides evidence that fares increased greatly, faster than elsewhere in the system, when a hub was developed at an airport. The author describes the reason for this being that the airline operates a large percentage of the gates, and can control the fares in markets because of higher frequencies of flights and greater exposure to passengers. Hanlon (1996) finds this also to be true, noting how flights connected to hubs have greater average fares than other routes served by the airline.

In the case of hubbing, it seems that in theory, hub airlines would reduce fares because of their savings on cost. What occurs, however, is airlines make use of their market power to turn a greater profit. By controlling the hub and the majority of markets that connect to the hub city, airlines can raise fares higher than if they did not control the hub.

2.4.2 Peaking and Price

The effect of banked flight schedules on fares is also split in opinion. It is perceived by Button (2002) that the short connections of banks reduce fares at hub airports greater than they would have been with long connections. Button argues that the narrow time window for changing aircraft actually lowers fares because traffic is concentrated into a short period. Button does appear to contradict himself, however, by stating that passengers have a high willingness to pay for the concentration of connecting services, which would imply that fares should be higher.

Button's contradiction is backed up by authors describing banked schedules to have higher fares. Mecham (2004) implies that there is a premium paid by the passenger to have such a convenient connection. Describing that passengers are certainly willing to give up time in their travel to fly on a lower priced ticket implies that the airlines' maximizing of connections came at a cost to the passengers. Luethi et al. (2009) agree with Mecham that a short connection is something of value and worth paying for by the passenger, noting that passengers will travel on the extended connections of depeaking only if fares are reduced.

The information presented on peaked schedules' effects on fares seems to lean towards causing fares to increase.

2.5 History of Airline Depeaking

Airlines have continuously adjusted schedules and experimented with ideas to better increase profits and reduce costs. As discussed in previous sections, there are trade-offs between peaking and depeaking. Thus, airlines have seen the benefits of depeaking at different periods over the past decade, and sometimes have repeaked a schedule after depeaking it. The following subsections describe the history of depeaking, to help add context for what happened in terms of supply changes and revenue shifts.

2.5.1 Major Airline Events of the Early 2000s

Depeaking was just one of the major events for airlines over the first part of the 2000s. This period, was marked by many of the legacy carriers experiencing bankruptcy for the first time. Dehubbing occurred and mergers took place. Figure 2.2 shows the major airline events that occurred during this time period, to provide context for discussion later on when depeaking took place.

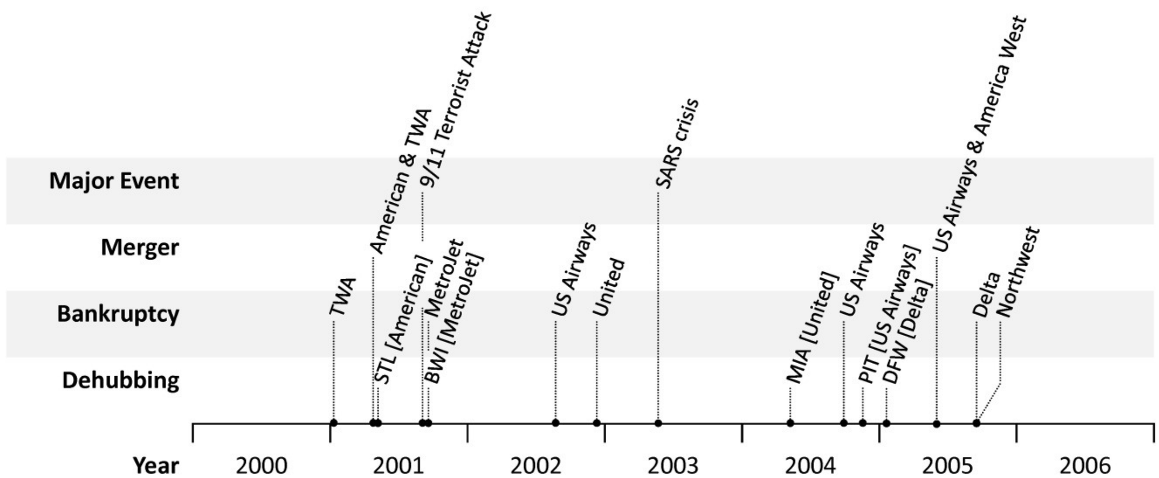

Figure 2.2 Timeline of major airline events in the first part of the 2000s.

The effects of the 9/11 terrorist attack and the SARS outbreak in the Asian-Pacific region caused a drop in traffic for the U.S. airlines. This unexpected loss of revenue pushed many of the airlines into bankruptcy, to merge, and to remove hubs from their network.

Depeaking was another effect of this period, and the following subsection describes the airlines that made this strategic move to change their cost structure.

2.5.2 Airline Depeaking Timeline

The combination of an era of tight finances and the rise of the Internet made the climate ripe for airlines to choose continuous scheduling at their hubs. Prior to 9/11, Continental Airlines reportedly depeaked its Newark hub (EWR) in either 1997 (Ott, 2002) or the summer of 2000 (McCartney, 2000). It subsequently saw a 20% reduction in delays (World Airline News, 2001). American depeaked ORD in early 2002, and DFW at the end of 2002. American reported many system-level benefits and decided to depeak MIA in 2004 (American's experience with depeaking is discussed further in the next section).

American's positive experience with continuous schedules influenced other airlines to do the same in the middle of the decade. United depeaked ORD in February 2004, Los Angeles (LAX) in June 2005, and San Francisco (SFO) in 2006 (United Airlines, 2006). United is of particular interest because initially it gained market share at ORD due to American's depeaking, but no analysis has been performed since United depeaked. United described the reasons for depeaking its hub as a means of cost reduction and as a way to increase efficiency. Depeaking at LAX, for example, enabled the airline to remove its United Express terminal and consolidate operations.

In 2005, Delta depeaked its Atlanta (ATL) hub in order to make its schedule less chaotic and more predictable (Hirschman, 2004). At the time, ATL handled twelve Delta banks of flights every day, each upwards of 90 flights arriving and departing. Through continuous scheduling, Delta was able to have employees work more steadily, and accomplish more during their shifts. The result was an increase in daily departures and destinations served from ATL. The company's jets increased their daily flying time by 8%, which meant they spent less time on the ground using valuable gate space. As a result, gates at ATL saw 8.5% more aircraft turns after depeaking. It is noted that later in 2005 Delta repeaked its ATL schedule. It is reported that Salt Lake City (SLC) and Cincinnati (CVG) also were depeaked in 2005 (Hirschman, 2004).

US Airways is reported to have depeaked their schedule in Philadelphia (PHL) in February 2005, and repeaked later that autumn. As described by Kirby (2004), US Airways depeaked in order to better position itself during bankruptcy as low cost rival competition increased out of PHL. According to the airline, it enabled them to operate 230 more daily flights system wide, and specifically a 7% increase in flights out of PHL. Simultaneously, they created two additional banks at Charlotte (CLT), their other east coast hub. The depeaking would aid in reducing aircraft turn times, relieving airfield delays, and increasing operation efficiency.

Alaska Airlines implemented a depeaked strategy at its Seattle (SEA) hub, although no year is mentioned for its implementation (Williams & Weiss, 2005). It is reported that the increase in aircraft utilization which resulted for Alaska due to its depeaking effectively added three additional aircraft to its fleet. Williams and Weiss also mention that Continental depeaked its hub in Houston (IAH), as well does Ott (2002), but no year is mentioned for this event.

Due to congestion on the airfield, John F. Kennedy International Airport (JFK) depeaked all operations in 2008 (Ferguson et al., 2010) a rare example of an airport instigating the decision to depeak. The motivation behind the scheduling change was the need for capacity controls. Simultaneously, the two other airports in the New York region, EWR and LaGuardia (LGA), reduced their overall schedule volumes. JFK, however, chose a different approach to maintain its daily flight volume by spreading out its banks of flights. The change enabled the airport to have fewer flight delays and fewer cancelled flights.

This airport-wide depeaking, such as what occurred at JFK, is argued by Jenkins, Marks, and Miller (2012) to have occurred at numerous airports nationwide over the second half of the 2000s. The authors note that many airports in the U.S. have progressively reduced the peaked nature of the combined airlines' schedules as they reached their FAA operational benchmark capacity. The airports depeak to avoid overscheduling throughout the day; they thinned down the peaks and boosted up the off-peak departures.

Internationally, several airports have started to depeak operations. Lufthansa depeaked its Frankfurt (FRA) hub in 2004 to decrease scheduled block times, in an effort to better handle demand variation (Frank et al., 2005). The airline saw an overall travel time reduction for 35 of its 50 most profitable flights. Even during a period where the airport saw a 6% increase in traffic, ground delays for the airline went down 50%. Scandinavian Airlines also depeaked its Copenhagen, Stockholm, and Oslo hubs to reduce costs (Hansen & Warburg, 2006).

2.5.3 American Airlines' Depeaking

American Airlines' experience with depeaking is the most documented in the industry. American was the first airline to create continuous schedules at several of their hubs, and the event made many headlines, particularly because it came at a time when its counterparts were filing for bankruptcy. Two studies review what occurred at American's hubs and came to different conclusions. One study found that depeaked schedules were overall a neutral or slightly positive move for an airline (Bogusch, 2003) and a second study was slightly skeptical of the benefits of depeaked schedules (Zhang et al., 2004). Neither study explicitly examined the revenue implications of depeaked schedules, these early studies focused on operational and cost measures, as described below.

One of the key effects of a continuous schedule is a more consistent experience for ground operations throughout the day. The number of flights arriving and departing has less variation across the time of day. The peak number of scheduled departures within a 15-minute period at ORD was reduced from 15 to nine. This resulted in more efficient staff utilization and the removal of four gates at both ORD and DFW. At DFW, American was able to consolidate its operations into two terminals and cease all flights at Terminal B. Aircraft utilization also improved, but so too did the on-time arrival rate. At ORD, five aircraft were freed up from use, and at DFW nine aircraft were freed up. The mean aircraft turn time decreased on average by five minutes at the hub airports, despite a system wide increase in minimum aircraft turn times to govern the depeaking. The airline realized approximately $100 million dollars in cost savings combined at ORD and DFW by switching to the continuous schedule (Reed, 2006). Overall, many benefits were seen in measures that indicated less variability in scheduling and greater resilience to delays.

Perceived decreases in passenger revenue associated from depeaking discourage some airlines from attempting the scheduling change. The risk in losing customers due to a reduction in potential connections is likely to reduce an airline's market share. American lost 4% of its market share at ORD compared to United Airlines, and lost 1% to other airlines at DFW. This is partly due to the increase in connection times, in the range of between 7-10 minutes per passenger, such that the average connection time was longer than United's. The degree of connectivity decreased, and ORD lost market share to the other American hubs, DFW (still banked initially) and St. Louis (STL). In addition, United actively sought to counter American's strategy, and made their schedule more connected and peaked than before, taking advantage of open runway time (Goedeking & Sala, 2003). In all, the on-time performance on both airlines improved at the hub.

Bogusch (2003) concludes that the decision to depeak "was neutral from a market share perspective, neutral or favorable from an operations perspective, and likely favorable from a cost perspective." The author makes the final point, however, without any rigorous analysis. Zhang et al. (2004) opine that that the airline's widely touted costs savings generated by depeaking are balanced out by losses in market share. These losses, due to layover times, challenge the "widely held view that service does not matter in the era of internet flight booking and declining business travel." The loss of market share, the authors state, should be more explicitly considered in the evaluation of depeaking operations.

2.6 Competition's Reaction to Depeaking

A depeaking airline's competitors have an opportunity to capitalize on the depeaking airline's schedule changes. The depeaked schedule of the hub airline frees up runway capacity and terminal space. Thus, there is potential for competitors to snag runway slots and expand their operations. In addition, broken connections by the depeaking airline can be recreated by competing airlines. At a network level, competitors can also adjust their own hub schedules to adjust for broken connections at the depeaked hub to gather traffic that would have traditionally gone through the depeaked hub.

A hub airline's competitors often avoid the time periods in which the flight banks are occurring. As shown in Figure 2.3, from Daniel and Harback (2008), the non-hub airlines (in grey) cluster their operations to the sides of Delta's banks where runway capacity is not restricted. This helps the competing airlines avoid congestion and delays caused by the rush of activity caused by the hub airline. During the banks, the competing airlines reduce their operations to near zero, preferring to cluster on either side. This diversion to the edges of peaks is caused by airlines choosing to structure schedules in order to minimize the cost to operate them (Daniel, 1995). By summing up all aircraft operating costs, the non-hub airlines see the fringe of the banks as the optimal point to keep costs down.

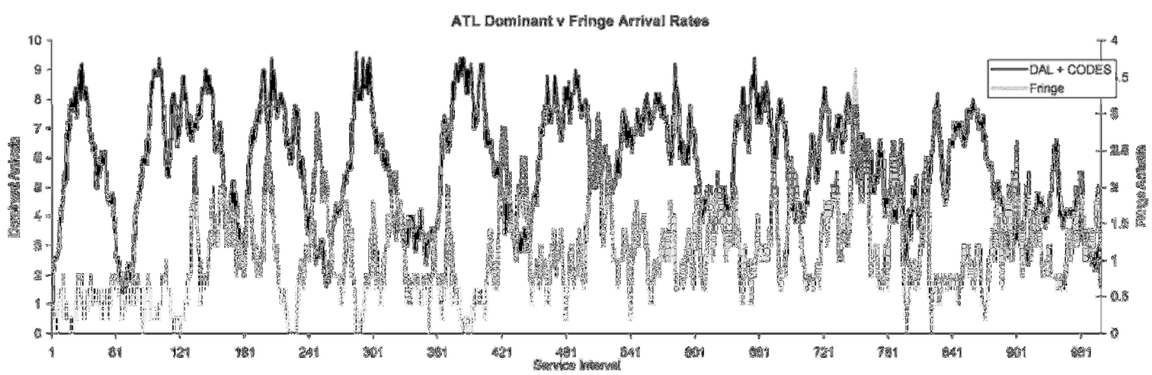

Figure 2.3 Arrival rates of hub and competing airlines in hub operations. Hub airline (black) has a peaked schedule and the competing airlines (gray) operate mostly between the banks. *Source: Daniel and Harback (2008)*

In some cases, there are two hub airlines operating out of an airport (e.g. ATL, ORD, and DFW). In this situation, when one of the hub airlines depeaks its banked schedule, the other airline is able to restructure their schedule to take advantage of the available capacity and broken connections. As previously mentioned, United did precisely this at

ORD when American depeaked in 2002 (Goedeking & Sala, 2003). After American's depeaking, United created a schedule which was even more peaked, and provided shorter and more connections. United was able to implement such a schedule because of the improvement in operating conditions caused by American's depeaking. In this case, the punctuality of both aircraft's flights improved. Delta underwent a similar change after American depeaked their schedule at DFW. Seeing an opportunity to capture American's passenger base that no longer could be served by American's schedule due to broken connections, Delta increased their number of flight banks from six to eight (Delta Air Lines, 2003; Ott, 2003). This change added an additional bank in the late morning and early evening periods, with the airline citing the schedule modification's goal as making the hub more productive.

2.7 Hubbing in Other Sectors

The airline industry is not alone in its use of the hub-and-spoke model for its networks. The freight airlines also make use of hub-and-spoke networks, while both freight and passenger rail have also exhibited this network structure. Of these three, only the passenger rail industry has felt an adaptation to the hub-and-spoke model needed to be made due to its inefficient use of resources.

In the past decade as passenger airlines explored the depeaking concept, air cargo carriers have gone the opposite direction (Gupta, 2010). Air cargo carriers have worked to achieve faster hub connectivity for packages and freight. In addition, they have extended services such as warehousing and truck-feeder services to improve the connection process.

Hub-and-spoke networks exist in a different sort of form for freight railroads, but the essential aspect of them still exists. Train engines travel to a freight rail hub where rail cars are transferred between train engines going to different destinations. These systems have synchronized arrivals and departures so cars do not dwell in train yards for extended periods of time, and connection times are reduced (Wiegmans et al., 2007). This hub-and-spoke system benefits small markets as trains can be compiled at the hub for these destinations, when normally they would receive sporadic point-to-point service. Lastly, just like airlines can use larger aircraft from hubs and gain benefits from economies of scale, so can freight railroads use longer trains from their hubs instead of increasing frequency which can get costly.

Passenger railroads also make use of hub-and-spoke systems to create a wide range of markets for their passengers. Through the use of a hub and connections, passenger railroads can reduce point-to-point service, use economies of scale to use longer trains, and provide more frequent service to smaller markets. Like a peaked airport hub, train station hubs make use of short connections for passengers to move between two trains, operating in Europe under integrated timed transfer systems (Clever, 1997). In the integrated timed transfer systems, vehicles arrive at depart from a station at approximately the same time so passenger waiting times are minimized.

The similarities between passenger rail and passenger airlines, in terms of peaks at hub airports, also extend to the inefficiencies inherent in such a system. Like airport hubs, rail hubs must be very large in order to hold the large number of trains that must be present simultaneously for transfers to take place. The integrated timed transfer system does not make use of the facilities and staff efficiently (Clever, 1997), with trains only staying for a short time and then departing. The train station remains empty for long periods of time.

To make more efficient use of the station, and to allow for small stations, Clever describes a spreading out of services, similar to depeaking. Like depeaking, arrivals and departures get spread out but in a way that still preserves important connections. The train hub would be operated in waves. In the first wave, all trains terminating at the hub drop off passengers and then wait in a holding area. The second wave is for trains passing through the station, and stop to exchange passengers. A final wave is for the terminating trains to come back to the terminal and pick up passengers to make outbound trips. By reducing the peak activity of a bank of trains, the train operator can still maintain good connections for passengers and make more efficient use of platforms, staff, and equipment.

2.8 Affiliate Airlines

The role of affiliate airlines in the depeaking process is an important consideration for a depeaking airline. Affiliate airlines often make up a large portion of the operations at hub airports, and the contracts that are drawn up between major carriers and their affiliates must be managed appropriately for a major carrier to depeak its hub.

Affiliate airlines developed in response to the creation of the hub-and-spoke network. Major carriers did not own enough aircraft to serve all the spokes they desired to have in their network, and thus feed arrangements with airlines composed of smaller regional aircraft were needed to connect to the spokes (Gillen, 2005). Today, all major U.S. carriers subcontract portions of their network to affiliate airlines (Forbes &

Lederman, 2011); these affiliates carry over 25% of domestic passengers. Over the past decade, enplanements on affiliates doubled and ASMs tripled. In some cases, the major airline wholly owns the affiliate, while in other cases the affiliate is an independent airline that is governed by a contract with the major airline.

2.8.1 Affiliate Airline Basics and Benefits

Affiliate airlines complement a major airline's mainline flights in order to bolster the offerings the major airline can provide to passengers. Major network carriers do not operate any small aircraft (Forbes & Lederman, 2011). By assigning an affiliate airline's smaller jets to spokes with lower demand, the major airline can benefit from the passenger base without using their larger aircraft. The major airline's decision to use an affiliate aircraft on a route is based solely on the type of plane needed for a route. Affiliate airlines also are beneficial for their cost advantage in operating smaller planes, including lower compensation for affiliate airline employees in relation to the major airline's own employees. This cost efficiency allows them to be used to offer greater frequency to enhance the service provided by the airline (Gillen, 2005).

The affiliate operates these routes under a codeshare agreement, with flights ticketed by the major airline under its own airline code. Affiliate aircraft have the paint and branding of the major airline. Through this, the major and affiliate airlines are integrated into a common network (Forbes & Lederman, 2011). Having the affiliate ensures for the major airline that a greater proportion of all traffic is kept online with a single carrier (Gillen, 2005). This provides a large benefit to the major airline, because the flights operated by the affiliate carrier generate positive externalities elsewhere in the major's network due to hub connections.

2.8.2 Types of Affiliate Airline Contracts

Up until the late 1990s, the primary form of contract that affiliate airlines had with major airlines were revenue sharing contracts (Forbes & Lederman, 2011). In the late 1990s, revenue sharing contracts began to be replaced with a new contract type known as capacity purchase agreements. This change was drastic: in 1996, 15% of all affiliate airline flights operated under a capacity purchase agreement; by 2003 this fraction had grown to 87%.

Revenue sharing contracts are structured such that the affiliate airline and the major airline shared ticket revenue from passengers who fly on both carriers (Forbes & Lederman, 2011). The passenger's fare revenue was split between the two carriers, typically in proportion to the distance traveled on each airline. The affiliate airline received all of the revenue for passengers who flew solely on the affiliate carrier's aircraft.

Capacity purchase agreements differ in that the affiliate airline receives a fixed payment from the major airline for each flight which the affiliate airline flies (Forbes & Lederman, 2011). The amount which the affiliate airline is paid is independent of the number of passengers on board the aircraft. The payment is based on estimates of the affiliate airline's cost, and agreed upon in the contract by the major and affiliate carriers. The payment includes enough to cover the estimated costs, and still provide a profit margin for the affiliate. Often, the agreement includes incentives for operational performance measures. Capacity purchase agreements give the major airline complete control over the affiliate airline's scheduling and inventory management.

The two contract types' effect on the relationship between the involved airlines' relationship and the affiliate airline's incentive to provide good service are markedly different (Forbes & Lederman, 2011). Revenue service contracts involve significant haggling between the two airlines when drawing up the agreement. Under these contracts, affiliate airlines desire to serve the most profitable routes because their revenue is directly related to traffic. The positive externalities that exist for the major airline due to the affiliate airline's additions to the network do little to benefit the affiliate. There is no incentive to serve routes that are solely beneficial to the major airline on a network level, but not attractive on a stand-alone basis. Route selection and scheduling decisions thus become very important in developing this agreement. The affiliate's risk exposure is high, but it incentivizes the affiliate airline to exert effort towards increasing demand on their routes.

Capacity purchase agreements reduce an affiliate's risk exposure, because the revenue is a predetermined amount based on the number of flights flown (Forbes & Lederman, 2011). Thus, haggling is reduced when writing the contract because there is no worry for the affiliate on scheduling or routing decisions. Affiliates are indifferent to where and when they operate. The primary issue for haggling for affiliate airlines in capacity purchase agreements is routes that have low on-time rates. Certain spoke airports have a higher potential for delays, and thus the affiliate airline haggles to avoid these routes – although the affiliate airline can still be protected by the major carrier building in considerable buffer time in the schedule.

Because the depeaking events occurred in the early 2000s, the affiliate airline contracts involved with depeaking are for the most part capacity purchase agreements. Depeaking airlines would thus still be contracted to reserve a set amount of capacity for their affiliate airlines to operate from the depeaked hub.

2.9 The Hub Airport and Its Revenue

The airports which serve as hubs have a different perspective on operations and revenue than a non-hub airport. Hub airports, like all airports, have a relationship with the city and the residents that live there, and build a relationship with the originating passenger base. An airport is the departure and arrival point for the residents and workers of a city, serving as a transportation facility for large regions.

A hub airport also has a relationship, though, with the hub airline, which it must work closely with to be profitable and successful. This relationship is more likely to control the airport's general planning than its relationship with the city. Due to the hub airline, the airport also effectively has a relationship with many of the passengers in the hub airline's system. To the rest of the country and world, it is simply a place to connect to their next aircraft. For example, think of all the people across the U.S. who have opinions about ATL's terminal layout, simply because they connected there a couple of times. This collection-distribution role the airport serves for the hub airline and its passengers has implications for the airport's economic policy (Kanafani & Ghobrial, 1985). The higher levels of connecting traffic at a hub airport, which is very different from originating traffic in its revenue-producing abilities, changes the airport's economic impact. The airport becomes less tied to the local economy as compared to one that serves primarily originating traffic.

The variety of relationships in which an airport is engaged affect how an airport operates and plans for the future. Their revenue stream is connected to the city, airline, and passenger base. Whether or not the airline has a peaked or depeaked schedule can greatly affect the money the airport generates. The following subsections describe how these different schedules play a role in an airport's earnings.

2.9.1 Issues with Being a Hub

There are great economic benefits to being a hub airport, and much can be gained by the city and airport authority. High levels of employment, connections to many destinations around the world, and indirect benefits of companies locating in the city are just many reasons why attracting an airline to an airport is desirable (Button & Lall, 1999).

There are also issues for a hub, many of which are unique to being a hub. The biggest issue, and which is more prone to affect airports serving as hubs, is a strain on capacity. The added volume created by the hub's presence creates problems from the nature of the traffic (Kanafani & Ghobrial, 1985). The hub airline contributes peak-load capacity issues on the aprons, runways, and terminals for the aircraft, and also strains the baggage handling system (Hanlon, 1996). Capacity-constrained hubs are common, and there are high risks for delays to both the hub airline's aircraft and other airlines' flights. These delays reflect negatively on the airport, and can give the airport a reputation amongst passengers and businesses of being a poor-performing facility. Such a reputation could lead to traffic choosing other airports over the congested hub airport.

In order to meet the operational demands of the hub airline, and reduce delay, airports must look to expand facilities and increase capacity. The airport must meet the activity demands of the hub airline or the airline will look to expand its business at another hub. Due to the hub airline, the airport must adapt to faster growth than a non-hub airport, and invest in additional capacity for runways and terminals frequently (Hanlon, 1996). This is pushed to a greater extreme when flight banks are in place, as the airside capacity needs are greater. These banks place a greater burden on airport facility development (Kanafani & Ghobrial, 1985), and one that may be too difficult for the airport to meet. While the airport may have plans of their own, the airside needs take precedence, as the landside surface area needs are not increasing as the hub airline expands – leaving originating passengers to not see much improvement landside. The airport and the hub airline must come to agreement on how to pay for and develop such expansions, and if the airport is capacity-constrained for some reason, the airport may have to tell the airline to explore other operational options – such as voluntary depeaking or mandatory slot controls.

The strong push by the hub airline for increased capacity and development at the airport is always a calculated risk for the airport. The airport becomes increasingly dependent on the hub airlines connecting traffic and less reliant on demand from the airport's local region (Kanafani & Ghobrial, 1985). If the airline does not perform well, or goes bankrupt, the airport suffers financial losses as well. Building infrastructure for the hub airline thus is a high-risk move, as it could go empty if the airline reduces operations, or even worse, pulls out of the airport entirely as a hub. Dehubbing is the ultimate burden for an airport, which airports such as Pittsburgh, St. Louis, and

Cincinnati have suffered through. Being dependent on another airline's entry and exit decisions is an issue all hub airports must contend with.

2.9.2 Commercial Revenue

Commercial activities are a critical portion of an airport's revenue. There are a wide variety of figures to describe how much supporting services contribute to the overall revenue, but it is often greater than the revenue generated through aeronautical operations (Doganis, 2001; Zhang & Zhang, 1997). These commercial services consist of a wide number of activity including parking services, banking, food and beverage, gift shops, newsstands, and car rental (Torres et al., 2005), and are central to the growth and economic stability for most airports. What must be understood in measurements of commercial activity is that the values can be skewed depending on an airport's definition of commercial activity. As noted by Graham (2009), Salzburg airport in Austria provides its own ground handling services, thus reducing the percentage of revenue for which commercial activity contributes. Although this subsection reports percentages, Graham recommends that commercial activity should be reported as revenue per passenger. That said, below is a sampling of airports worldwide and how important commercial activity is to an airport's revenue stream.

- Non-aeronautical revenue comprises half of all operating revenue in a sample of 75 U.S. airports (Appold & Kasarda, 2006).
- Medium to large U.S. airports have 75-80% of revenue come from commercial operations (Doganis, 2001).

- Commercial revenue in European airports is 48% of total revenue (Graham, 2009).
- Commercial activity accounted for 60% of the British Airports Authority revenue (Jones, Viehoff, & Marks, 1993).
- Concession revenue alone accounts for over 65% of revenue at Hong Kong International Airport (Zhang & Zhang, 1997).

The key concept to grasp from these figures is that commercial revenue is very important to an airport's finances. Over the early part of the 2000s, however, sales per passenger were decreasing at airports (Bork, 2007). Because spending money at shops is low priority on a passengers list when they arrive at the airport, the airport often has to make strong efforts to encourage passengers to shop. As discussed by Appold and Kasarda (2006), between 54-68% of passengers purchase food or beverages in the airport and 11-37% purchase non-food items. Maximizing commercial revenue is critical for an airport's development.

2.9.3 Commercial Revenue for Hub Airports

A hub airport has many passengers walking through its terminals, but this does not necessarily mean high revenue streams. Because a large portion of a hub airport's passenger traffic are only transferring between aircraft, these passengers do not have the opportunity to park or rent cars (Van Dender, 2007). For this reason, on a per passenger basis, the airport is unable to generate the same amount of commercial revenue as airports with higher levels of originating traffic (Kanafani & Ghobrial, 1985). Thus, transfer traffic is not as attractive to airport operators as compared to originating traffic (Hanlon, 1996).

Hub airports must adapt to the different passenger characteristics to still garner sales. The circulation patterns of connecting passengers are very different from originating passengers (LeighFisher et al., 2011). With short layover times, for example, and connecting passengers rushing to get to their departure gate as soon as possible, airports would need to locate concession directly on their circulation path or near the gate.

2.9.3.1 Connection Times and Revenue

The banked schedule patterns of hub airlines serve only to reduce airport commercial revenue. Good fast connections mean less opportunity for a passenger to spend money at an airport shop (Hanlon, 1996). As passengers rush between gates, they are unable to make purchases (Kanafani & Ghobrial, 1985). Airlines typically believe that longer connection times has a negative effect on passengers, but when considering a passenger who may desire to make a food or beverage purchase, a longer connection time could in fact be beneficial to the airline attracting a passenger (Encaoua, Moreaux, & Perrot, 1996). Depeaking thus could increase the revenue airports and airlines receive from passengers by extending the amount of time connecting passengers spend in the terminal.

The connection time of passengers (or as airports perceive it, the dwell time) is related to the amount of money spent on concessions. Transfer passengers are a captive market for retailers (Crawford & Melewar, 2003; Hanlon, 1996), but they are also time-sensitive, so increases in dwell time should lead to increased spending (LeighFisher et al., 2011; Theis et al., 2006). The enforced free time that passengers have makes them more likely to make purchases (Appold & Kasarda, 2006), although it is seen that by Torres et al. (2005) that the longer time does not increase the amount of spending, only the likelihood of spending. Torres et al. noted that if you exclude passengers not buying anything, there is no time relationship between the amounts of money passengers were spending at the airport. Overall, it appears that higher concession revenue can be achieved through an increase in connection times.

2.9.3.2 Terminal Congestion and Concession Revenue

The primary negative effect of banked schedules on commercial revenue is the minimizing of dwell time, and thus shopping time, for passengers. Banked schedules, however, can have a secondary negative effect on airport concession due to increased terminal congestion for passengers. Passengers in a banked schedule flood the terminal simultaneously, congesting the terminal halls, shops, and eateries. Appold and Kasarda (2006) describe that congestion can hamper commercial sales in terminals with limited space because it reduces the potential that a passenger can access a shop. Congestion also impacts a passenger's use of dwell time (Graham, 2009), slowing them down during their walk between gates and reducing the likelihood that the passenger has time to shop. Capital spending to increase space is not always a possibility, so airports must find the balance of commercial establishments and room for passengers to circulate.

2.9.4.3 Getting the Airline to Agree

Leaving suitable time for passengers to purchase food, beverages, and retail items can be a conflict of interest between airport authorities and airlines (Hanlon, 1996). The airport and airline are essentially in a trade-off relationship where both are looking to maximize profits (Lin, 2006). Airlines with banked schedules want connections maximized and connection times reduced. This increases congestion and reduces potential shopping time, hurting the revenue of the airport. Depeaking the airline schedule benefits both parties because when performed well, useful connections are maintained while airline costs are cut, while connection times increase and benefit the airport.

Depeaking can be very attractive to airlines that hold shares in the airports they operate out of, or directly control the airport facilities. Examples of this situation include Lufthansa in Munich's Terminal 2 and JetBlue in JFK's Terminal 5. By optimizing terminal operations to extend connection times, while still providing good connections, concession revenue can increase, and the airline shares in this additional revenue generated (Fu, Homsombat, & Oum, 2011). If an airline chooses to depeak an airport where it receives revenue from the terminal, it puts itself in a very advantageous position.

2.9.4 Positive Purchasing Environment

Reducing congestion in the terminal, through depeaking or another means, is important psychologically for encouraging passengers to make purchases and improving an airport's commercial revenue.

An airport is inherently a stressful place, but also is a location where people feel high levels of excitement. Up until passengers pass through security, anticipation and excitement are building simultaneously with stress. There is stress from getting to the airport on time and having travel plans go smoothly, all of which typically reduces as soon as a passenger passes security and enters the departure hall (Crawford & Melewar, 2003; Entwistle, 2007). The period from when a passenger passes security and boards their plane is a "happy hour" of time in which they are comfortable, yet still excited, and are ready to make purchases. Figure 2.4 is a diagram of this period in relation to passengers' feelings of stress and excitement.

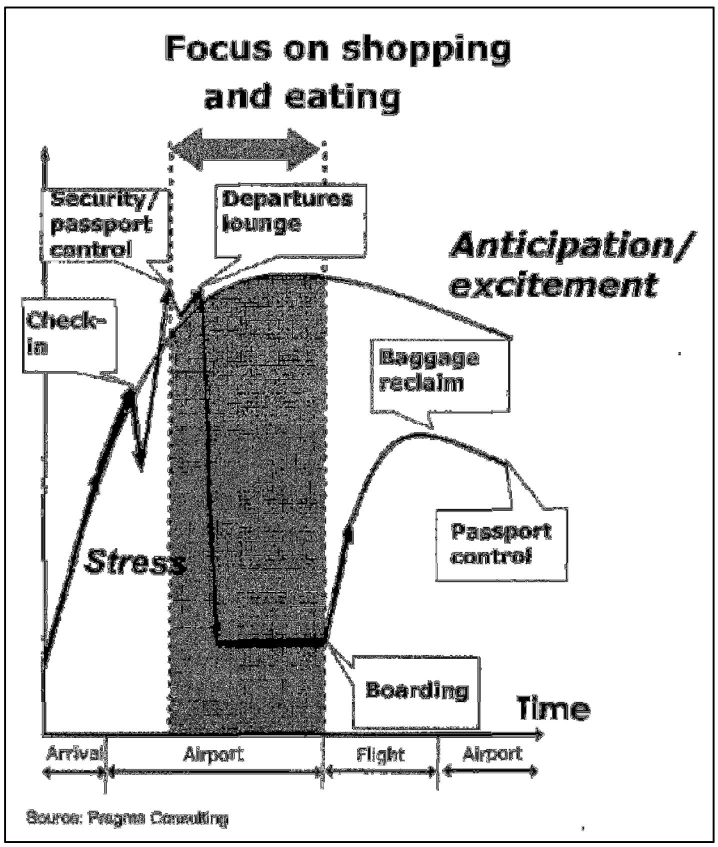

Figure 2.4 Passenger stress and excitement and the relationship to shopping. *Source: Entwistle (2007)*

Airports can capitalize on this period by keeping the departure hall as stress-free as possible. Passengers must be in the proper emotional state to buy items, as it factors into whether they will shop and how much they want to spend (Bork, 2007; Crawford & Melewar, 2003). The goal is to increase impulse buying, and encourage those who want to purchase to feel comfortable doing so.

The connecting passengers in an airport hub feel high levels of stress having to make a transfer. Additional stress can be added if the transfer is short. The congestion during the transfer may also make them not relaxed enough to shop (Graham, 2009). Depeaked hubs, with longer connections, inherently will have connecting passengers who are less stressed because there is less congestion and more time to transfer. The additional time to shop and the lower stress have a high potential to considerably increase an airport's concession revenue over what it was in a peaked schedule.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is a description of the analysis steps of the study. It details several of the processes which were coded in SAS (Statistical Analysis Software), and the reasons particular decisions were made throughout the study. The aim is for future researchers to be able to reproduce the analysis and make changes for their own needs. SAS code is included in the Appendices of this document.

The chapter begins with a description of the structure of the study along with the goals and research questions that were developed based on the literature review. Detail is then given to the different types of data used in the study and why they were chosen. The next part describes the preparation done in order to use the datasets, particularly the cleaning processes. The analysis is then described including how cases were chosen, how schedules were reproduced, and how the retained cases were compared with one another. Particular attention is given to how peaks are identified and the depeaking measurement. Lastly, the methodology use to quantify the effect of an increase in connection time, such as what happens during depeaking, on revenue is presented.

3.2 Study Structure

The study is designed to compare the different instances of depeaking in the U.S. that occurred in the early 2000s. A case study approach is used in order to assess the different schedule changes made by the depeaking airlines, and how revenue was affected for the airlines after choosing to depeak a hub. The supply side of the airline's depeaking is analyzed first, to assess the structural changes in the schedules before and after depeaking. The demand analysis is then coupled to the supply results to assess how revenue shifts occurred in relation to the supply changes. The approach also includes a network-level comparison of changes in passenger itinerary choices that occurred after depeaking. On-time performance is also analyzed in relation to depeaking. A linear regression model is used to explore the spoke level decisions hub airlines make when depeaking. The research provides a better understanding about what conditions are best for an airline to achieve positive results from a depeaked schedule.

3.2.1 Project Motivation and Goal

Previous studies have lacked an understanding of how revenue is affected by depeaking, and how the scheduling changes affect other airlines. Bogusch (2003) examines the performance of American Airlines before and after depeaking to see how market share and on-time performance were affected, but does not examine what changed in American's ticket sales and revenue. Zhang et al. (2004) discuss revenue briefly, comparing the revenues of flights through depeaked hubs to the total revenue of the airline in the same markets.

The goal of this research project is to determine the effects of depeaking on the volume and cost of sold tickets, network level changes in schedules, and passenger traffic. One of the key aims is the linking of the supply data to the changes in demand and on-time performance of the airline which depeaked. The research will lead to a greater understanding of what aspects of a hub make it suitable to be depeaked.

A second goal of this study is to compare the different degrees of depeaked schedule implementation. American Airlines has received the bulk of attention in the literature, and this study examines some of the other airlines' experiences with a depeaked schedule.

A third goal is to develop a robust measure of peaking and depeaking that can be used for quickly assessing how much an airline depeaked its schedule. This involves being able to automatically identify peaks, and developing the logical reasoning behind a suitable depeaking measure.

Lastly, the effect on a depeaked airline's competition in the system will be studied. American Airlines was concerned greatly about how depeaking at ORD would affect United, and American tracked several performance measures to make sure their strategy did not have a negative impact or benefit competitors (Ott, 2003).

3.2.2 Research Questions

The purpose of the study is to better understand depeaking. Through the research endeavor, the following research questions will be investigated:

- What were the differences across airlines' implementation of a depeaked schedule?
- What were the changes in demand due to depeaking?
- How did depeaking affect revenue in terms of ticket sale volume, price, and mix of traffic?
- What were the effects on other airlines in the system due to an airline depeaking?

- What were the changes in operations due to depeaking for both the airline implementing continuous schedules and other airlines?
- How is airport revenue affected by a major airline depeaking?

3.3 Datasets

The supply and demand data for this study are publicly available from the Office of Airline Information of the Bureau of Transportation Statistics (BTS)[1]. Each dataset is described below in relation to this study.

3.3.1 Supply Data

Supply data provide schedule information that is needed to compare an airline's operations before and after depeaking. In this study, the BTS database of Airline On-Time Performance Data[2] is used as a measure for supply. The database provides a list of the majority of flights flown in the U.S. Although it would be ideal to use the Official Airline Guide (OAG)[3] to recreate schedules as it is more complete than the On-Time database, this was not a viable option due to the fact that historic OAG files back to 2000 were not available from the airline that is collaborating on this study and were prohibitively expensive to purchase.

The On-Time database provides detailed records of flight-level information and can be used to calculate the number of flights in a given period and determine measures

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[1] http:// http://www.bts.gov/programs/airline_information/sources/

[2] http://www.transtats.bts.gov/DatabaseInfo.asp?DB_ID=120&Link=0

[3] http://www.oagaviation.com/Solutions/Aviation-Data/OAG-Schedules-Data

of peaking and depeaking. The top domestic U.S. carriers that carry at least one percent of all domestic scheduled-service passenger revenue report on-time flight information. The database provides information on whether a flight was delayed, diverted, or cancelled. Information on each flight's departure time, arrival time, carrier, and departure date is also provided. The scheduled CRS flight time and actual flight time are both included. The tail number of the aircraft (defined as a unique identification number for a specific aircraft) is provided. Using this dataset, it is possible to construct a representative schedule an airline offered at a particular airport at a particular point in time. The On-Time database enables a comparison of delay costs before and after depeaking.

When using the On-Time database, one must be aware that slight changes occurred in reporting over time. For example, the format of the flight data changed from MM/DD/YYYY to YYYY-MM-DD. In addition, during a period in 2001 to 2002, the reported tail numbers became corrupted in the database. By inspecting the datasets, however, it was seen that the tail numbers were corrupted consistently between different tail numbers. This is useful because one can still make use of the dataset using tail numbers, as long as knowing the precise tail number is not important (e.g. N123AA corrupted to N&%&8* each time).

3.3.2 Demand Data

Demand data in this study are used to determine the traffic in airline markets and the ticket revenue airlines gained during the study period. It is useful to be able to measure passenger behavior before and after a schedule becomes depeaked. The demand dataset for this study is the Airline Origin and Destination Survey (DB1B)[4] provided by BTS. The DB1B is a ten percent random sample of all lifted (or used) airline tickets on reporting carriers.

This database contains three datasets, namely the Coupon, Market, and Ticket data. The Ticket dataset is a list of all the tickets in the sample, with an itinerary identification number used as a key variable. The Market data is linked to the Ticket dataset by the itinerary ID, and it is a list of the directional market routes traveled on the ticket. A market is identified by a break in the traveler's trip, such as staying for an extended period at the destination. Each of the markets is identified by a unique identifier called the market identification number. Lastly, the Coupon dataset is a list of all the segments flown on each ticket. The coupon level is the lowest level to break down the ticket, and the coupons are linked to the Market and Ticket datasets with the itinerary ID and the market ID.

Fare information is available at the ticket and market level. The Ticket dataset includes the full fare paid by the traveler for the entire itinerary. The Market dataset includes fare data for each directional market, but the fare is prorated by distance. The Coupon dataset does not contain fare data, and how this is handled is discussed later.

The DB1B database was chosen over two other demand datasets. CRS booking data is not used because it is primarily a travel agency database, and under represents LCCs because it does not include web bookings. The CRS dataset was still applicable and was used in the study by Bogusch (2003), but the rise of internet sales has caused it to become heavily biased towards legacy carriers. Two other BTS datasets, the T-100

[4] http://www.transtats.bts.gov/DatabaseInfo.asp?DB_ID=125&Link=0

Market and Segment databases, are not used because this study requires information about connections and passenger fares and T-100 does not contain itinerary or revenue information.

DB1B is a suitable dataset because it does not have a bias towards particular airlines, and provides connection and fare information. The data are organized by quarter, and listed by the origin and destination airports. Information on the specific flight date, flight number, and time, however, are not included.

3.3.3 Supplemental Datasets

Several other datasets are used in this study to support the research. These were often used in preparing the two primary datasets: the On-Time database and the DB1B database. These include spatial data for the National Airspace System, the Standard Industry Fare Level (SIFL) calculation, the Marketing Information Data Transfer (MIDT) dataset, the Schedule B-43 inventory for tail numbers and seating capacity, and the Port Authority of New York and New Jersey (PANYNJ) traveler surveys.

3.3.3.1 Spatial Airport Data

Geographic Information System (GIS) data was gathered on airport location from the 2011 National Transportation Atlas Database (NTAD)[5]. The point file Public-Use Airports was used to spatially locate the airports in the GIS environ. Included in this data is attribute data for the physical and operating characteristics of each airport as well as usage categories. Only airports that exist for the public's use are included in the NTAD

[5] http://www.bts.gov/publications/national_transportation_atlas_database/2011/

dataset. Unlike the T-100 data, the airport codes in the two spatial databases are assigned by the Federal Aviation Administration. These are not always the same as the IATA codes.

3.3.3.2 Standard Industry Fare Level

Part of the cleaning process for the DB1B database involves comparing market fares to the Standard Industry Fare Level (SIFL)[6]. The SIFL was created by the ADA as a way of limiting the Civil Aeronautics Board discretion to prescribe fare levels (Office of Aviation Analysis, 2012). The SIFL is maintained by the U.S. Department of Transportation (USDOT), and is updated on a half-year cycle. The initial SIFL was based on 1979 fares, and became the standard measurement for determining the reasonableness of fares. In practice, it has been applied to the unrestricted coach fare.

The USDOT SIFL calculation is described by Good (Good, 2011). The SIFL calculation makes use of the market distance, and not the non-stop distance between an origin and destination. Thus a flight with a connection at the hub should use the total distance flown over the two flight legs. In addition, the calculation calculates the SIFL as an additive function of terminal charges and mileage rates. Each flight has a base terminal charge, and a per mile rate based on the distance traveled. The first 500 miles flown are assumed to have one rate, the next 1000 miles a slightly lower rate, and any mileage above that at an even lower rate. Each of these mileage groups get summed on top of the ones prior to it, such that a flight of 600 miles would have a calculation of:

*SIFL = terminal charge + (0-500 mile rate)*500 miles + (501-1500 mile rate)*100 miles*

[6] http://ostpxweb.dot.gov/aviation/X-50%20Role_files/standindustfarelevel.htm

3.3.3.3 Marketing Information Data Transfer

In order to create a list of potential connections in a peaked and depeaked schedule, it was necessary to determine minimum connection times (MCT) and maximum connection times (MxCT) for each case study airport. To gather this information, booking data was used. Booking data provides the tickets which were sold to passengers, and thus provide insight into the length of connections that were considered reasonable to make by the airline, travel agent, and/or passenger.

A sample of domestic U.S. itineraries was pulled from the June 2010 Marketing Information Data Transfer (MIDT) dataset. The MIDT dataset includes itinerary information for bookings that occurred through travel agencies on every carrier in all markets. Each record is a unique itinerary, and includes the origin, destination, arrival and departure date and times, connecting cities, carriers, flight numbers, equipment types, and the number of passengers who booked on each specific itinerary. Access to this dataset was granted from a major U.S. airline.

3.3.3.4 Tail Number Database

A standard measure of capacity in the airline industry is Available Seat Miles (ASM). Similarly, it is standard practice to report revenue for flights as Revenue per Available Seat Mile (RASM). In order to create these measures, seating capacity for aircraft must be gathered. The On-Time database provides tail numbers, so with a dataset of registered tail numbers and each aircraft's respective seating capacity, ASM for the schedule can be generated.

The Schedule B-43 Inventory[7] provided by BTS is used to provide a list of tail numbers with their respective seating capacities. Data was downloaded for the period from 1992 to 2009, and compiled into a single list. Because seating capacities can change over time as airlines add or remove seats from the airplane, only the most recent entry for each tail number is retained in the list.

3.3.3.5 Port Authority Traveler Surveys

Evaluating the effect of an increase in connection due to depeaking on concessions revenue is useful to show how depeaking affects airport revenue. The PANYNJ collects passenger information through traveler surveys. PANYNJ reports their data each year in their Annual Air Traffic Reports[8]. This data has been used by Seaman (2011) to examine the demographics of airline passengers and the link to concession sales. The data are summarized for each airport owned by the PANYNJ – JFK, LGA, EWR, and SWF (Stewart International) – and as a total for the year. The data includes the average dwell time for both OD and connecting passengers, the percentage of passengers connecting, the amount of food and retail purchased per passenger, the percentage of passengers who purchases food and retail, and the average income of the passenger base.

3.4 Preparing the Datasets

In order to use the BTS datasets for this study, several data cleaning and pre-processing steps needed to be performed. Data cleaning routines were designed to eliminate clear

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[7] http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=314

[8] http://www.panynj.gov/airports/general-information.html

errors in the database. Data processing routes were written to (1) assign affiliate airlines to parent airlines' schedules in order to fully understand the schedules the depeaking airlines constructed and (2) standardize time zone information in order to construct a consistent time measurement. The following subsection describes the time zone modifications.

3.4.1 Time Zones

The FAA data are reported using flight times that reflect the time zones of the specific airports at which the aircraft is arriving from and departing at. Thus two different time zones can be used when reporting on an aircraft's flight. In order to create a consistent time for the purpose of tracking specific aircraft, all times were converted to Greenwich Mean Time (GMT). Dates were changed as needed to reflect the time zone difference if the time in GMT caused the flight departure or arrival to be a day earlier. To establish the time zones of each airport, an ArcGIS map was created with the locations of all U.S. airports in the National Airspace System (NAS) and the time zones of the world. Each airport was attributed using the map with the airport's difference in hours from GMT so that it can be used in making time adjustments.

When changing time zones of airports, it is critical to note whether Daylight Savings Time (DST) was in effect at the airport's location at the time of the flight. Until 2006, DST took effect from the first Sunday in April to the last Sunday in October. In 2007, the Energy Policy of Act of 2005 (109th Congress, 2005) changed DST to take effect starting on the second Sunday in March and lasting until the first Sunday of November.

Several parts of the country do not follow DST or have changed their policies of following DST over the past decade. This list most notably includes the states of Hawaii, Arizona, and parts of Indiana. Many airports in Indiana switched from not observing DST to observing the change in 2006. Some airports, however, were in counties that were already observing DST prior to 2006, such as Evansville Regional Airport. Using the ArcGIS map of the NAS airports and time zones, the DST changes over time were overlaid so that each airport could be attributed with the correct time zone and DST information. When cleaning and pre-processing the data, this information was joined to the list of flights so that times could be appropriately changed to GMT. Months in which DST started or stopped had to be split in two, for the dates which operated under DST from those that did not (April and October, 2006 and earlier; March and November, 2007 and after).

3.4.2 Cleaning the On-Time Performance Database

Cleaning the On-Time Performance data was an important step in the schedule reproduction process. The goal of the cleaning the data was to remove errors so that the flights that would compose the schedules would be valid. To provide a starting point for cleaning the On-Time data, recommendations were gathered from Arikan et al. (2008). These guidelines removed what Arikan and co-authors considered erroneous data.

- An aircraft whose scheduled departure time from an airport is earlier than the same aircraft's scheduled arrival time of its previous flight to the airport.
- An aircraft which flies successively on the same origin and destination route on the same day.

- An aircraft which arrives at an airport and its immediate next flight is from a different airport in less than five hours.

Over a three year period from 2005 to 2007, the Arikan and co-authors removed a little over 1 million flights from the On-Time Performance data, approximately 5% of the data.

In cleaning the database for this study's purposes, the Arikan guidelines were used as a starting point. Through many iterations of cleaning the data and error checking to ensure the process worked, the following process was created:

1. Remove all blank tail numbers and tail numbers that were three characters or less
    - It is necessary to have tail numbers to recreate the airline schedule to ensure flights did not have errors. A missing tail number does not allow this and thus is removed. It is assumed that tail numbers of three characters or less are errors.
2. Remove all cancelled flights.
    - Cancelled flights are not useful for the assessment of what historically occurred at the airport.
3. Remove all diverted flights.
    - The actual arrival and departure times are used to clean the schedule. It was found while creating the cleaning process that CRS times introduced more errors during schedule recreation than actual flight times. Thus, because diverted flights did not fly between the origin and destinations the flight records claim, they do not have actual arrival and/or departure times, and thus are removed from the data.

4. Remove an aircraft's flight whose actual departure time from an airport is earlier than the same aircraft's actual arrival time of its previous flight to the airport.
    - First, sort aircraft list by tail number, and each tail number by departure and arrival times in GMT.
    - Next, assume that the first flight of the month for each tail number is a valid flight, and will be kept. Only subsequent flights can be removed.
    - When an error between two flights occurs, the latter of the two flights is always the one removed. It is assumed that because the earlier of the two flights did not have an error with its own preceding flight and has been retained, it is a valid flight.
    - This process is done iteratively. During each of the iterations through an aircraft's flights, all errors of this type are flagged. The first occurrence of a tail number's flights chronologically is removed during each loop through the aircraft's schedule.
5. Remove an aircraft's flight which arrives at an airport and its immediate next flight is from a different airport in less than five hours.
    - This check is based upon the origins and destinations of flights which have no time conflicts. Five hours is used as a default time required for an aircraft to deadhead to another airport. The process is performed iteratively.
    - When two flight records are found to not meet this requirement, they are assessed based on the flights which occurred before and after the pair of flights. The one which is out of place is removed. This is different from

the time check, which always removes the latter flight. In the origin-destination check, either can be removed.

- This check is not flawless in the logical process that was developed to catch errors. There are instances where an incorrect portion of a tail number's itinerary is chosen over what is correct from a visual inspection. The differences are minor, however, and affect well less than one percent of flights.

In performing the cleaning process, there were sometimes aircraft tail numbers that have an exceptionally large number of flight records with overlapping flight times, the type of error flag from step 4 in the process just described. Usually there was only one aircraft per month with which this occurred. It is postulated that these tail numbers act as "temporary plates" in the airline industry, as the same tail number is listed flying to several locations at a given time. These tail numbers were entirely removed from the dataset because they caused so many errors during the cleaning process.

Through the cleaning process, between one and six percent of data were removed from each month of flight records, with an average of about three percent. The cleaned datasets were then able to be used to recreate the flight schedule at given airports, and analyzed statistically for depeaking measures.

What follows is an example of a portion of the On-Time Performance data being cleaned. Assume for this example, that the tail number used is not one of the tail numbers which is a "temporary plate", and thus has only a handful of errors from the step 4 of the cleaning process. Table 3.1 displays the example through a flow chart of the On-Time data cleaning process, with sample records from the On-Time Performance Database. As it progresses through the steps of the cleaning process, flights are deleted that do not meet criteria. All of the example flights in the table are considered to have taken place on the same date.

Table 3.1 Cleaning Process to Remove Errors from On-Time Database

Process Step	Tail Number	Cancelled	Diverted	Origin	Destination	Departure Time (EST)	Arrival Time (EST)
Sort data by tail number and departure times.				PHX	HOU	2110	2330
	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	PHL	1045	1151
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	N745UW			CLT	SAN	1805	2358
	N745UW	Yes		CLT	DCA	1950	2055
	N745UW			SAN	DFW	2352	253
	N82			RDU	EWR	1622	1801
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW		Yes	SFO	SMF	2046	
	N945SW			SFO	EUG	2359	201
1. Remove all blank tail numbers and tail numbers of three characters or less				~~PHX~~	~~HOU~~	~~2110~~	~~2330~~
	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	PHL	1045	1151
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	N745UW			CLT	SAN	1805	2358
	N745UW	Yes		CLT	DCA	1950	2055
	N745UW			SAN	DFW	2352	253
	~~N82~~			~~RDU~~	~~EWR~~	~~1622~~	~~1801~~
	N945SW			TUS	LAX	758	936

Table 3.1 (Continued)

	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW		Yes	SFO	SMF	2046	
	N945SW			SFO	EUG	2359	201
2. Remove all cancelled flights	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	PHL	1045	1151
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	N745UW			CLT	SAN	1805	2358
	~~N745UW~~	~~Yes~~		~~CLT~~	~~DCA~~	~~1950~~	~~2155~~
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW		Yes	SFO	SMF	2046	
	N945SW			SFO	EUG	2359	201
3. Remove all diverted flights	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	PHL	1045	1151
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	N745UW			CLT	SAN	1805	2358
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	~~N945SW~~		~~Yes~~	~~SFO~~	~~SMF~~	~~2046~~	
	N945SW			SFO	EUG	2359	201
4. Remove aircraft's flights whose actual departure time from an airport is earlier than the same aircraft's actual arrival time of its previous flight to the airport	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	~~N745UW~~			~~RIC~~	~~PHL~~	~~1045~~	~~1151~~
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848

Table 3.1 (Continued)

FIRST ITERATION (Only first error is removed for each tail number)	~~N745UW~~			~~CLT~~	~~SAN~~	~~1805~~	~~2358~~
	~~N745UW~~			~~SAN~~	~~DFW~~	~~2352~~	~~253~~
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201
SECOND ITERATION (Only first error is removed for each tail number)	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	~~N745UW~~			~~CLT~~	~~SAN~~	~~1805~~	~~2358~~
	~~N745UW~~			~~SAN~~	~~DFW~~	~~2352~~	~~253~~
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201
THIRD ITERATION (No more time errors)	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			PHL	BOS	1330	1507
	N745UW			DFW	CLT	1602	1848
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			PDX	SMF	1141	1322
	N945SW			SMF	PHX	1350	1537
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201
5. Aircraft's flight which arrives at an airport and its immediate next flight is from a different airport in less than five hours. **FIRST ITERATION Only first error is removed for each tail number. Pairs of errors are checked to see which fits in the schedule.**	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	~~N745UW~~			~~PHL~~	~~BOS~~	~~1330~~	~~1507~~
	~~N745UW~~			~~DFW~~	~~CLT~~	~~1602~~	~~1848~~
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	~~N945SW~~			~~PDX~~	~~SMF~~	~~1141~~	~~1322~~
	N945SW			SMF	PHX	1350	1537

Table 3.1 (Continued)

	~~N945SW~~			~~SMF~~	~~SFO~~	~~1400~~	~~1445~~
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201
SECOND ITERATION **Only first error is removed for each tail number. Pairs of errors are checked to see which fits in the schedule.**	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			DFW	CLT	1602	1848
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	~~N945SW~~			~~SMF~~	~~PHX~~	[illegible]	[illegible]
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201
FINAL CLEANED SCHEDULE	N745UW			CHS	CLT	721	823
	N745UW			CLT	RIC	928	1059
	N745UW			RIC	CLT	1112	1221
	N745UW			CLT	DFW	1313	1459
	N745UW			DFW	CLT	1602	1848
	N745UW			SAN	DFW	2352	253
	N945SW			TUS	LAX	758	936
	N945SW			LAX	SMF	1012	1133
	N945SW			SMF	SFO	1400	1445
	N945SW			SFO	EUG	1525	1727
	N945SW			EUG	SFO	1810	1959
	N945SW			SFO	EUG	2359	201

Note: The grayed out flights during step 5 of the process are the pairings that do not line up with one another and are analyzed during the iteration. The flight scratched out in bold is the one that the logical process decides does not belong. In all of the steps, the lightly scratched out flights are also marked as potential errors, but are not assessed during that particular iteration. It is possible in step 4 and 5 that those flights are no longer marked as errors once the cleaning process deletes prior errors, as seen with the second and third iteration of step 4 above.

One of the important parts of the cleaning process is its iterative set-up for step 4 and 5 in the cleaning process. Iteration in the process and deleting only one flight per tail number during each loop through the data makes sure one error does not have a cascading effect by making several other flights to be tagged as errors. It is possible that by removing one bad flight, many flagged errors become unflagged. For example, in Table 3.1, the last flight of the day for N745UW (SAN-DFW) is initially flagged as an error, but once the previous flight record (CLT-SAN) is removed as an error, SAN-DFW is no longer an error because the flight leaves from a different airport over 5 hours than it last left previous airport, and thus is assumed to be deadheading during that time.

3.4.3 Adding Affiliate Airlines to Schedule

Capturing the passenger traffic served by affiliate airlines is important for recreating the schedule, creating depeaking measures, and analyzing airline revenue. Affiliate airlines fly a large portion of routes out of airline hubs, and often account for over half of the flight departures. The major hub airlines, however, are the ones that determine when and where the affiliate airlines fly, and thus it is necessary to include the affiliate airlines that fly for a depeaking airline in the schedule for that airline's hub.

3.4.3.1 Challenges with Affiliate Airlines

There are several challenges associated with including affiliate airlines in reproduced airport schedules from the On-Time database. First, not all affiliate airlines have their flights reported in the On-Time database. Federal regulations require that only certain airlines report their on-time statistics: airlines that carry one percent or more of the total domestic scheduled passenger revenues. Which airlines qualify at the one percent level for a given year is determined by the passenger revenue of the 12-month period of activity ending on June 30 for the previous year. Thus in January of each year, the airlines which must report are subject to change (Bureau of Transportation Statistics, 2011). An example of this change is shown in Table 3.2. In 2002 only ten airlines reported to the On-Time database, whereas in 2003, a total of 17 airlines reported.

All the major airlines fly enough flights that their aircraft movements are consistently reported in the database, but most of the affiliate airlines do not fly enough passengers to be required to report their on-time data. Of the ten airlines in 2002 that reported to the On-Time database, only one was an affiliate airline: American Eagle Airlines. A year later, five affiliate airlines were reporting their performance data. In addition to American Eagle, the new affiliate airlines reporting in 2003 were: Atlantic Coast Airlines (DH), Atlantic Southeast Airlines (EV), SkyWest Airlines (OO), and ExpressJet Airlines (RU).

Table 3.2 Reporting Airlines to the On-Time Database in 2002 and 2003

2002	2003
AA	AA
AS	AS
	B6
CO	CO
	DH
DL	DL
	EV
	FL
HP	HP
MQ	MQ
NW	NW
	OO
	RU
	TZ
UA	UA
US	US
WN	WN

Because not all affiliate airlines report to the On-Time database, it may not be possible to fully reproduce a depeaking airline's schedule. If, for example, half of the flights for a given depeaking airline's schedule in 2003 were operated by an affiliate airline that did not report performance data in that year, the reproduced schedule would be incomplete. Analysis on this schedule in the context of the objectives of this study would be fruitless.

The second challenge with affiliate airlines is that the affiliate may fly for different (or multiple) carriers over time. Some affiliate airlines are fairly simple to assign to a parent airline, e.g.: American Eagle has only operated flights for American Airlines and Comair has only operated flights for Delta. Other affiliate airlines can be much more complex. SkyWest Airlines has flown for many different legacy airlines over time, changing parent airlines and often operating for two or more airlines simultaneously. When reproducing schedules, it is critical to know which parent airline an affiliate airline in the database was flying for at a given time and where the affiliate airline was flying.

A robust method is needed to determine which affiliate airlines flew for which parent airlines and to which destination during different periods of time. In order to accomplish this, the DB1B ticketing database was used. In a given quarter of data, for all of the depeaked hub airports, each unique combination of ticketing airline, operating airline, reporting airline, and spoke airport is pulled from the DB1B database. This provides a full list of which affiliate airline flew for which parent airline between the parent airline's hub and a spoke airport at a given point in time.

The third challenge with affiliate airlines is the large number of unimportant combinations that exist in the DB1B dataset. For the fourth quarter of 2005 at CVG there are 1,693 combinations of ticketing carrier, operating carrier, reporting carrier, and spoke airport. Of these 1,159 averaged less than five passengers per day between CVG and the spoke airport, as seen in Figure 3.1. It is believed that this large number of combinations reflects how reporting is affected by the variety of ways that passengers get ticketed, codesharing, and ticket changes.

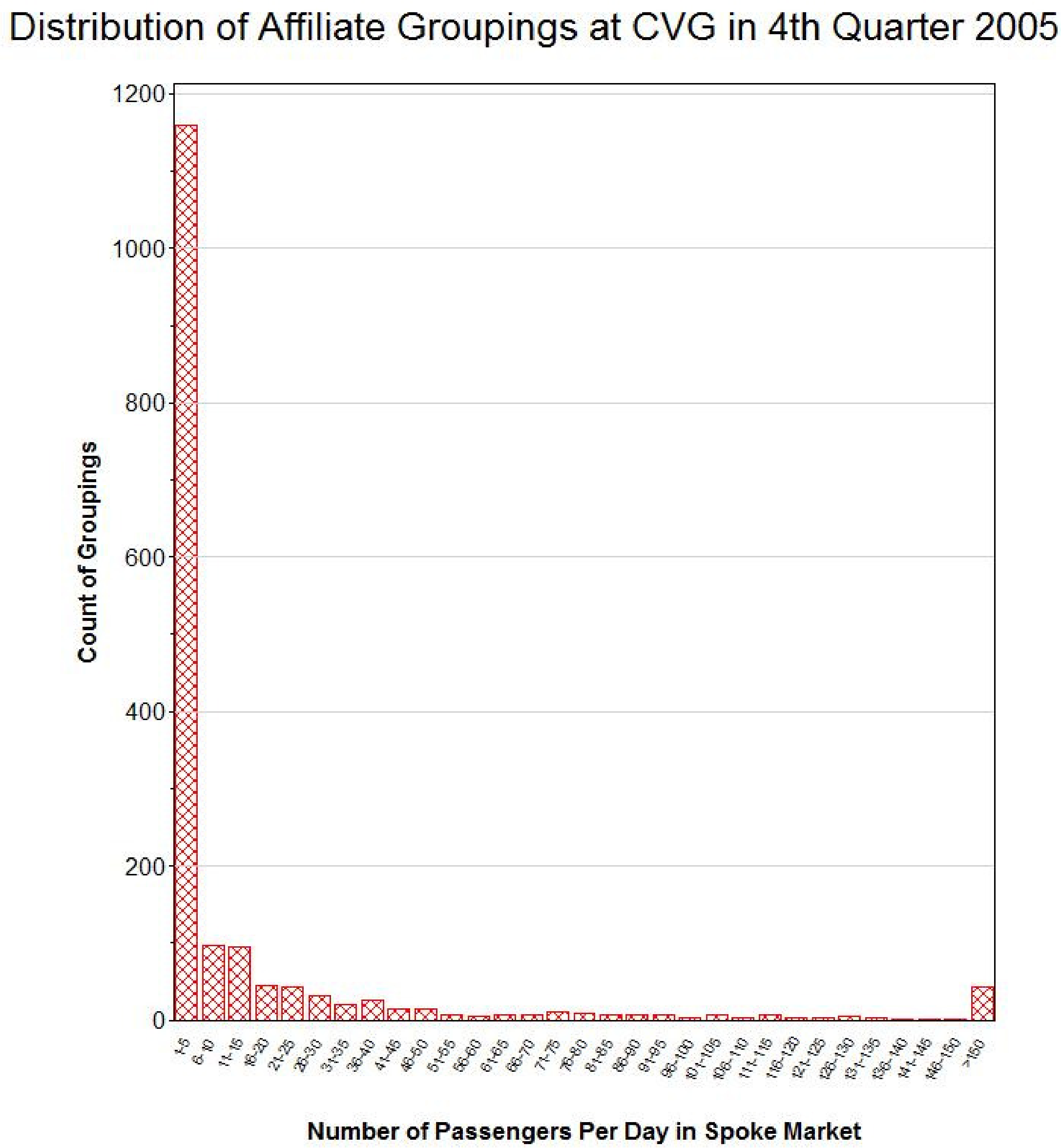

Figure 3.1 Distribution of the number of passengers in affiliate groupings. The histogram reflects the number of passengers per day in the different markets served from CVG by unique combinations of operating carrier, ticketing carrier, and reporting carrier.

3.4.3.2 Decision Process for Affiliate Matching

In order to reproduce a depeaking airline's schedule at a hub airport at a given point in time, the inclusion of affiliate airline operations is necessary. The problem in including these operations is the affiliate airlines that report their operations to be recorded in the On-Time database are not listed with the airline for which they flew. In addition, it is possible for a number of affiliate airlines to have flown for a depeaking airline from a hub airport, so there is no quick solution. Affiliate airlines that reported their performance to the On-Time database must have their operations credited to the airline they flew for to create the schedules for the major airlines at a given airport. In order to credit these, a list was created from the DB1B dataset.

The first step in preparing a list from DB1B to match to the On-Time database was to generate all unique combinations of the fields *ticket_carrier*, *operating_carrier*, *reporting_carrier*, and the *spoke* airports flown to from the depeaking hub. The spoke airports can be either an origin or destination served from the hub airport.

Next, all unique combinations in which the *ticket_carrier* field is equal to the *operating_carrier* field were removed from the initial list. It was assumed that if these two fields were equal, then the *ticket_carrier* was the air carrier who made the schedule for the particular combination. Only the major carriers were assumed to make schedules, and these were already credited properly in the On-Time database. Thus there was no need for them to be changed and do not need to be in the DB1B list.

The next step was to remove all combinations in which less than five passenger operations occurred per day on average. When looking at Figure 3.1, these combinations are all encompassed within the first bar in the histogram. These combinations were deemed immaterial and were not considered when changing affiliate airline codes to major carrier codes in the On-Time database. Five passengers per day on average was chosen because this cutoff value enabled removal of a large portion of combinations, and had an intuitive interpretation; further, rules such as these (eliminating thin paths from schedule analysis) is common to airline practice. Because the DB1B database is a 10% sample of tickets, and there are approximately 90 days in a quarter, the threshold for the count of unique combinations in the DB1B dataset was 45 (representing a 10% sample of 90 days at 5 passengers per day). *Reporting_carrier* was needed up until this step because it helped pick out the less substantial combinations. After this step, *reporting_carrier* can be removed, and combinations that are redundant can be combined.

Following the removal of immaterial combinations, the next step removed all combinations where *operating_carrier* was a major scheduling airline (legacy airlines, JetBlue, Southwest, AirTran, etc.). It was assumed that these combinations were scheduled by the respective major scheduling airline.

The final step was to check if the various operating carriers remaining in the list were uniquely matched to a ticketing carrier. If they were, those combinations which had a unique match could be assigned to be changed in the On-Time database. If they were not, it had to be decided which combinations should be assigned to one another in the On-Time database.

The decision-making process to determine which operating carrier/ticketing carrier pairs is called exception processing, and is performed manually. By the end of exception processing, each combination of the variables *operating_carrier*, *ticket_carrier*, and *spoke* were assigned to either be changed in the On-Time database, or to be excluded altogether. This exception processing combines knowledge of which affiliates historically primarily flew for a certain carrier at certain airports, which combination has more passengers per day, and if the spoke is a hub for the ticketing carrier. For example, in Step 6 of Table 3.3 that follows, SkyWest (OO) is listed as an affiliate for both United and Delta at ATL. Because ATL is a hub for Delta, the combination of SkyWest/United/ATL is excluded from being changed in the On-Time database. Thus, whenever OO is found as the *carrier* in the On-Time database flying to or from ATL, *carrier* will be changed to DL. The exception process results for the cases studies are shown in Appendix C.

Table 3.3 shows a flow chart of the affiliate airline matching process with sample combinations from the DB1B dataset. As it progresses through the steps, combinations are deleted that do not meet criteria.

Table 3.3 Decision Process for Affiliate Matching
Note: By the end, four combinations are to be attributed to the On-Time database, seen in bold text.

Process Step	**Operating Carrier**	**Ticket Carrier**	**Reporting Carrier**	**Spoke**	**Avg # of pax per day**
1. Create list of all unique combinations from DB1B of *ticket_carrier*, *operating_carrier*, *reporting_carrier*, and *spoke*	DL	DL	DL	ATL	502
	DL	DL	DL	SFO	376
	DL	NW	NW	DTW	482
	DL	EV	EV	SLC	207
	DL	EV	OO	ATL	12
	DL	EV	OO	SLC	3
	DL	OO	EV	ATL	54
	DL	OO	MQ	ATL	2
	DL	OO	OO	ATL	106
	UA	OO	OO	ATL	9
	UA	UA	OO	LAX	24
	UA	UA	UA	LAX	371
2. Remove if *operating_carrier=ticket_carrier*	~~DL~~	~~DL~~	~~DL~~	~~ATL~~	~~502~~
	~~DL~~	~~DL~~	~~DL~~	~~SFO~~	~~376~~
	DL	NW	NW	DTW	482

Table 3.3 (Continued)

	DL	EV	EV	SLC	207
	DL	EV	OO	ATL	12
	DL	EV	OO	SLC	3
	DL	OO	EV	ATL	54
	DL	OO	MQ	ATL	2
	DL	OO	OO	ATL	106
	UA	OO	OO	ATL	9
	UA	OO	OO	LAX	24
	~~UA~~	~~UA~~	~~UA~~	~~LAX~~	~~34~~
3. Remove if # of passengers per day < 5	DL	NW	NW	DTW	482
	DL	EV	EV	SLC	207
	DL	EV	OO	ATL	12
	~~DL~~	~~EV~~	~~OO~~	~~SLC~~	~~3~~
	DL	OO	EV	ATL	54
	~~DL~~	~~OO~~	~~MQ~~	~~ATL~~	~~2~~
	DL	OO	OO	ATL	106
	UA	OO	OO	ATL	9
	UA	OO	OO	LAX	24
4. Remove *reporting_carrier* and combine redundant combinations	DL	NW	.	DTW	482
	DL	EV	.	SLC	207
	DL	EV	.	ATL	12
	DL	OO	.	ATL	54+106 =160
	UA	OO	.	ATL	9
	UA	OO	.	LAX	24
5. Remove where *operating_carrier* is a major scheduling airline	~~DL~~	~~NW~~		~~DTW~~	~~482~~
	DL	EV	.	SLC	207
	DL	EV	.	ATL	12
	DL	OO	.	ATL	160
	UA	OO	.	ATL	9
	UA	OO	.	LAX	24
6. Search for unique *operating_carrier/ticket_carrier* combinations. Perform manual exception processing for the remaining.	**DL**	**EV**	**.**	**SLC**	**207**
	DL	**EV**	**.**	**ATL**	**12**
	DL	**OO**	**.**	**ATL**	**160**
	~~UA~~	~~OO~~	~~.~~	~~ATL~~	~~9~~
	UA	**OO**	**.**	**LAX**	**24**

When the final list of combinations of *ticket_carrier*, *operating_carrier*, and *spoke* were ready, these could be attributed to the On-Time database. The change was made using the *carrier* field in the On-Time database. For a give combination, the entries in the On-Time database were checked to see if the origin or destination is the depeaking hub, the corresponding destination or origin was equal to the *spoke*, and the *carrier* was equal to the *operating_carrier*. If these three conditions are met, *carrier* was changed to be the *ticket_carrier*. This signifies that the ticketing carrier was the airline which created the schedule for that particular flight, and should receive credit for it in schedule reproduction.

3.4.4 Adding Seating Capacity

The seating capacities of the aircraft listed in the On-Time database are matched by tail number to the list from the B-43 database. Between 85 and 90 percent of the tail numbers in the On-Time database are able to be matched with a tail number in the B-43 database. This is slightly higher than Barnhart et al. (2010), which matched approximately 75 percent of flights in the Airline Service Quality Performance database with the B-43 tail number list. According to Barnhart et al., 100% of the tail numbers do not match because tail number information is sometimes inaccurate or non-existent in the B-43 database.

Leftover unmatched tail numbers are assigned seating capacities through a three-pass ordered assignment process. After each pass through the tail numbers, the tail numbers with newly assigned seating capacities are not included as “matched” tail numbers for subsequent passes.

1. The first pass through the unmatched tail numbers checks to see if a given unmatched tail number has an airline and an OD pair as other matched tail numbers that operated for the same airline between the same OD pair. If so, the average seating capacity for that airline on that OD pair is assigned to the unmatched tail number.

2. The second pass through the unmatched tail numbers checks to see if a given unmatched tail number has an OD pair as other matched tail numbers that operated between the same OD pair. If so, the average seating capacity for that OD pair over all airlines is assigned to the unmatched tail number.
3. If there are no non-stop flights present with tail numbers in the OD pair, an average capacity for all markets served in a given distance range is assigned to the remaining unmatched tail numbers. Distance ranges are by 500 miles increments, and seating capacities are averaged across all airlines.

With seating capacities attributed to tail numbers in the schedule, both the actual and estimated capacities, it is possible to make calculations involving ASM.

3.4.5 Cleaning the DB1B Database

The DB1B cleaning process was important to creating a database of demand and revenue information that was usable for the purposes of this study. The goal was to have a consistent set of ticket coupons, attributed with fare data that could be compared in different markets before and after a depeaking event.

Several studies in the literature were examined for how they cleaned the DB1B data. The goal was to gain perspective on what types of errors could exist in the dataset, and what screens could be made to create a dataset fit for our needs. It is important to have consistency in the types of ticket coupons analyzed.

Borenstein in several papers makes use of DB1B data (Borenstein, 1989, 2005; Borenstein & Rose, 1994), and the cleaning guidelines he has developed encompasses correcting keypunch errors as well as restricting the data to one-way or roundtrip travel ensuring there is consistency in analyzed trips. The follow tickets are eliminated under Borenstein's guidelines:

- Tickets that include a destination or change of plane at a U.S. airport not in the top 200 largest airports
- Tickets that are open-jaw or circle trips
- Interline tickets
- Tickets that have more than two coupons between a given O&D
- Tickets that include more than four coupons
- Tickets with at least one segment in first-class (except on Southwest and JetBlue, where all coupons are called first class)

Error checking for keypunch mistakes includes removing:

- Tickets with a fare greater than five times the USDOT's SIFL for the O&D distance of travel
- Tickets with fares less than $10

This study makes use of some of these guidelines, and adjusts them for what was deemed important for this study's purposes. In order to capture all destinations in the U.S., no airports were deleted regardless of size. Because this study looks only at the coupon level, open-jaw, circle trips, and interline tickets are left in the dataset.

Borenstein removes tickets that have anything that has more than two coupons in market, and our study also uses that restriction. This restriction removes double connection markets, which when prorated, often have coupons with very low fares. In addition, part of the analysis looks at revenue for connecting flights, and by only allowing one connection per market, it reduces the complexity of analysis and creates a more uniform set of flights. A restriction is also put, on the number of coupons in a ticket, which with two coupons in a market, is capped at four coupons in an itinerary.

The Borenstein studies and many other studies (Cristea & Hummels, 2011; Dana & Orlov, 2007) all remove first class fares from their analysis. The reason being is these fares skew any revenue analysis, and likely disproportionately to certain markets. Borenstein also removes fares which have fares five times greater than the SIFL level for a market, which is adopted in this study, instead of the flat $9999 fare cutoff used by Cristea & Hummels (2011). Each of the studies also have a low-end cut off for fares, ranging from $10 per ticket for the Borenstein studies, $25 for Dana & Orlov (2007), and $100 for Cristea & Hummels (2011). These low fare cutoffs exist mostly to remove tickets that are frequent flyer trip redemptions. This study uses $5 per market, which is derived from half of the $10 Borenstein ticket cutoff.

There is also a trend to remove trips below a distance cutoff. These short trips were assumed to be land segment transfers between airports in the same metropolitan area (such as from LGA to JFK). Authors had different distances for the exclusion. Thirty-five miles was suggested such that transfers between two airports in the same city would not be dropped (Cristea & Hummels, 2011), while another drops all trips (both land and air) below fifty miles without any stated reason (Dana & Orlov, 2007). This study is not concerned with trips within the same city, but trips between two airports that are close together are worth keeping. Thus, the screen used for distance in this study is land trips under fifty miles.

In summary, the following are the set of DB1B cleaning rules used in this study, in the order they are performed, with short explanations of each.

1. Remove all itineraries that have more than four coupons and all markets with more than two coupons.
    - Itineraries with greater than four coupons are rare, but often have odd routings that look to be the product of mileage running and create complexities in analyzing revenue for connecting passengers. In addition, prorated fares become very small with so many segments.
2. Remove all itineraries that have at least one first-class ticket
    - The entire itinerary is removed because the ticket fare is prorated by distance over the markets. Thus, even if a market was flown entirely in coach, and one leg of a different market on the same itinerary was flown in first-class, the market fare for the market flown in coach will be higher due to the prorating.
3. Remove tickets with abnormally high fares.
    - Each market is assessed to see if the market fare exceeds the SIFL level by five times for that particularly market.
    - For any itinerary that has at least one market which exceeds the SIFL level by five times, the entire itinerary is removed from the Coupon and Market datasets. This is because the market fares are prorated, and thus any other markets affiliated with this itinerary should not be included
4. Remove tickets with low fares.
    - Each market is assessed to see if the market fare is below $5.00.

- For any itinerary that has at least one market which has a fare below $5.00, the entire itinerary is removed from the Coupon and Market datasets.

5. Remove coupons that have short distances.
    - Each coupon is assessed to see if the distance of the leg is less than 50 miles and does not have an airline for the ticketing carrier. These legs are assumed to be ground transfers between airports, often in the same metropolitan area (JFK/LGA/EWR, SJC/SFO/OAK, and MIA/FLL).
    - Only the specific coupon is removed with the short distance. Other coupons are left in the dataset. This is last step of cleaning, so removing single coupons from an itinerary does not affect later steps.

Through the cleaning process, around fifteen percent of all itineraries, corresponding to nineteen percent of the coupon data, were removed from each quarter of ticket data. The cleaned datasets were then able to be used to attribute revenue information to different origin and destination pairs in the supply data, and analyzed for their role in determining spoke destinations to shift in the schedule.

3.4.6 Prorating Fares

The Coupon dataset does not have fare information attributed to it, but coupon level fares are necessary for attributing revenue information to different markets flown from a hub. Multi-coupon markets must have fare data split between the coupons that compose the flights in the market. In order to create coupon level fare data from the market level fare data, two methods were assessed for performing the calculation: (1) linearly prorate coupon fares using a ratio of distances in the market, or (2) split the fares using a ratio of the square root of the distances in the market.

Method 1 of calculating coupon level fares is a common method to split up fares across two flight legs. By using the relative distance out of the total flown market distance, a fare can be easily calculated (Ater & Orlov, 2010; Dana & Orlov, 2007; Li & Netessine, 2011). In fact, the Market dataset's fares are prorated by a ratio of distances for the different markets in an itinerary. The fare would be calculated as such:

$$Coupon\ Fare\ for\ Leg\ 1\ = \frac{distance_{leg\ 1}}{distance_{leg\ 1} + distance_{leg\ 2}} \times Market\ Fare$$

Method 2 of creating coupon level fares computes the square root of the distance of the segments in the itinerary. This method takes into account that there is a fixed cost for any flight legs which is operated, and the per mile rate decreases as the distance flown increases (Le, 2006; Wang et al., 2008). The SIFL calculation is an example of this rationale. Le (2006) notes that the idea to calculate fares in this manner came from Dr. Tassio Carvalho of American Airlines. The fare would be calculated as such:

$$Coupon\ Fare\ for\ Leg\ 1\ = \frac{\sqrt{distance_{leg\ 1}}}{\sqrt{distance_{leg\ 1}} + \sqrt{distance_{leg\ 2}}} \times Market\ Fare$$

The effect of the square root method is that shorter distance fares receive a larger portion of the market fare than the longer distance fares in the market. This is accounting for the fixed cost of any given trip. Figure 3.2 shows how a given fare in the square root method is larger to a certain point. In a two-leg market, the point where the linear and square root lines is when the two legs have equal lengths.

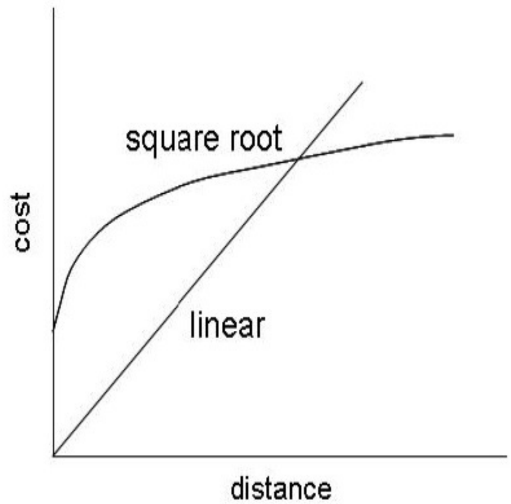

Figure 3.2 Comparison of linear versus square root prorating of leg distance. Square root prorating helps account for fixed cost. *Source: Le (2006)*

Both methods had similar distributions of prorated fares, with the square root method having a distribution slightly less skewed towards higher fares. It was determined, however, that the impact of our assumption of one technique over another is minimal. Both methods would be used to assess revenue before and after depeaking. As long as there are not vast differences in the distances aircraft are flying from an airport before and after a depeaking date then how one prorates the fares should not impact the results. Fares, both before and after depeaking, would be equally affected by either prorating methods. We assume that there is not a vast difference in the distances aircraft flew before and after depeaking, and thus either method would be good for comparison. Despite the rationale behind the square root method, the linear method was chosen over the square root method for this study because of its simplicity in calculation and more common usage – the market fare that is being prorated from the BTS dataset was itself prorated linearly!

3.4.7 Choosing Time Periods for Case Studies' Datasets

A major contribution of this study is using publicly available supply and demand data and linking them into a single analysis. This combination allows for revenue analysis on historical schedules. An issue with using the publicly available datasets provided by BTS is the On-Time database and the DB1B database have different time periods. The former has specific date and time information for each flight and is distributed on a monthly basis. The latter, however, provides only the calendar quarter in which a passenger ticket was traveled on as temporal information.

3.4.7.1 Time Periods Used for Analysis

In order to have the same time periods for comparison of markets, it is necessary to thus either aggregate the supply data for comparisons to a quarter of demand data, or create average daily values from the demand data and compare it to a single day of the supply data. Because the fine details of the airline schedule were preferred for measuring depeaking and connections, the time period was chosen as a single day, with averages of the demand data used for comparisons with supply.

Choosing to use a single day to represent the supply of an airline for a period of time (the peaked period or the depeaked period) will not precisely match up with the average of the demand data, but still provides a consistent measure across cases within the study. By averaging demand data, one includes all of weekdays, weekends, and holiday traffic and fares, and thus the revenue values which are being assumed for a single day are not precisely what would have occurred on the typical day being used for the supply data.

The single days used to represent the supply data is a Tuesday one to two weeks before depeaking for the peaked schedule and a Tuesday one to two weeks after depeaking for the depeaked schedule. Tuesdays that are within three days of a national holiday are avoided.

Choosing the peaked and depeaked quarters to be averaged for daily demand was more complex than choosing the peaked and depeaked days for the supply data. Because a depeaking event is unlikely to happen on the first or last day of a quarter, the same quarter corresponds to the representative before and after days. Thus a quarter of demand data includes both tickets flown on a peaked schedule and tickets flown on a depeaked schedule. It is not possible to distinguish which tickets in a quarter were flown on either schedule. Because of this issue, it is necessary to use the quarter before and the quarter after to represent the demand before and after depeaking. Thus, if an airport was depeaked in the second quarter, the first quarter and third quarter would serve as the peaked and depeaked demand data, respectively.

An exception to the demand data quarter decision is made if the depeaking date is within one week of the start or end of the quarter. In this case only one of the thirteen weeks of the quarter operated under a different schedule from the rest of the quarter. The demand data for that quarter thus has a reasonably large enough proportion of one schedule type's resulting traffic and fares that it was deemed appropriate to use as the representative quarter. The corresponding quarter for the other schedule type would remain the quarter before or after the depeaking quarter, but now the corresponding supply date would be within that quarter.

An example of how time periods are determined for use in this study is shown in Figure 3.3. Note how in Figure 3.3 (a), the peaked and depeaked quarter do not contain the peak and depeak dates quarter, and in Figure 3.3 (b) the depeaked quarter includes some dates which still have a peaked schedule.

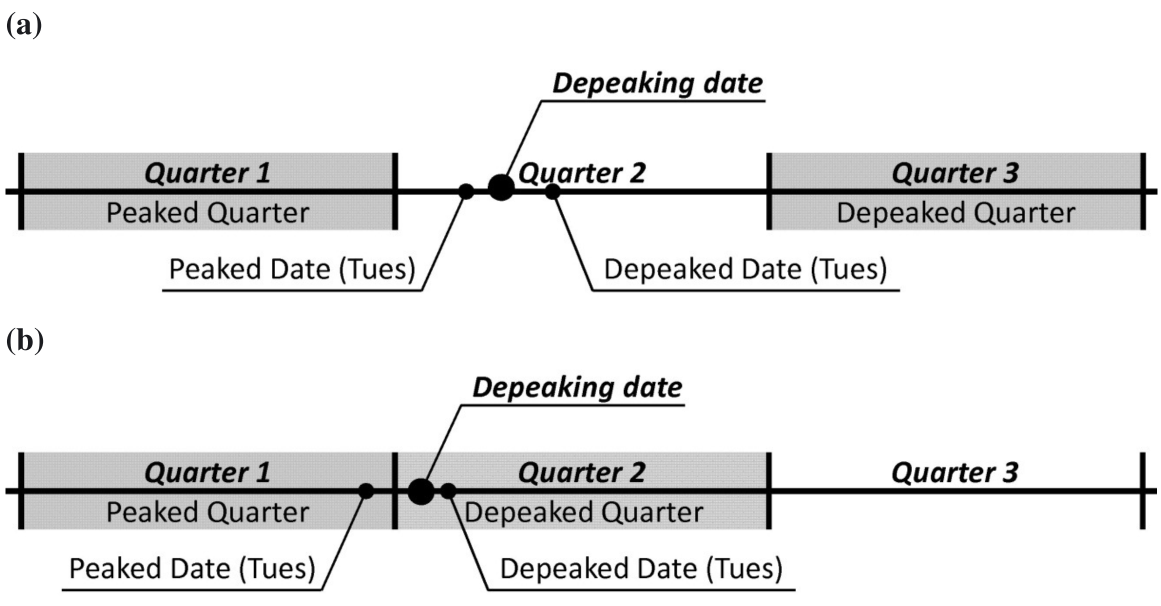

Figure 3.3 Time periods for supply and demand data used in analysis. Peaked and depeaked dates refer to dates in supply data, while peaked and depeaked quarters refer to quarters in demand data. (a) shows the situation where the depeaking date is in the middle weeks of a quarter, while (b) shows the situation where the depeaking date is early (or late) in a quarter.

3.4.7.2 Validating Supply-Demand Time Period Decision

With the supply data coming from dates immediately before and after the depeaking date, and the demand data coming (generally) from the quarters before and after the depeaking quarter, a check was performed to see how much the supply shifted in the months prior to depeaking, and the months after. Tuesday schedules in the quarter prior to depeaking were compared to the date used as the representative peaked schedule, and similarly for the quarter after depeaking and the representative depeaked date. Generally, the supply barely changed over these periods (see Results chapter for the degree of change), and the decision to use the system shown in Figure 3.3 is validated.

Because the demand data is quarterly, and from the beginning to the end of the analysis of each case nine months elapse, seasonality of prices must be considered. Year-over-year controls are put in place to standardize revenue and fare changes across the industry and within the airline. These controls adjust for changes across the industry, within the airline, and major external events.

3.5 Analysis Methodology

The case study approach to this project was chosen because each occurrence of depeaking has unique reasons for its implementation. The airline hubs at which flight banks were shifted to continuous schedules vary in geography, the number of airline competitors, capacities, and flight volumes. A case study allows an understanding of depeaking within the bounds of the circumstances under which it occurred. Each case can be evaluated separately and general conclusions drawn from comparing across different cases.

The setup of each case focuses on three primary parts, outlined in bold in Figure 3.4. The first part examines the supply in reference to how the flight schedule changed for the depeaking airline and its competitors. The second part focuses on demand and will examine how revenues changed, how the passenger base responded to the changes, and the changes for competitors. Lastly, the operations of the airlines that were affected by depeaking are studied in terms of occurrences of delay. Along the way, after a portion of the supply analysis, the cases which do not have verified depeaking are terminated. The cases carried through the demand and operations analysis are compared with one another through a difference-in-difference analysis and a multivariate regression at the spoke level. In addition, a separate project stream looks at airport revenue through simple regression.

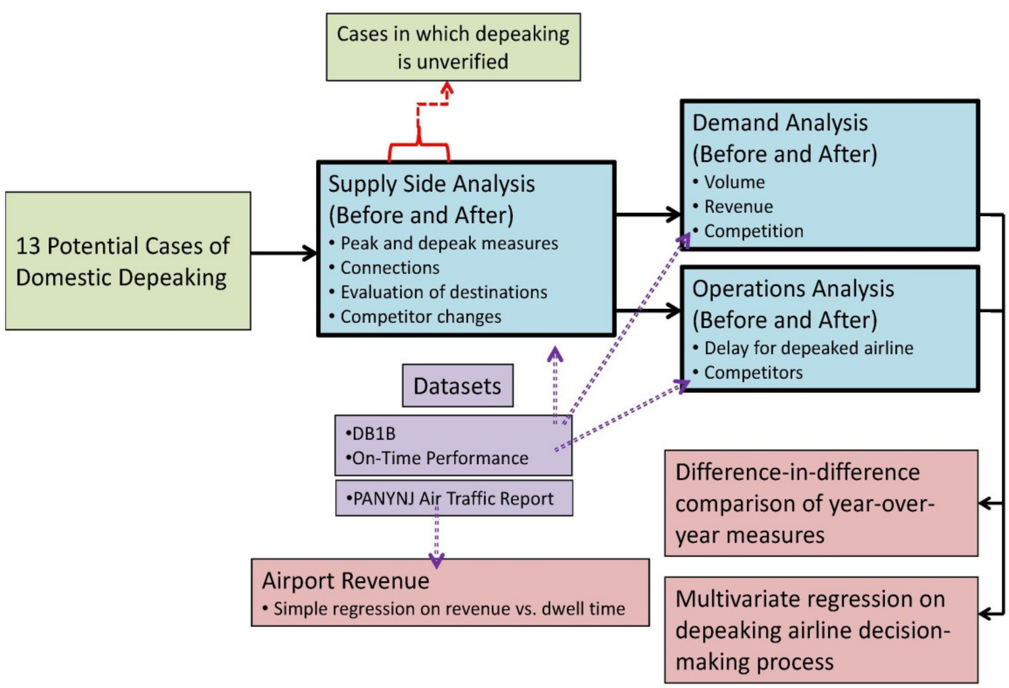

Figure 3.4 Conceptual framework of analysis steps.

The following section describes how cases were chosen, the steps taken with the data to prepare parameters, and how the analyses were performed.

3.5.1 Choosing Cases

A number of case studies were identified early in the study using findings from the literature review. From this initial set, the cases were reduced in number based on whether it was possible to identify if the airline in the case actually depeaked the hub. This section describes the initial list and why certain cases were not carried through to the full study.

3.5.1.1 Initial Case List

Only the domestic airline implementations of depeaking that have been noted during the literature review are examined for potential case studies. International examples are not included because this study only makes use of U.S. domestic data.

The literature review identified many occurrences of depeaking since 2000, with a wide range of information currently available on them. Not all instances of depeaking have been discussed in depth or studied through quantitative analysis in the literature. Several of the depeaking examples were only casually mentioned in the literature as having occurred, but were without additional information or references. In looking for potential instances of depeaking or verifying when they happened, it was sometimes necessary to use Internet airline forums. Using these forums, evidence could be initially found on which airports were depeaked and the time period or the precise date the depeaking occurred. Due to the uncertainty and lack of information on many of the depeaking cases, the list of potential occurrences need to be checked for when and how they occurred before any are chosen to be carried through the full analysis.

For this study, thirteen instances of depeaking were identified as potential case studies. Each of these was mentioned either in the literature or in online forums. The thirteen potential cases are listed by airline, hub, and the year each reportedly depeaked in Table 3.4.

Table 3.4 Depeaking Occurrences for Selection of Case Studies

Airline	Hub	Year Depeaked
Alaska	SEA	No Information
American	DFW	2002
American	MIA	2004
American	ORD	2002
Continental	EWR	2000
Continental	IAH	No Information
Delta	ATL	2005
Delta	CVG	2005
Delta	SLC	2005
United	LAX	2005
United	ORD	2004
United	SFO	2006
US Airways	PHL	2005

A map of the cases and their location in the U.S. is shown in Figure 3.5, with the airlines noted next to each airport and the year of reported depeaking.

The American cases for ORD and DFW were assessed first, to validate the procedure such that the measure results are similar to those found in Bogusch (2003). The remaining cases were then verified in no particular order to check if depeaking had occurred during the past decade.

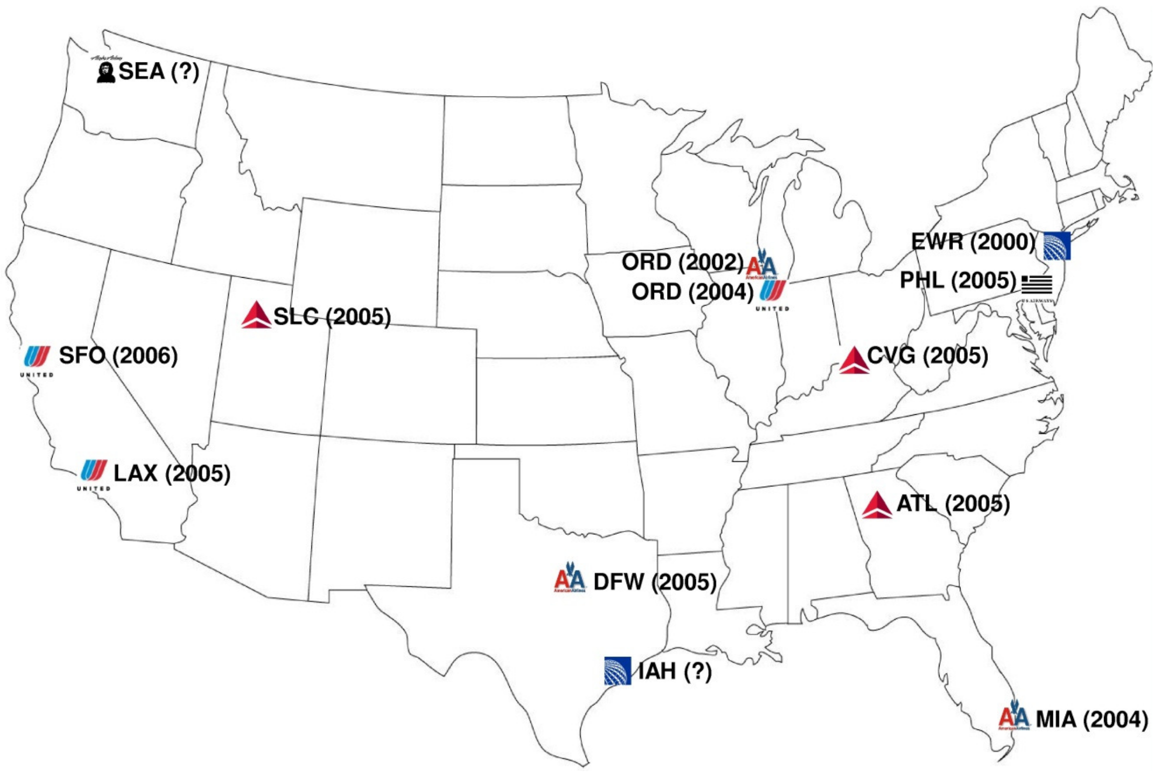

Figure 3.5 Map of the reported U.S. depeaking cases.

3.5.1.2 Removed Case Studies

To ensure the case studies were credible, each was assessed by their change in supply, as described at the beginning of the Supply Analysis section that follows. Those which had an identifiable difference between before and after schedules, such that the depeaking can be verified, were kept as a potential case study. Just because the following cases are removed from the study, does not necessarily mean the airport did not get depeaked. In a few cases, it was because there was a lack of data available for verification (e.g. obvious affiliate airline carriers were missing from the On-Time database).

The following subsections describe the cases that were not able to be verified for depeaking, and the reasons this occurred. The next section then lists the final set of cases and the date they depeaked.

3.5.1.2.1 Alaska Airlines at Seattle

Alaska Airlines was reported to have depeaked SEA by Williams and Weiss (2005), citing an Alaska Airline's 2004 publication. Recreating the schedule proved to be difficult because Alaska Airline's primary affiliate carrier, Horizon Air Industries (QX), did not report On-Time performance data in years 2004 and earlier. Horizon flew many routes for Alaska during this time period, and thus it is not possible to fully reproduce the schedule.

3.5.1.2.2 American Airlines at Miami

American Airlines was reported to have depeaked MIA in May 2004 (Jiang, 2006). Reproducing the schedules did not provide enough evidence of depeaking to say with certainty when MIA was depeaked, or if it was at all. As seen in Figures 3.6 and 3.7, there is a banked schedule structure in both April and May of 2004. The latter seems to have had the peaks reduced slightly and slightly spread out, but not depeaked into a continuous schedule. It must be noted that MIA has an extensive international network, and lacking the international flights in the schedule for reproduction means there is a large portion of the traffic not represented. The lack of international data, for MIA in particular over other airports, further reinforces the airport as a case study to be excluded.

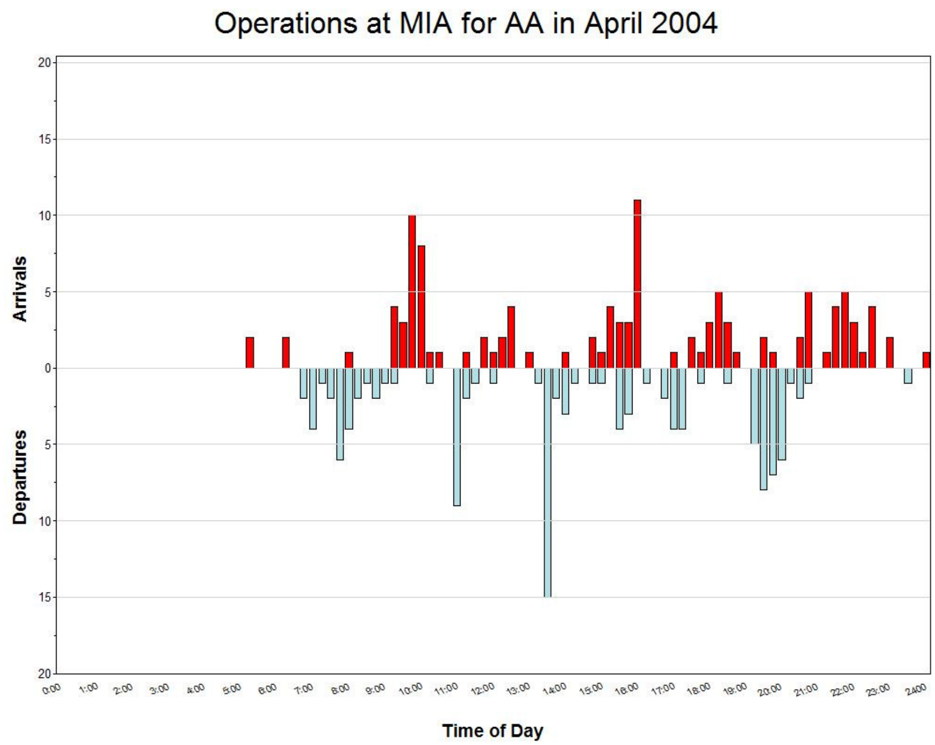

Figure 3.6 Recreated schedule of AA's operations at MIA in April 2004. The schedule has banks indicating the peaked schedule.

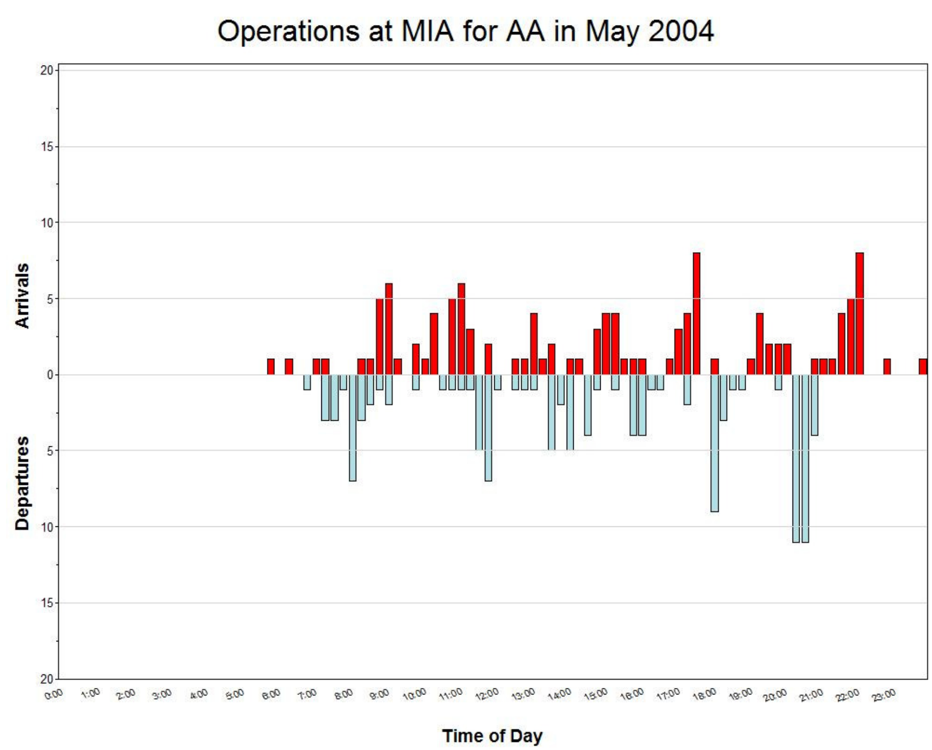

Figure 3.7 Recreated schedule of AA's operations at MIA in May 2004. The schedule still has banks, although not as intense in flight frequency, but still indicating a peaked schedule.

3.5.1.2.3 Continental Airlines at Newark

Continental Airlines was reported to have depeaked EWR in 1997 (Ott, 2002) or the summer of 2000 (McCartney, 2000). Based on the schedule reproduction, 1998 appeared to be the time period when EWR was depeaked. Although it is difficult to tell when the depeaking occurred – it appears to have occurred gradually over a several month period – it is clear that the schedule changed from December 1997 to September 1998, as seen in Figures 3.8 and 3.9. Recreating the schedule proved to be difficult because Continental Airline's primary affiliate carrier, ExpressJet Airlines (RU), did not report On-Time performance data during this time period. ExpressJet flew many routes for Continental during this time period, and thus it is not possible to fully reproduce the schedule.

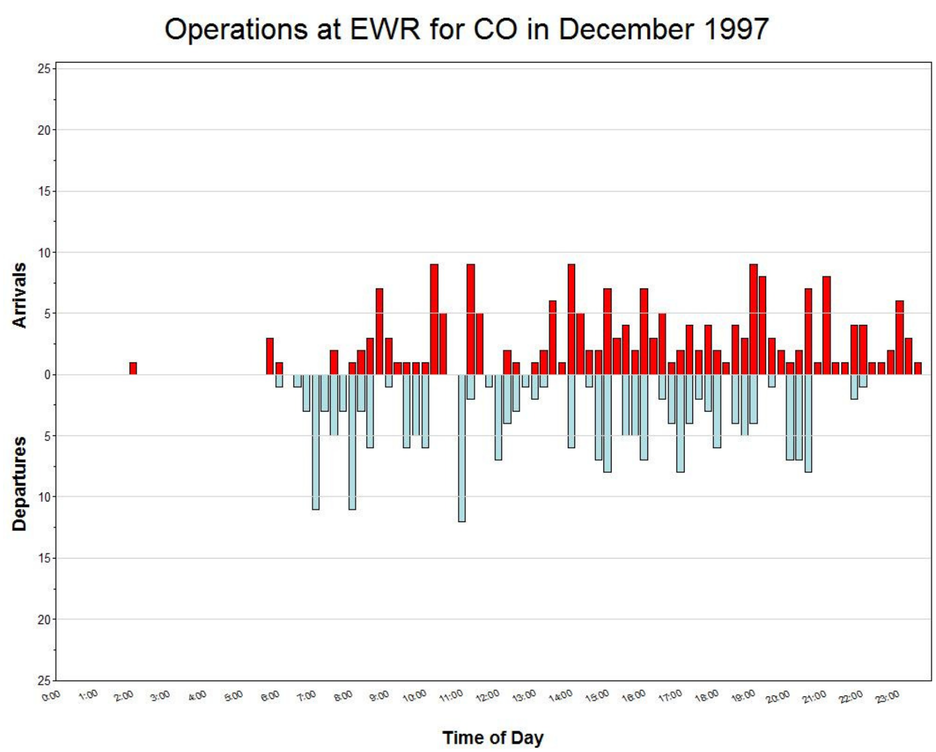

Figure 3.8 Recreated schedule of CO's operations at EWR in December 1997. The schedule still appears to have banks during this time period.

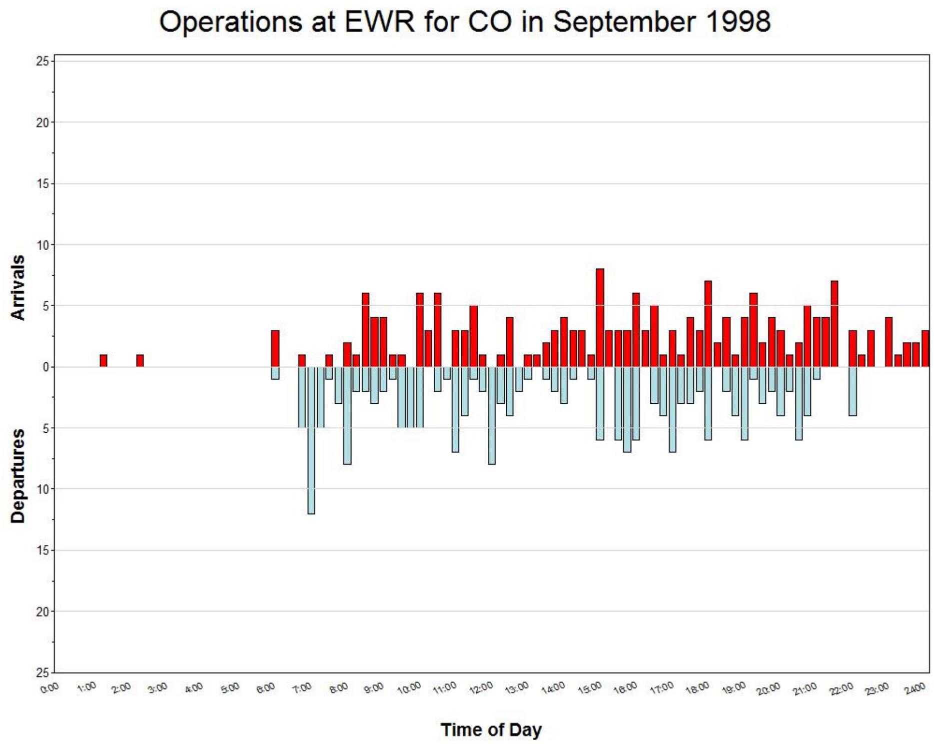

Figure 3.9 Recreated schedule of CO's operations at EWR in September 1998. The schedule looks depeaked as compared to the December 1997 schedule.

3.5.1.2.4 Continental Airlines at Houston

Continental Airlines was reported to have depeaked IAH in 2005 or prior, as mentioned by Williams and Weiss (2005), although Continental was claimed to have been experimenting earlier than (Ott, 2002). Continental's schedule was recreated at IAH for the years prior to 2005, and there was no indication that Continental ever removed the banked structure from its schedule. A strong peaked schedule exists continuously throughout the early part of the decade. It appeared that Continental never depeaked IAH.

3.5.1.2.5 Delta Airlines at Cincinnati

Delta Airlines was reported to be planning to depeak CVG in a news article from 2004 (Hirschman) along with SLC and ATL. Delta's schedule was recreated from the date of the article to early 2006. During the late summer of 2005, it seemed that Delta had done some spreading of peaks at CVG for the arrival banks only, as displayed in Figure 3.10. Through analysis of the schedule during the second half of 2005, it appeared that Delta decided to reduce the CVG hub instead of depeak the banks. By December of 2005, the volume of flights per day had dropped from around 1,140 in August, to 680 in December. The number of destinations was also scaled back, from 126 to 115. The banked schedule form was retained through the schedule reduction. It appears Delta did not depeak CVG.

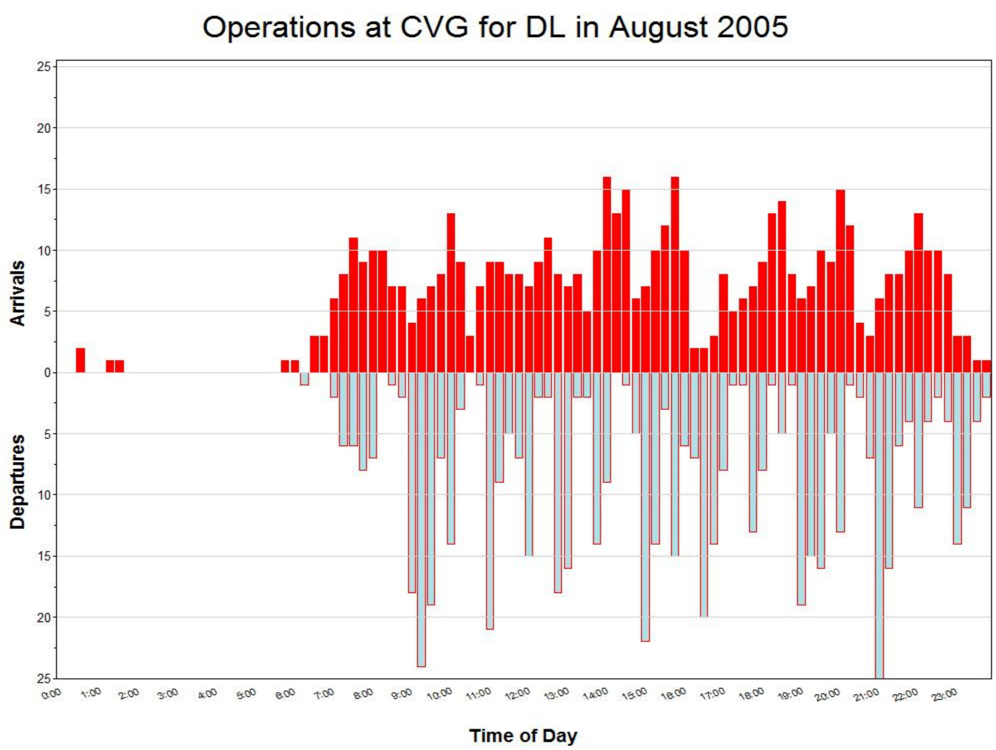

Figure 3.10 Recreated schedule of DL's operations at CVG in August 2005. Note the peaks in the arrival banks are less defined than those for the departures.

3.5.1.2.6 Delta Airlines at Salt Lake City

Delta Airlines was reported to be planning to depeak SLC in a news article from 2004 (Hirschman) along with CVG and ATL. Delta's schedule was recreated from the date of the article to early 2006, and there was no indication that Delta ever removed the banked structure from its schedule. A peaked schedule exists continuously during this period, although the schedule gets reduced in number of flights in late 2005. The number of flights per day drops from 744 in August to 504 in December, while the number of destinations served is reduced from 84 to 81. It appears that Delta never depeaked SLC, but instead reduced its activity at the hub instead while maintaining the banked structure.

3.5.1.2.7 United Airlines at Chicago

United Airlines was reported to have depeaked ORD in a company news brief in April of 2004 (United Airlines, 2004), describing that the schedule at ORD was depeaked in February of the same year as a means of reducing congestion at the airport. Recreating the schedule proved to be difficult because one of United Airline's primary affiliate carriers, Air Wisconsin (ZW), did not report On-Time performance data in years 2004 and earlier. Air Wisconsin was one of three affiliate airlines to operate flights for United from ORD during this time, alongside Atlantic Coast and SkyWest that did report performance data in 2004. Because Air Wisconsin served many destinations for United from ORD during this time period, it is not possible to fully reproduce the schedule. The flight schedules that can be reproduced are shown in Figures 3.11 and 3.12, displaying the schedule in January and March. A change certainly occurred, but analysis on what happened is not recommended due to the lack of information on flights flown by Air

Wisconsin. The incomplete schedule does not allow for verification of depeaking in February 2004, nor analysis on how United depeaked ORD.

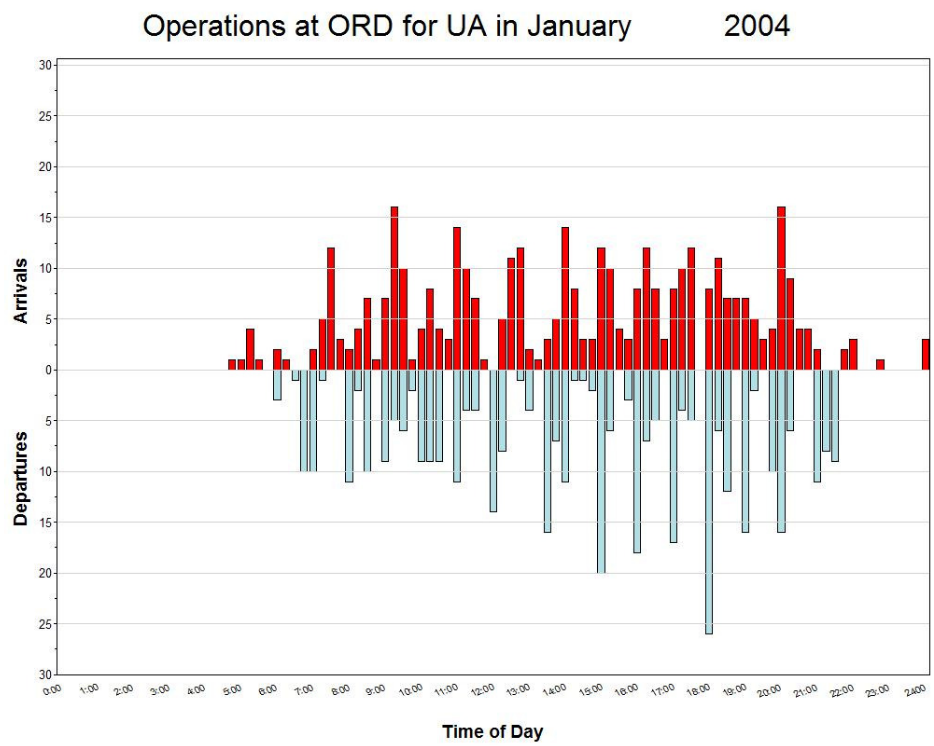

Figure 3.11 Recreated schedule of UA's operations at ORD in January 2004. This shows the schedule before UA's depeaking at the airport. The schedule is not able to be fully reproduced without Air Wisconsin, and thus United's depeaking at ORD is not included in this study.

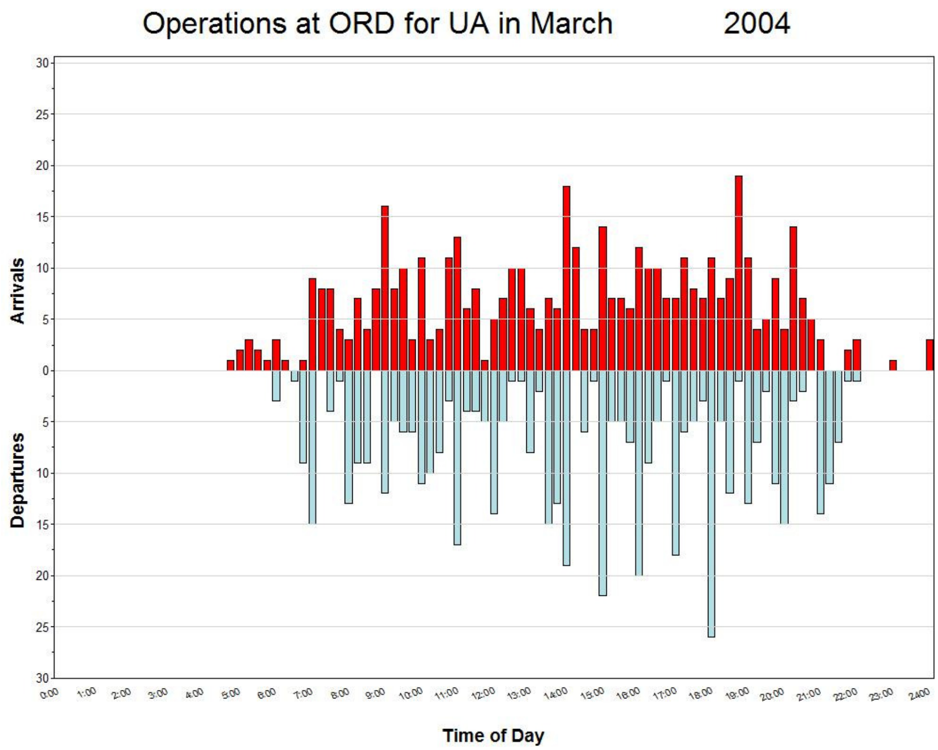

Figure 3.12 Recreated schedule of UA's operations at ORD in March 2004. This shows the schedule after UA's depeaking at the airport. The schedules are not able to be fully reproduced without Air Wisconsin, and thus United's depeaking at ORD is not included in this study.

<u>3.5.1.3 Final Case Study List</u>

Six of the initial cases were verified as having been depeaked by the airport's hub airline. Each of these cases had a clear indication the depeaking occurred, such that peaks beforehand were clearly identifiable, and the change when depeaked was obvious. In Table 3.5, each of the airlines and airports are listed along with the date of depeaking is recorded if the depeaking is verified.

Table 3.5 Final Case Study List of Verified Depeaked Airports

Airline	Hub	Date Depeaked
American	ORD	April 7, 2002
American	DFW	November 1, 2002
Delta	ATL	January 31, 2005
US Airways	PHL	February 6, 2005
United	LAX	June 7, 2005
United	SFO	January 9, 2006

3.5.2 Schedule Reproduction and Measurements

Reproducing the schedule for each case study makes use of a cleaned On-Time performance database file with the affiliate airline codes changed to be the parent airline. The schedule is recreated for a Tuesday for the month of interest. Only the airline of interest's flights are retained for the reproduced schedule. Each flight is labeled as a departure or arrival into and out of the airport, and placed into bins representing the 96 15-minute periods throughout a day. 15-minute periods were chosen to stay consistent with Bogusch's (Bogusch, 2003) study.

Unlike the cleaning process which made use of actual arrival and departure times, the schedule reproduction process uses CRS times. The CRS times provide information on the flights that were actually scheduled by the airline at an airport, before actual operations occurred. These times better achieve the goals of this study.

Using a table of daily flights classified into type of flight and time, a visual display of the schedule is created, which has been displayed several times so far in this report. Arrivals are plotted above the x-axis, and departures plotted below the y-axis, similar to what was seen in Jiang (2006).

Several measurements are made on this schedule and used later for the supply analysis. These parameters which describe the schedule include:

- the number of operations throughout the day,
- the number of unique destinations served from the airport,
- the maximum number of one type of operation (either arrival or departure) in a given 15-minute period,
- the maximum combined number of operations in a given 15-minute period,
- the coefficient of variation of the number of flights in 15-minute period for both arriving flights and departing flights,
- the number of arrival banks,
- and the number of departure banks,
- the percentage of flights that operated within flight banks,
- the percentage of flights operated by affiliates,
- the number of potential connections between arriving and departing flights,
- the average number of potential connections per arriving flight,
- the maximum number of connections between any two spokes,
- and the total ASM offered from the airport by the hub airline.

To calculate the three parameters referencing banks, the flight banks need to be defined and identified from the schedule. The process to do this is described in the next section. The parameters involving connections are described further in 3.5.4.

Each spoke airport from the hub is summarized by the average inbound and outbound flight times, ASM, number of flights per day in and out of the hub airport, number of flights in and out of the peak (for peaked schedule only), the percentage of those flights in the peaks, and the competitors operating between the spoke and hub.

3.5.3 Measurement of Schedule Banks

Measuring the degree to which a schedule depeaked provides an important measure for comparison among depeaking cases. A measure of depeaking, however, first needs a measure of peaking to compare against within each case, so that comparisons can then be made later between cases. As such, the banks of the peaked schedule need to be identified, so that the corresponding depeaked measure can be compared against it.

There is a need to develop a robust measure of schedule peaking. As discussed by Kanafani and Ghobrial (1985), typical peak-hour statistics are not suitable for capturing flight banks as the banks occur over shorter periods of time and throughout the day. The only measurement that could be used for peaking and depeaking comparisons in the literature was the peak index, used by Jenkins, Marks, and Miller (Jenkins et al., 2012). The peak index is a granular approach to describing an airport's schedule, measuring the coefficient of variation of one-hour periods of activity through the day. Standard deviation is not enough because it is unique to each sample. Increases in the peak index over time indicated a change to more peaking, while decreases in the peak index showed a depeaking airport. Jenkins, Marks, and Miller applied the peak index across all operations at the airport, and not a specific depeaking airline.

The peak index is useful in many regards, and a similar version of it is used in this study. The coefficient of variation is measured only on the depeaking airline's schedule, and using 15-minute periods. The more granular approach is used to better capture the reality of flight banks – they often are 45 to 60 minutes in length, and thus hour-long periods miss out on much of the intricacies of banking.

Another way of looking at the measurement of peaking and depeaking was to quantify the percentage of flights that existed within banks. This required banks to be able to be found consistently. Two methods were considered to identify the banks: 1) employing a Fourier series to decompose the schedule's periodic nature and 2) a heuristic procedure to find the local maxima in the schedule.

3.5.3.1 Fourier Series for Finding Banks

A Fourier analysis was performed to assess whether the periodic banks in a peaked flight schedule could be decomposed into a sum of a number of sine and cosine functions. The hope in combining these oscillating functions was to be able to express the aggregated time series data as a continuous function. As a continuous oscillating function, it would be simple to identify the peaks of the banks and the troughs between.

The Fourier series was not useful in identifying banks in the schedule. When running the Fourier analysis large errors were created. The reason these errors arose is the non-periodic distribution of the banks throughout the day and the varying lengths of the banks. The time between the banks are not consistent, as there are longer lengths of time between banks midday than in the mornings and evenings. In addition to the irregular spacing between banks, the banks themselves are of varying lengths, typically ranging between 45 and 90 minutes. The lack of periodicity causes the Fourier series to break down, even with upwards of eighteen curves.

3.5.3.2 Identifying the Flight Banks in the Schedule

Because of the irregularity in the spacing and length of banks, a heuristic procedure for identifying banks was developed specifically for this study, as the researchers were unable to find a method in the literature that could be used to identify local maxima in aggregated time-series data. The measure used to determine the degree to which a schedule is peaked is the percentage of flights that are within the flight banks of a schedule. To make this measurement, one first has to locate where the banks are in an airline's schedule. The following sections describe the method used to identify flight banks in an airline's schedule, prior to the schedule being depeaked, and how the measurement is made for before and after depeaking.

To find the flight banks in an airline's schedule, a two-step process was created. The first step is identifying the 15-minute periods of the day which would be considered peaks in the schedule. The second step is adding to the peaks by examining the 15-minute periods on either side of the identified peaks. Each of the two steps has several criteria used to include 15-minute periods into flight banks.

In order to perform the process, statistical measures of the 15-minute periods must be collected. Arrivals and departures are maintained as separate populations for these statistical measures and throughout the equations that follow. The variable used is the magnitude of operations $X_{i,t}$ in a given 15-minute period (where i is an airport-airline combination and t is a 15-minute period within the day's schedule being examined). This generic form of the variable could be written as $A_{i,t}$ or $D_{i,t}$ for arrivals and departures, but is left as X for simplicity in the expressions that follow. When a 15-minute period is identified to be a peak in the bank of the schedule, the period is denoted by $X_{i,t'}$.

The entire day is used for the population set for 15-minute periods, and thus N=96 in both the arrival and departures populations. For both populations, the mean and standard deviation are calculated, giving μ_A, σ_A, μ_D, and σ_D, but in the expressions that follow the generic μ and σ are used for simplicity.

3.5.3.2.1 Identifying Peaks

The first step in finding the banks in a schedule is identifying the departure peaks and arrival peaks. Four checks were developed to find the peaks in a schedule, and they are performed in order. These are listed in Table 3.6.

Table 3.6 Checks Performed to Identify Peaks Within a Daily Schedule.

Check 1
$X_{i,t} > \mu + 1.5\sigma$
Check 2
$X_{i,t} - X_{i,t\pm 2} > 2\sigma$
Check 3
$X_{i,t} \geq min\left\{X_{i,t^{1-2}}\right\}$
Check 4
$X_{i,t} > X_{i,t+1}\boldsymbol{and}\, X_{i,t} > X_{i,t-1}\boldsymbol{and}\, X_{i,t} > \mu + \sigma$

Note: $X_{i,t^{1-2}}$ indicates a 15-minute period which already is identified as a peak in the first two checks.

The first of these four checks attributes peak status to 15-minute periods that have operations greater than 1.5 times the standard deviation above the mean. The second check attributes peak status to 15-minute periods which have operations greater than two standard deviations more than a 15-minute period which is thirty minutes earlier or later. This second check is perform in addition to the first check because peaks may not always be extremely high, but are distinct from their surrounding 15-minute time periods. By looking before and after thirty minutes, it is possible to tell if a large sudden increase in volume occurred, which indicates a bank occurring. The thirty minute value is used because flight banks are typically 45 minutes to one hour in length, so the peak of a bank would be about thirty minutes into the bank. Figure 3.13 shows the identified peaks after the first two checks.

The third check attributes peak status to any 15-minute period which has operations greater than or equal to the smallest peak identified with check 1 and 2. The fourth and final check attributes peak status to any 15-minute period which has operations greater than both the 15-minute periods directly before and after, and is greater than one standard deviation above the mean. Figure 3.14 shows the peaks after the final two checks in peak identification.

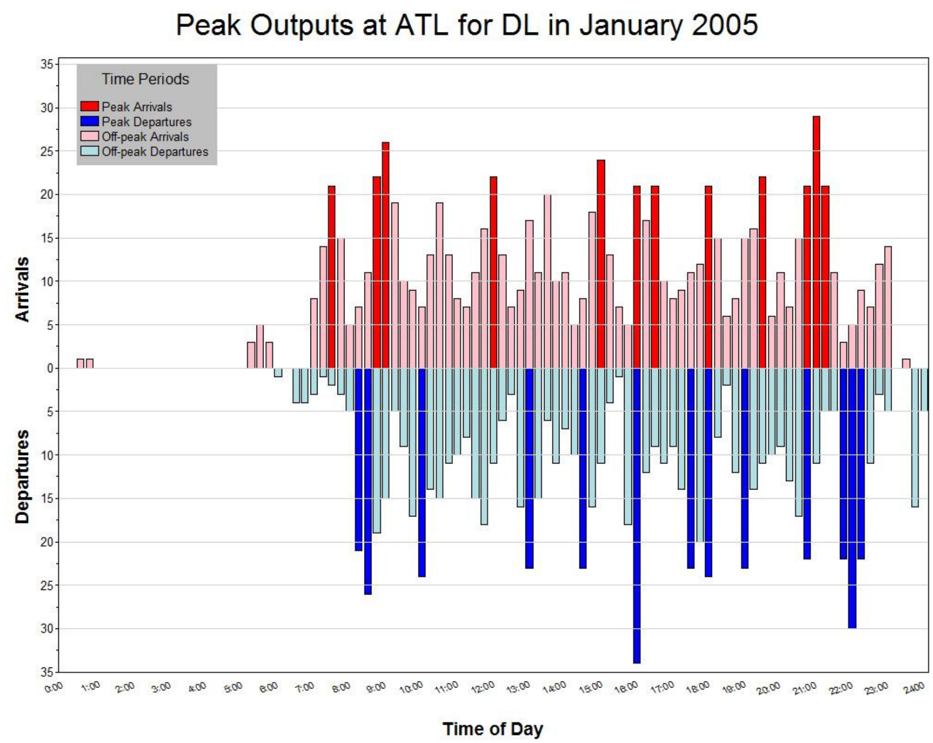

Figure 3.13 Example of identified peaks after Checks 1 and 2. Shown using Delta's January 2005 schedule in Atlanta.

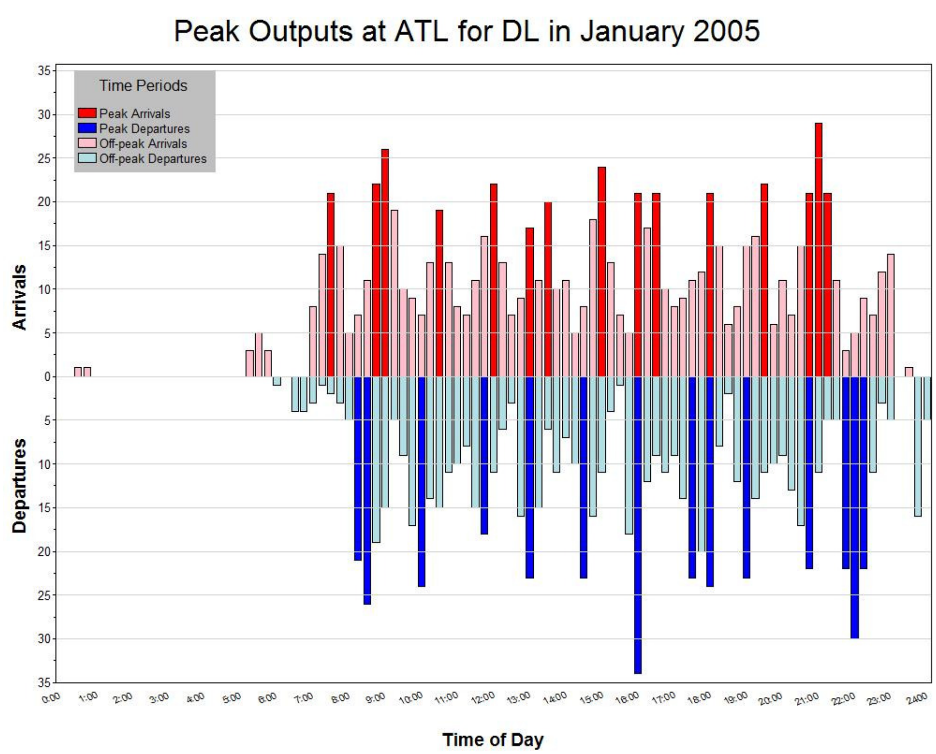

Figure 3.14 Example of identified peaks after all four checks. Shown using Delta's January 2005 schedule in Atlanta.

3.5.3.2.2 Filling out the Banks

The second step in identifying the banks is to add the portions of the schedule which are next to peaks and should be considered as part of that peak's bank of flights. There are two parts to this step. The first part adds to the side of the peaks based on two checks, including a minimum for the first check, as shown in Table 3.7. The first check assesses 15-minute periods which are immediately adjacent to a peak 15-minute period, and adds them to the bank if they are greater than two standard deviations below the peak. These 15-minute periods must, however, be greater than 0.25 standard deviations below the mean. The second check assesses 15-minute periods and adds them to the bank if they are greater than the mean. In addition, any 15-minute period that is between two peaks identified in step one is added automatically to the bank.

Table 3.7 Checks Performed to Add to the Peaks Within A Daily Schedule.

Check 1		**Minimum Requirement**
$X_{i,t'\pm 1} > X_{i,t'} - 2\sigma$	AND	$X_{i,t'\pm 1} > \mu - 0.25\sigma$
Check 2		
$X_{i,t'\pm 1} > \mu$		

Note: $X_{i,t'}$ indicates a 15-minute period which already is identified as a peak in the first step.

Figure 3.15 shows the banks as they are identified after the first part of the adding step.

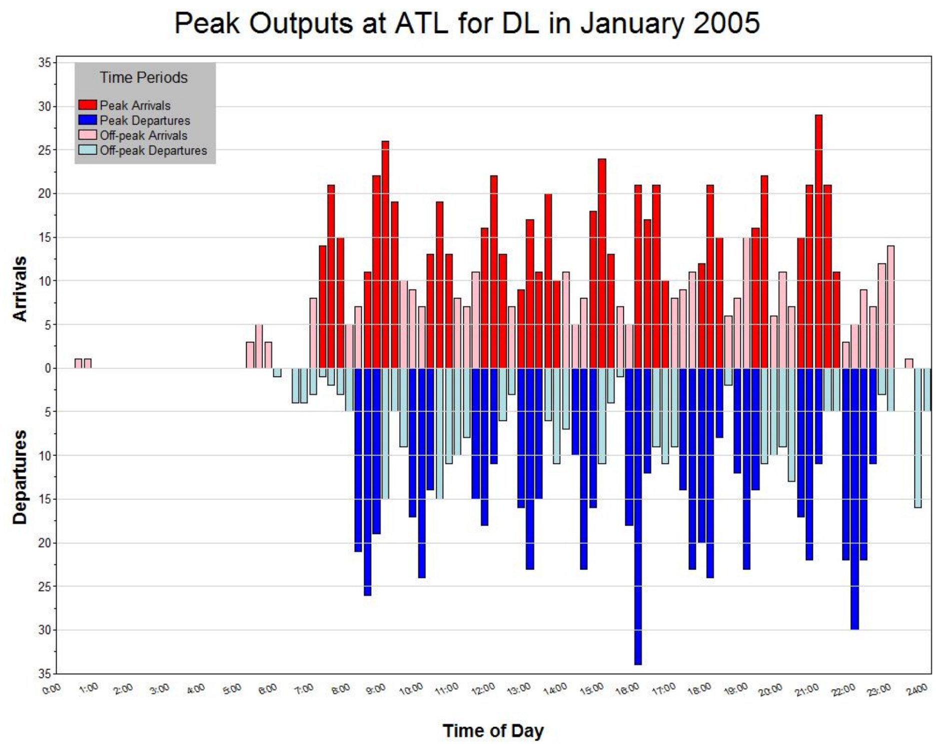

Figure 3.15 Example of flight banks after the first part of the adding step. Shown using Delta's January 2005 schedule in Atlanta.

The second part of the step of adding to the banks adds a 15-minute period to a bank if the 15-minute period is next to a bank and is greater or equal to the adjacent periphery 15-minute period of the bank. This part is repeated until there are no more possible 15-minute periods to add that satisfy this condition, shown in Table 3.8. Figure 3.16 shows the final banks as they are identified after this second part of the adding step. $X_{i,t''}$ refers to a 15-minute period, which is not a peak, but has been identified as a peripheral part of a bank.

Table 3.8 Iterated Step to Build Up the Remainder of the Banks

$$X_{i,t'\pm1} \geq X_{i,t'} \ \boldsymbol{or} \ X_{i,t''\pm1} \geq \ X_{i,t''}$$

Note: $X_{i,t'}$ indicates a 15-minute period which already is identified as a peak in the first step. $X_{i,t''}$ indicates a 15-minute period which already is identified as part of a bank, but is not the peak, from the first part of the second step.

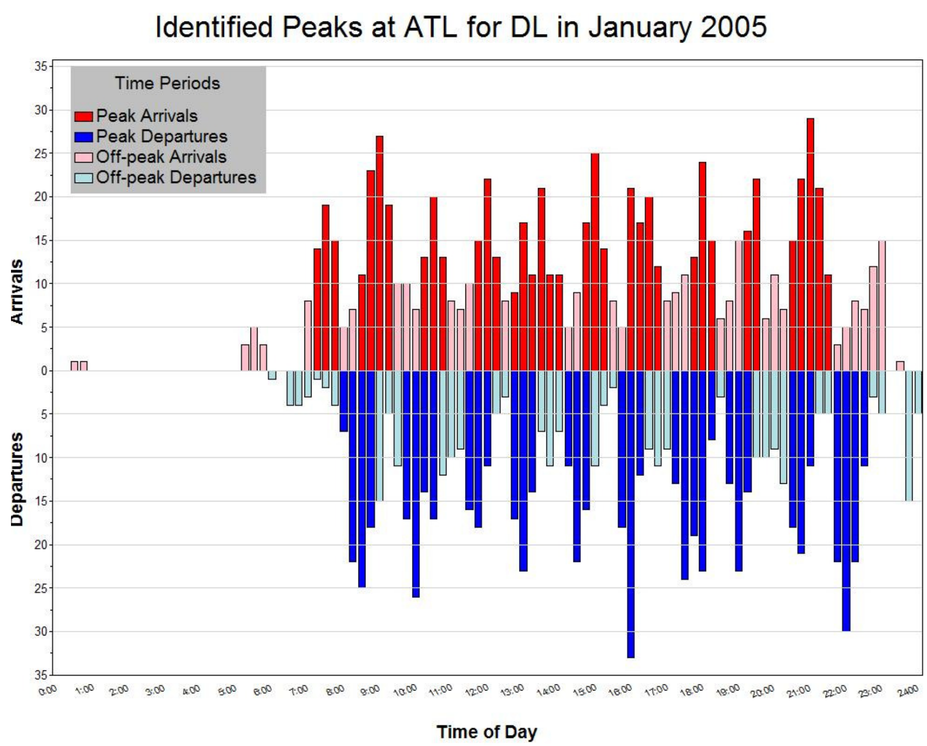

Figure 3.16 Example of flight banks after the second part of the adding step. Shown using Delta's January 2005 schedule in Atlanta.

As shown in the example, ten banks are identified for Atlanta as of January 2005, ranging from 45 minutes to 90 minutes for the arrival banks, and 45 minutes to 75 minutes for the departure banks.

3.5.3.3 Measurement of Depeaking

A key aspect of this study is to determine if a schedule was depeaked, and if so, the degree to which it was depeaked. Once peaks are identified, a method to compare the peaked schedule to a depeaked schedule, coupled with a comparison of coefficients of variation (a modified version of Jenkins, Marks, and Miller's peak index), aids in determining if a schedule depeaked.

3.5.3.3.1 Percentage Depeaking Measure: First Attempt with Bank Shadow Assumption

As mentioned earlier, one of the measurements made on the schedule was to calculate the percentage of flights that occurred within the flight banks. When the schedule is peaked, the meaning of this parameter is straightforward: the percentage represents a degree to which the airline clustered its flights into banks. If 100% of flights were within banks, the peak measure would be 100%. Creating a similar and appropriate measurement for a depeaked schedule, however, is slightly ambiguous.

The initial depeaking measure developed in this study involved overlaying the peaked schedule's flight bank time periods (e.g. 7:15-8:00, 8:30-9:30, etc.) onto the depeaked schedule. This measurement was based on the assumption that airlines depeaked their schedules by maintaining the same banks, but spread out each bank slightly over a longer time period and reducing the peak level of operations. Under this assumption, flights were shifted away from flight banks, without a major schedule overhaul, and the time periods of the banks in the peaked schedule are transferred to the depeaked schedule. This action would thus have "bank shadows" left in the depeak shadows, where it would be easy to see the previous banks. It also assumed that flight times were kept essentially the same for flights in the banks, while the flights that were spread out received the major changes. The number of flights within these bank shadows as a percentage of all flights was calculated and compared to the similar measure of the peaked schedule. The application of this is shown in Figure 3.17, with the banks from Figure 3.16 projected onto the depeaked schedule.

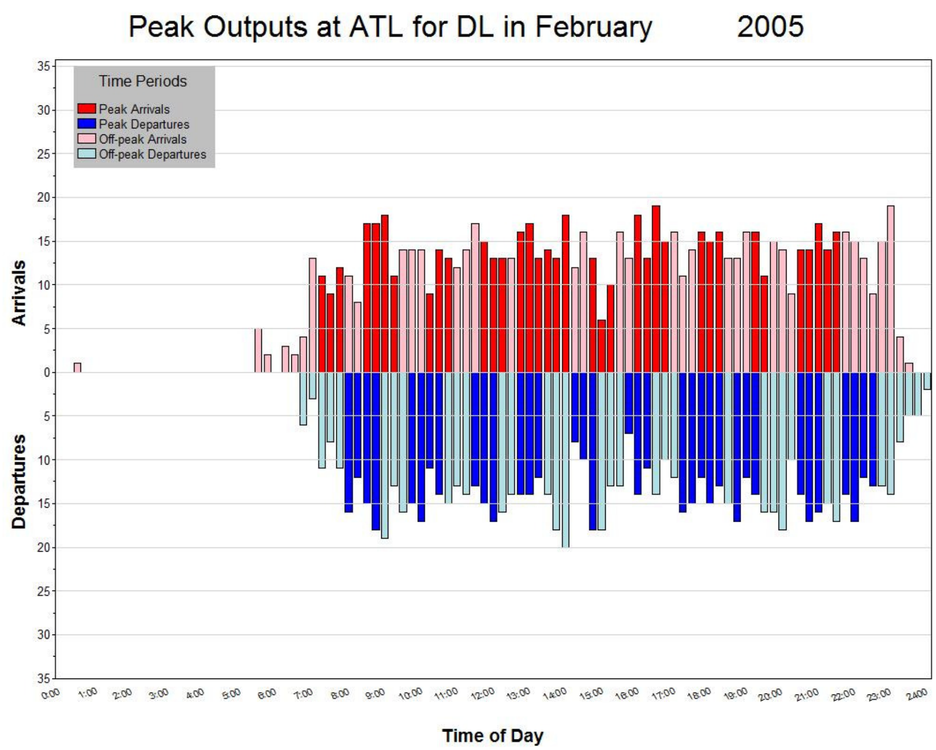

Figure 3.17 Incorrect initial depeaking measure using bank projection assumption. Bank shadows are shown as peaks in red and blue.

The assumption that a depeaked schedule always retains the time periods of the peaked schedule's banks was incorrect. As seen in Figure 3.17, this type of depeaking does not seem to be occurring. There were several bank shadows that had operation levels less than the rest of the day. This observation meant that the depeaking measure was arbitrary, and would not be good for comparing depeaking measures across cases. It is clear that the assumption was incorrect, as a more robust measure is needed.

3.5.3.3.2 Percentage Depeaking Measure: Second Attempt with Most Activity Assumption

The refined depeaking measure tosses out the assumption that the bank's time periods are retained. The assumption instead is the entire schedule was depeaked and wholly recreated. To calculate a depeaking measure, it is thus preferred to simply find the busiest periods of the depeaked schedule and calculate the number of operations during these times. This measure can then be compared to the peaked measure, where one is then comparing two measures that calculate the busiest periods of a flight schedule. Effectively, it is a measure of the concentration of activity between the two schedules into periods of the day.

The measure requires a count, *n*, of the number of 15-minute periods in the peaked schedule that are in banks. The *n* busiest 15-minute periods in the depeaked schedule are then identified, and highlighted in the depeaked schedule. If, for example, *n* is equal to 12, then a comparison is made between the busiest three hours-worth of 15-minute periods in the peaked and depeaked schedule. The number, *n,* of 15-minute periods in banks in Figure 3.16 is calculated, and the *n* busiest minute periods are highlighted on the schedule seen in 3.18. The percentage of operations in these 15-minute periods as compared to all operations in the day is calculated as the depeaking measure. This value is compared to the peaking measure to show the difference between the concentration of activity in the peaked schedule versus the depeaked schedule.

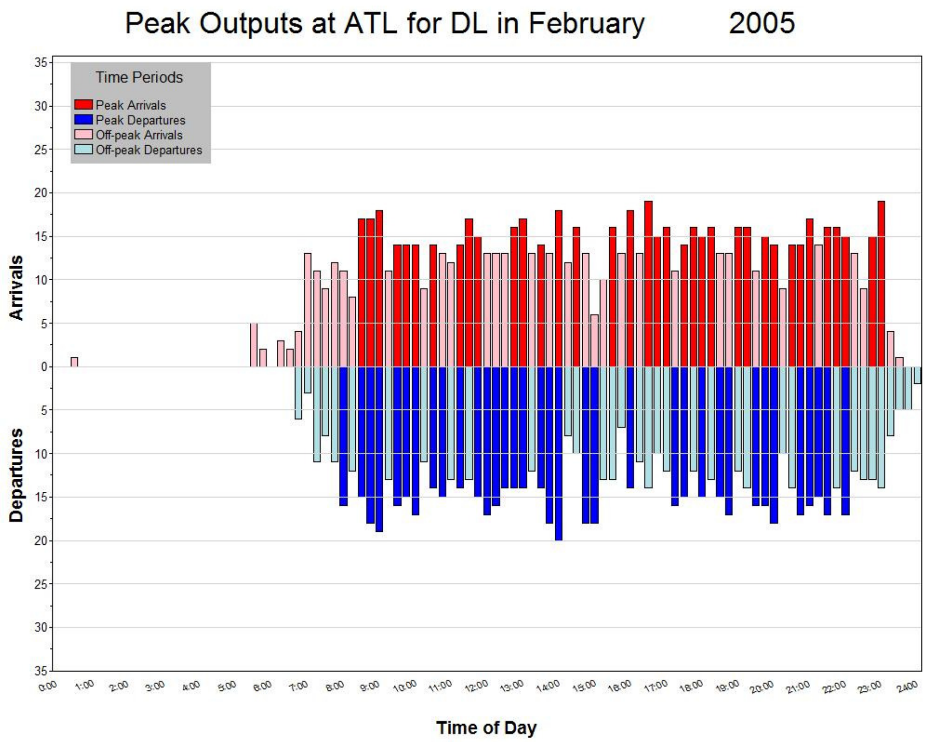

Figure 3.18 Final depeaking measure using the *n* busiest 15-minute periods. Figure 3.16 is used to calculate *n* for this example, as the busiest 15-minute periods from the peak schedule are identified and used for the depeaked schedule.

3.5.3.3.3 Coefficient of Variation Depeaking Measure

In addition to the percentage depeaking measure, a second measure was created as a complementary tool for evaluating depeaking. The second measure makes use of the variance in the schedule throughout the day. The coefficient of variation for the number of operations in the schedule's 15-minute periods are calculated, and compared between the peaked and depeaked schedules. This is different from Jenkins, Marks, and Miller's (2012) peak index which used one-hour periods. The coefficients of variation are calculated separately for arrivals and departures, so each schedule has two values of standard deviations.

A high coefficient of variation indicates a peaked schedule, as there is a greater difference between the busiest and slowest periods. A lower value coefficient of variation indicates a more depeaked schedule, such that the 15-minute periods have a more consistent level of activity through the day. Coefficients of variation, unlike standard deviation, can be compared between cases since they reflect the magnitude of operations in their measurement of variation from the mean.

3.5.4 Creating Connection Opportunities

A critical measure to the changes in supply is the number of potential reasonable connections between aircraft at the depeaked hub airport before and after depeaking. In order to calculate connections, the minimum and maximum connection times denoted as MCT and MxCT, respectively, needed to be calculated for each case study airport. Each airport has a different MCT, based on the geometry of the airport and congestion within the terminal (Hanlon, 1996). If a terminal was purposely built to facilitate short connection times, the MCT for the airport could be lower. Airports with a large proportion of long-haul flights require greater MCTs because of longer loading and unloading times.

The MCT and MxCT are calculated from the MIDT dataset. All trips with passenger connections between the hub carrier's aircraft are included in the distribution of passenger connection times for a given hub airport. Each passenger is considered a single case, so a multi-passenger ticket gets included once for each passenger. From the distribution, the MCT was chosen as the 5^{th} percentile of connection times for a given airline at the hub airport. The MxCT was chosen as the 75^{th} percentile. A passenger is considered able to make a connection between two flights if the arriving time of the first flight and the departing time of the second flight is greater than the MCT for the airport, the time needed to walk between the two airport gates, and less than the MxCT, a time considered reasonable to most passengers to wait between flights. A graphical example of how this is calculated in shown in Figure 3.19. In this figure, the bold arrival flight carries passengers who desire to make a connection onward. Their choice set is limited to departing flights that leave after the MCT and before the MxCT, with respect to the arrival time. Potential connecting departing flights are shown in bold.

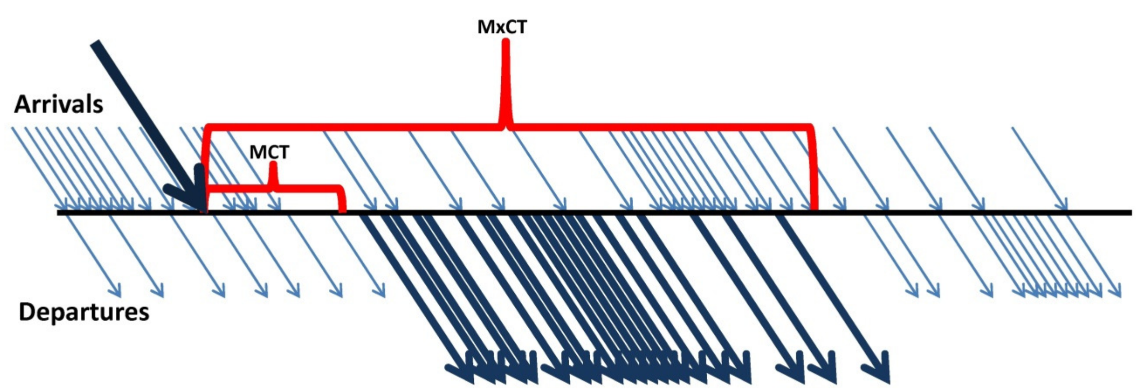

Figure 3.19 Connection creation technique using MCT and MxCT. For a given arrival flight, shown in bold, the set of potential connections are departure flights that leave after a minimum connection time (MCT) and before a Maximum Connection Time (MxCT), shown in bold.

Connection lists were generated by examining each arriving flight for an airline at the hub airport and determining all possible connections from the airline's set of departing flights. Departing flights which have a destination that is the same as the originating airport for the arriving flight are not considered a connection. The number of potential connections is calculated in three ways: 1) for the entire day for an airline at the hub airport; 2) for each spoke airport to all other spoke airports over an entire day; and 3) for each market pair.

3.5.5 Supply Analysis

Each case study will include analysis on how changes to airline schedules occurred when the airline depeaked. The depeaking airline is assessed through an examination of its flight schedule before and after its implementation of depeaked schedules. The cases are examined individually, and then compared as a group.

3.5.5.1 Degree of Depeaking

The first step in the supply analysis is to visually inspect the reproduced peaked and depeaked schedules. Looking at the schedules side-by-side, using the same scale, gives the researcher perspective on how peaked the schedule was, and what it was transformed to through the depeaking decision.

Next, the schedules are evaluated through the two depeaking measures – the peak and depeaking percentages and the coefficient of variation of flights in 15-minute periods. It is important to measure the degree to which each depeaked to compare the airlines for their different approaches to making a depeaked schedule. It is critical to consider how peaked, and how many banks, the initial peaked schedule had, because the airlines already had unique conditions they were operating under prior to depeaking.

A useful way to see the change in the airline's schedule types is to visually examine the distribution of activity within the 15-minute periods of a day. Plotting the 15-minute periods from the most to least busiest in terms of the number of operations, as seen in Figure 3.20, shows how the depeaked schedule has a much more consistent level of operations throughout the day. This is done separately for arrivals and departures.

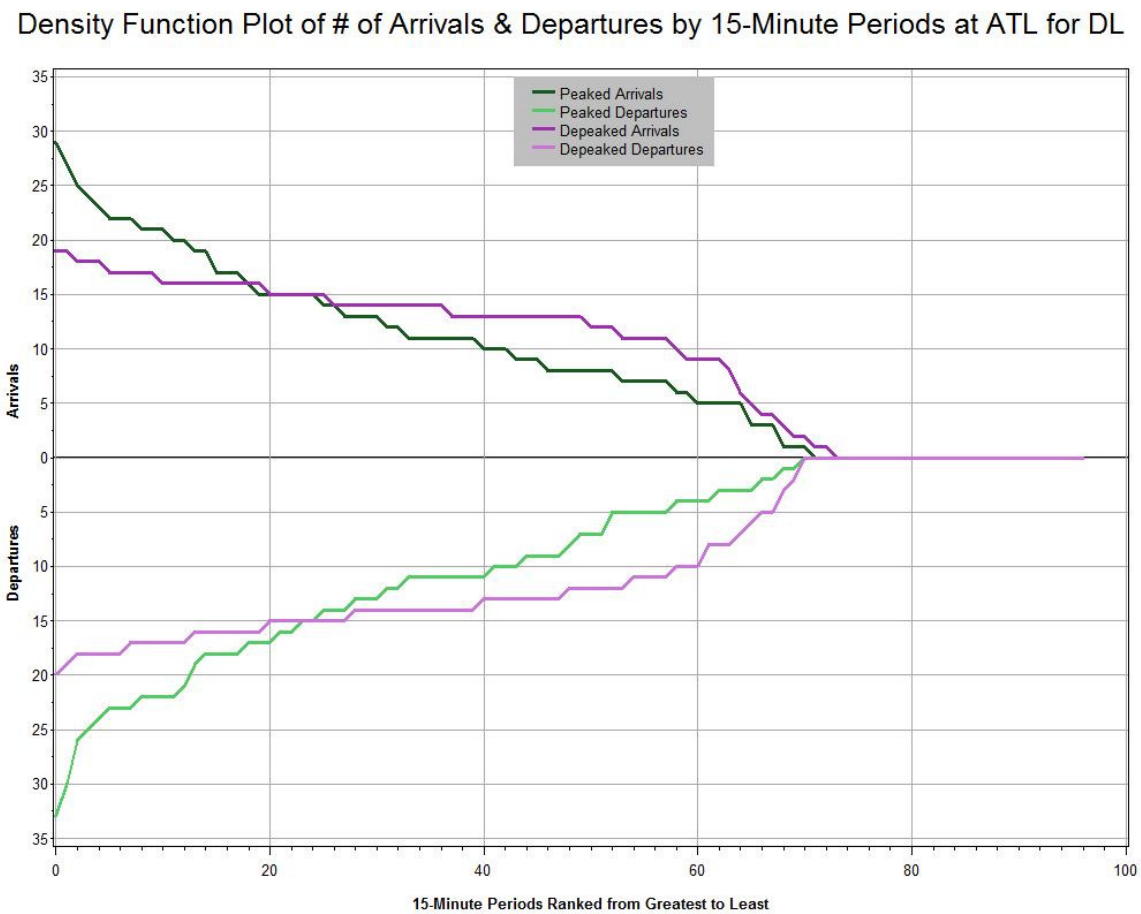

Figure 3.20 Change in 15-minute period activity distributions. The depeaked schedule has a more level distribution of flights across its 15-minute periods.

<u>3.5.5.2 Capacity Effects</u>

Comparing the peaked and depeaked schedules for their level of activity and flight offerings available through the hub enables understanding of how depeaking affected the airline's business. The change in the number of operations per 15-minute period across the day shows how an airline reduced their gate, staffing, and equipment needs, and establish how much the airlines chose to spread out their peaks. The maximum number of operations per 15-minute period also shows how busy runway operations became during the peaks.

The offerings to passengers before and after depeaking are reflected in the number of potential connections between all markets in the two schedule types. The number of ASMs reflects the total capacity of the airline to serve their passenger base. The total number of operations and the number of destinations similarly indicate what the airline did with its change in schedule, such as adding capacity or destinations. This is useful in understanding the goal of an airline that has constructed its depeaked schedule.

The change in the number of connections also provides indication on how the airline restructured its schedule to maintain connections. It is possible from the schedule changes that connections could either decrease or increase.

3.5.5.3 Spoke Level

The changes that happen at the spoke level help to reveal the results of the airline's decision to depeak. Each destination from the hub receives some change from the peaked schedule when banks are removed and the depeaked schedule is implemented. The change in supply is examined for shifts in capacity as well as the change in the number of connections to other markets. Each spoke destination is compared before and after depeaking for the frequency of flights, number of connections, and total ASM. Spokes are tagged for positive and negative changes. This comparison begins to reveal the airline's strategy in shifting flights around, which is further examined in the demand analysis.

Spokes are also examined for their connections through the hub to other destinations. This market level examination of connections before and after depeaking shows how the airline changed its network through the hub and which markets they chose to reduce with the depeaked schedule.

3.5.5.4 Affiliate Airlines

The proportion of flights operated by the major airline's affiliate airlines is examined before and after depeaking. Changes in this value indicate how the airline's contractual promises to the affiliate airline had to be figured in when depeaking. In addition, using the reproduced schedule figures with the proportion of affiliate airline flights in each 15-minute period shows where in the schedule affiliate airline flights were moved during depeaking.

3.5.6 Demand Analysis

The changes in demand due to depeaking are the least understood in the literature. In this study, the demand analysis is focused on assessing how passengers were affected within the system, the effect of dropped connections in the itineraries of passengers in market pairs, and the changes in revenue due to depeaking. The demand analysis is connected to many of the variables produced by the supply analysis. Four revenue analyses were performed focused on the depeaked hub: 1) the change in total revenue, 2) the changes in revenue for each spoke, 3) detailed demand parameters on each spoke route for the hub airline, and 4) the network effects for the depeaking airline.

Revenue is calculated from the DB1B data, which as mentioned previously, is a ten percent sample of all tickets on reporting carriers. Although some of the data is removed during the cleaning process, such that ultimately the data is less than a ten percent sample, the revenue is still multiplied by ten for adjustment. This multiplication could create small differences between quarters' datasets, as each have different amounts of data removed, but these differences are not accounted for in this study. The revenue is further adjusted to calculate average daily revenue, dividing the total revenue by the number of days in the quarter.

When discussing revenue, it is important to consider that the revenue between two time periods cannot be directly compared. Rising and falling ticket prices, seasonality, changes within the industry, and inflation all affect revenue for an airline at a given point in time. Before discussing the demand analysis, how to control for these external variables that affect revenue is discussed.

3.5.6.1 Revenue Normalization Measures

Depeaking analysis must be considered in the context of what is occurring in the rest of the industry. Large industry changes such as mergers, dehubbing, and fuel prices can all affect revenue. Ticket prices change from season to season, and with inflation over time. When comparing revenue over time periods, it is critical to compare the revenue in comparison to the rest of the industry.

To control for the changes observed in the before and after quarters at the depeaking airport, the RASM for the industry overall, other airlines, and the depeaking airline as a whole are compared for the same time periods. Within each case, the change in revenue can be compared for the depeaking airline at its hub airport against the revenue generated for the airline as a whole. This same change can also be compared to the industry's overall change.

When comparing revenue between cases, there is the same issue of dealing with different time periods. To handle this issue, the change in revenue for the depeaking airline at its depeaked hub is expressed as a percentage change as compared to the overall revenue change in the industry during that time period. This percentage change can then be compared between cases to see which depeaking case, for example, had the most positive revenue change against the rest of the industry.

3.5.6.2 Overall Revenue Change

The first step of the revenue analysis is an examination of the revenue for the depeaked hub as a whole. The revenue at the airport for only the depeaking airline is calculated for the before and after depeaking periods. The RASM is also calculated for the two schedule types, as a whole for all aircraft serving all destinations. These figures can be compared across cases, after normalization.

3.5.6.3 Overall Spoke Revenue Change

The second step of the revenue analysis is an examination of the revenue changes at the spoke level. Each spoke airport's revenue is summed for all flights occurring between the depeaked hub to the spoke airport on the depeaking airline. This calculation is made for the peaked and depeaked period, and then compared for each spoke. The number of spokes which had an increase or decrease in revenue and RASM are reported to show

how, at a high-level view, the depeaking had an effect on revenue in the depeaking airline's markets.

3.5.6.4 Spoke Revenue Change

At the spoke level, there are many changes that happen simultaneously in terms of revenue. For a given spoke, revenue may go up or down for a number of reasons. Fares could go up for example, while traffic could decrease, and revenue could go up or down depending on which factor was more influential on the revenue stream. The following parameters are calculated for both the peaked and depeaked schedule:

- average fare for a spoke airport from the hub,
- average daily number of passengers,
- average daily revenue,
- and RASM.

In addition to the revenue figures, the types of passengers are recorded to better understand the passenger base that booked tickets on the depeaking airline. The number of passengers flying between the spoke and the hub on non-stop tickets and as part of a two-coupon ticket is calculated. For each of these two passenger groups flying in the hub-spoke market, the average fare and revenue is calculated. These figures are calculated for both before and after depeaking. The change in each hub-spoke pair for the percentage of passengers flying non-stop versus connecting onward is calculated and compared before and after depeaking to assess how the schedule change affected the passenger type.

3.5.6.5 Airline Network Effects

When an airline depeaks one of its hubs, traffic may get shifted within the airline's network. The opposite can occur as well under different conditions, with the depeaked hub gaining traffic from the other hubs in an airline's network. As fares and connections change at the depeaked airport, passengers may fly through the depeaked airport more, shift to another hub airport in the airline's network, or move out of the airline's network entirely. For example, if connection times get longer and make a connection undesirable, passengers may fly through another of the airline's hubs.

All markets in the airline's network are compiled – whether non-stop, through the depeaked hub, or through other hubs – and compared before and after depeaking for changes in fares, passengers, revenue, and percentage of traffic in terms of all airlines and of the depeaking airline. Capturing this effect of depeaking on the rest of the airline's network aids in explaining how depeaking affects the system as a whole.

3.5.6.6 Relationship Between Supply and Demand

Key to this study is linking the supply and demand measures to understand how shifts in the supply affected the demand and revenue. High-level parameters such as the depeaking measures, changes in ASM, number of flights and destinations, and the number of connections available at the hub are linked to the overall revenue, RASM, traffic, and average fares. Each case is examined on its own and then compared between one another, using the normalization technique to see the relationship between depeaking and revenue.

At the spoke level, the spoke level supply changes are related to the spoke level demand changes to see how different markets were affected by depeaking. Using these relationships, it is possible to see how broken connections affected the revenue to different airports, or decreased the share of connecting passengers. It is also possible to examine the underperforming routes prior to depeaking and see if those were the ones most likely to lose connections in the new schedule. This process provides insight into the airline's decision-making process on when to remove possible connections.

3.5.7 Operations Analysis

Depeaking is expected to improve the utilization and on-time rates for aircraft for the depeaking airline. By spreading out the demand for gates and staff at an airport, an airline becomes less at risk to being overwhelmed by aircraft, passengers, and baggage, and thus can more readily respond to disruptions to the schedule. This ultimately shows up in the performance of the airline through improved on-time rates. In addition, changes to the taxi-in and taxi-out times after depeaking acts as a performance measure for airside congestion.

The operations analysis focuses on the on-time performance of the depeaking and competing airlines to examine the effect of continuous schedules. In each case study, the depeaking airlines will be examined for changes in carrier delay and taxiing times. Data are analyzed at the month-level because at the daily level weather and disturbance events can greatly affect operations. The quarter-level is not used because the issue of seasonality becomes more noticeable. The month prior to the month in which depeaking occurs is chosen for the peaked schedule operational measures, and the month after the depeaking month is chosen for the depeaked schedule measures. If depeaking occurred on the last or first day of a month, two consecutive months were used instead. The data are from the On-Time Performance database.

Departures and arrival delays are analyzed separately. The factors that cause these delays are slightly different, despite sharing some similarities. An aircraft is considered a delayed aircraft if it is 15 minutes behind its scheduled departure or arrival time, as per the definition used by BTS. In this study, an aircraft can be considered a delayed aircraft for its departure and not for its arrival, and vice versa. The measures which are collected for both arrivals and departures are:

- Average time of delay for all aircraft (early aircraft have negative delay)
- Average time of delay for all aircraft (early aircraft have zero delay)
- Number of on-time aircraft
- Number of delayed aircraft
- Percentage of aircraft which are delayed
- Average time of delay for delayed aircraft
- Total delay time for delayed aircraft

In addition, two additional measures are recorded, but not for both arrivals and departures:

- Average taxi-out time for departures
- Average taxi-in time for arrivals

These changes are related to the degree of depeaking which occurred, in order to understand if increased spreading of banks lead to increasingly better on-time performance.

Competitors at a depeaked hub will likely also benefit from the change in scheduling in terms of on-time performance. The potential for delay caused by the banks of a peaked hub affects all airlines, and thus the benefits of a continuous schedule on on-time rates for a depeaking airline should also benefit its competitors. Operational measures are collected for the competing airlines at the depeaked hub for comparison with the depeaking airline, both before and after depeaking.

3.5.7.1 Operations Normalization Measures

The operational portion of the depeaking analysis must be considered in the context of what is occurring in the rest of the industry. Major weather events, for example, can affect entire regions of the country, and delay aircraft throughout the system. Seasonality also has some effect, as higher demand during different times of the year can cause aircraft to not perform as well. Thus, it is useful to compare the operational performance of the depeaking airline and its competitors at the depeaked hub to the operation performance of the rest of their respective networks and the industry as a whole.

To control for the non-observable changes that occurred between the before and after months at the depeaking airport, four variables are compared between the depeaking case, the rest of the airline's network, and the industry overall. These four variables are the average departure delay for delayed departing aircraft, the percent of departing aircraft which are delayed, the average arrival delay for delayed arriving aircraft, and the percent of arriving aircraft which are delayed. Within each case, the change in operations can be compared for the depeaking airline at its hub airport against the operations for the airline as a whole and the industry's overall change, to gain perspective if the changes seen are unique to the depeaking airline.

3.5.8 Competition

Depeaking airlines affect more than their own hub operations. The competition at the hub airport is also affected by the removal of flight banks. Elsewhere in the aviation system, traffic may shift to or from other airlines. In some cases, an airport serves as the hub for two airlines, and thus the competing hub airline has an opportunity to retool their own schedule to respond to the reduced strains on capacity.

The following subsections describe the parameters which are used in this study to describe competition. The last of the subsections describes the particular cases where two airline hubs operate out of the same airport, and one of them becomes depeaked.

3.5.8.1 Herfindahl Index

In order to measure the degree to which an airline dominated in a given hub-spoke market, the Herfindahl index is used. This index is a measurement of the concentration of an industry or market in relation to the number of firms who participate; it could be described as a weighted market share that takes into account that firms with a larger presence receive more than their share of business. In terms of airlines, this can be described as the market power influence of the dominant carrier. On a given trip, for example, the dominant carrier's flights are more likely to be at the right time of day for a traveler, and thus the passenger will choose that carrier. On subsequent trips, the passenger will think first of the dominant carrier when booking, and a positive feedback loop results. Thus the dominant carrier gets more passengers than what would be expected simply by its proportion of flights in the market.

The Herfindahl Index has been used by many previous studies when describing the competition in a market. Researchers have used it as a measure of market power in studies dealing with Open Skies Agreements (Cristea & Hummels, 2011), price dispersion to passengers (Borenstein & Rose, 1994; Van Dender, 2007), and in hubbing (Borenstein, 1989).

To calculate the Herfindahl Index, one sums up the squares of the proportion of flights in a market for each firm (p_i), as seen in the formula below:

$$Herfindahl\ Index = \sum_{i=1}^{N} p_i^2$$

The Herfindahl Index can be between zero and one, with zero indicating an infinite number of firms with equal market share and one indicating a monopoly. Thus larger numbers indicate a market where one airline dominates over other competition, typical for hub-spoke markets because of the hub airline's presence.

The Herfindahl Index is used as an input in the spoke level analysis of this study when running linear regressions.

3.5.8.2 Competition at the Hub Airport

The spoke level results from the supply analysis also include a list of competitors for each of the depeaking airline's markets. Each competitor in each market is analyzed by the number of daily flights in and out of the hub airport that are offered, the ASM for the same day of the schedule reproduction, and the average inbound and outbound flight times. These supply figures are produced for the before and after periods surrounding the hub airline's depeaking. It is noted which spokes gained or received service in relation to the depeaking.

For demand effects, the competitors at the hub are analyzed for their changes in revenue, due to passenger demand changes. RASM is examined for each of the airlines in each spoke market, and the average fare is recorded. In addition, the proportion of traffic on the competing airlines is compared, calculating the market share that each airline has in the hub-spoke market. When analyzing this before and after depeaking, it is possible to see which competitors, and on which routes, benefited the most from depeaking.

A similar analysis is performed at the system level, essentially an assessment of how the national system was affected by the depeaking of a single hub. In this part, the competing routes of other airlines that may or may not go through the depeaked hub are assessed to see how ticket sales changed and if shifts in prices occurred. All OD markets through the depeaked hub are compared with other airlines' performance in the same OD markets before and after depeaking. The key measurement is whether passengers left the system or rather were displaced. For example, the OD market of Boston to Seattle, as it connects through ORD on American, is examined to see its volume and revenue level before and after depeaking. The same market is then assessed as it connects through other airlines' hubs such as Delta in Atlanta, Continental in Denver, United in ORD, etc. As part of the process, it is determined if the depeaking change gave revenue to other airlines.

3.5.8.3 Competition Indicator Variables

In preparation for linear regression at the spoke level, several indicator variables are produced. These are determined at the spoke level, so are only in relation to the spoke airport or flights between the hub and the spoke airport, depending on the variable. These variables included:

- The depeaking airline is the largest carrier in the market (1 if yes, 0 if no)
- The airport is a dual-hub, a hub for two airlines
- The airport depeaked the same day another dehubbed (1 if yes, 0 if no – Delta dehubbed DFW the same day it depeaked ATL)
- Spoke is north or south of depeaked hub (1 if north, 0 if south)
- Spoke is east or west of depeaked hub (1 if east, 0 if west)
- Spoke is another hub for the depeaking airline
- Spoke is a hub for another airline
- Spoke is a Southwest Airlines focus city

These indicator variables are included in the regression models to see if any of these factors are significant in an airline's depeaking decision-making process.

3.5.8.4 Dual-Hub Depeaking

There are three cases in which the depeaking airline has a competing airline also operating a hub at the same airport. These dual-hub depeaking cases provide an opportunity to see how a major airline with hub operations adjusts its schedule to the additional capacity in the terminals and on the tarmac. The three cases are listed in Table 3.9. Of these, two airlines (Delta at DFW and United at ORD) operated a peaked schedule before and after depeaking, while one (AirTran at ATL) operated a continuous schedule.

Table 3.9 Dual-Hubbing Cases

Depeaking Airline	Hub	Hub Competitor	Competitor Schedule Type
American	DFW	Delta	Peaked
American	ORD	United	Peaked
Delta	ATL	AirTran	Continuous

For the competitors in these dual-hub cases all schedule measures are created to assess their schedules before and after depeaking. Differences in the number of destinations served, operations per 15-minute period, and the number of potential connections are most indicative as to whether the competitor had a reaction to depeaking. The peak measures are also telling, and are useful for determining if the competitor created an even more peaked schedule (in the DFW and ORD cases) to take advantage of freed capacity. If the coefficient of variation increases and the peak percentage rises, it is likely that the airline increased clustering of operations to provide faster connections in order to counter the depeaking airline's longer transfers.

The competing airline also is assessed for changes it made within the depeaking airline's bank periods. Regardless of whether the competitor made their schedule more peaked, it may have shifted operations into the depeaking airline's bank shadows. Using reproduced schedule diagrams, the bank shadows from the depeaking airline's peaked schedule can be overlaid on the competitors' schedule, both before and after depeaking. An example is shown in Figure 3.21, with American's bank shadows on United's post-depeaking schedule. The percentage of the competitor's flights that are within these banks shadows can be calculated before and after depeaking to assess the competitor's strategy.

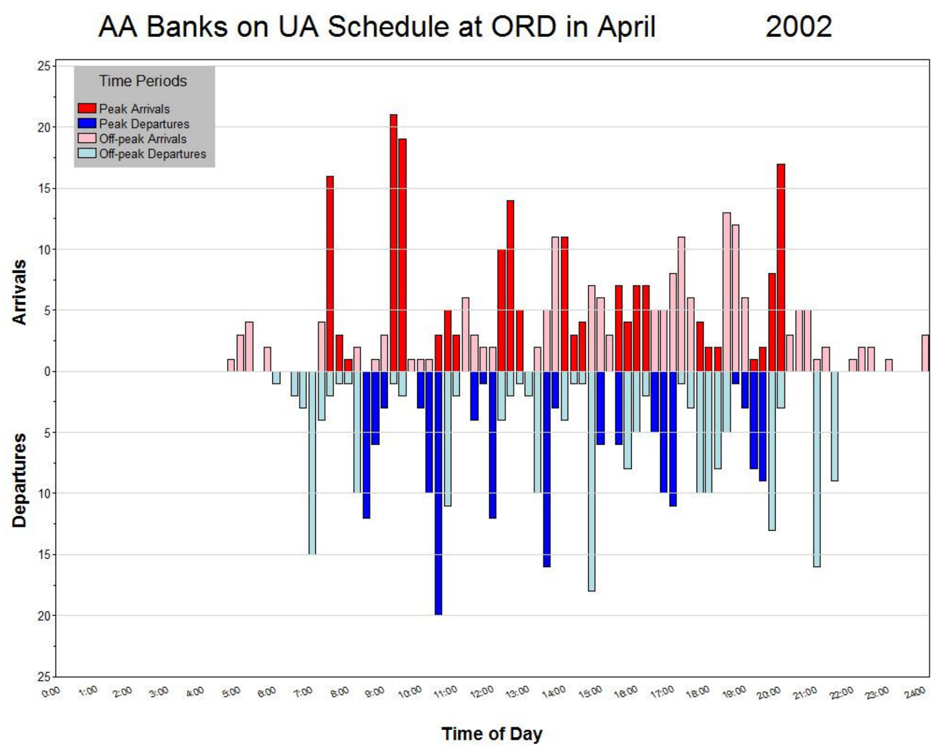

Figure 3.21 Depeaking airline bank shadows on competitor schedule. Shown here using American's bank shadows, post-depeaking, on its competitor, United's, peaked schedule.

The dual-hub competitors' schedule measures are calculated at several points to see if they had prior notice of depeaking and reacted to it, waited for depeaking to occur in order to react, or did not react at all. In addition to the dates which the depeaking airlines' schedule measures are calculated, the competitors' schedule measures are calculate three months before depeaking, one month before depeaking, one month after depeaking, and three months after depeaking.

3.5.9 Multivariate Relationships

The spoke level is suited for a linear regression model to analyze the types of factors that are used in making depeaking decisions. All spoke airports which are served by the hub airline before and/or after depeaking during the depeaking period are included in the regression model. The goal of this analysis is to use the before period supply and demand measures to predict changes in supply in the depeaking period. Using the revenue figures from the peaked quarter, such as RASM, total revenue, and average fare, it is possible to evaluate the changes in supply. This model is useful to hub airports which could potentially predict what hub airlines would do in terms of their route network if that airline decided to depeak. Doing so provides insight into the motivation for the airline to increase or reduce connections between certain markets and for particular spokes, and for increasing or reducing the frequency of flights from the schedule.

The model developed in this study is one that predicts the changes in flights to and from the spoke airport from the hub. Thus, six roundtrip trips by the airline's aircraft in a given day to a spoke airport would be credited for 12 flights. The reason for doing so is that many spoke airports have an uneven number of arrivals and departures. The change in flights was chosen over predicting the change in ASMs because it is a variable that cannot be decomposed into other variables. When airlines consider ASMs, they have to consider both frequency and aircraft type, which increases the ambiguity in predicting the changes. A change in ASMs may not be due to depeaking, but could involve decisions that are more focused on fleet types such as new aircraft purchases or crew capabilities.

Table 3.10 List of Variables Used in Developing Supply Prediction Model

Variable Class	Variable Sub-Classes
Supply	Initial number of flights
	Log of the initial number of flights
	Available seat miles
Traffic	Total number of passengers
	Number of direct passengers
	Number of connecting passengers
	Percent connecting passengers
Revenue	Total revenue
	Revenue per available seat mile (RASM)
Ticket Fares	Average ticket fare
	Log of average ticket fare
	Average ticket fare for direct passengers
	Average ticket fare for connecting passengers
Connections	Number of daily potential connections to other spokes in the network
	Log of the number of potential connections
Flight Banks	Percent of flights in banks
	*Majority of flights are in banks
Competition	Number of competitors on route
	Herfindahl Index in terms of flights
	Market share in terms of flights
	Market share in terms of number of passengers
	*Monopoly route
	*Largest carrier in terms of number of flights
	Available seat miles of competitors
	Total number of passengers served by competitors
	Average fare of competitors
	Ratio of depeaking airline's fare to average competitor fare
	Number of flights for competitors
	*Hub is also a hub for a competitor
	*Spoke airport is a hub for a competitor
	*Spoke airport is a Southwest Airlines focus city
Locative	Average distance
	*Spoke airport is north of hub airport
	*Spoke airport is east of hub airport
Other	*Another airport of depeaking airline was dehubbed on same day (DL)
	*Spoke airport is a hub for depeaking airline

***Indicator variable (1 = yes)**

A number of variables were considered in preparing the models. These are listed in Table 3.10, although some have been discussed previously as competition indicator variables in

3.5.8. All variables are in terms of flights between the spoke and the hub, and are refer to the levels of supply and demand during the peaked period.

For the variable of the ratio of the depeaking airline's fare to the average competitor fare, routes which did not have a competitor were assigned a ratio of one for use in a model.

An iterative modeling approach was used to determine the set of variables that were associated with an airline's decision to add or remove flights during the depeaking process.

Each regression model was examined to ensure it satisfied the linear regression modeling assumptions related to linearity, normality, and homoscedasticity. The linearity assumption aims to establish there is in fact a linear relationship, as opposed to a non-linear relationship, between the dependent and independent variables included in the model. The normality assumption can be ensured by checking that there is no outlier driving the model's relationships because of the large standard error a model not fit to an outlier would have. The homoscedasticity assumption is verified by checking the constant variance of the errors versus the predictions, ensuring too much weight was not given to one part of the data. Many regression models also have an independence assumption with regards to a serial correlation, but because there is no time element to this study, this assumption does not need to be checked for. Models were also checked for outliers that could be affecting model results.

In order to verify models which failed the tests of assumptions, count models with Poisson distributions were developed to ensure that the directions were consistent with the regression models. In these models, the predicted variable (change in flights) was adjusted such that the minimum value of the variable, a negative number, was shifted to become zero. Count models are not able to predict negative values.

In developing the various regression models, an overall regression model was attempted to be developed that included all case studies. Because of the wide variety of factors that each airline considered in depeaking, however, as will be discussed in Chapter 4, this model did not have any significant results. The correlation was consistently very low, and thus indicated that a comprehensive model that could predict depeaking changes was not possible. This helped solidify that each depeaking case has unique factors. For future airports that may experience depeaking, it would be necessary to determine which case they are most like before choosing to run a model to predict the supply changes that would occur.

3.5.10 Assessing Depeaking and Effects

The regression models provide insights into the decision-making process that airlines used to determine which airports to increase or decrease service to. In order to evaluate supply, revenue, and on-time impacts, a difference-in-difference comparison and year-over-year measures were used in order to isolate the effects of depeaking and control for external factors that may have had a large impact on revenue measures for the industry as a whole.

3.5.9.1 Difference-in-Difference Technique

Comparing the RASM of the depeaking airline at the depeaked hub to the rest of the airline and the industry is useful, particularly if done using a difference-in-difference technique. Using difference-in-difference has been used to discuss a localized change in the perspective of the larger industry for airlines in the past. Examples of the method's usage includes measuring the change in market power before and after alliance-building occurred in 2003 (Li & Netessine, 2011) and assessing the originating passenger volume for airports that adopted Transportation Security Administration procedures versus those that did not (Blalock, Kadiyali, & Simon, 2007). Difference-in-difference refers to a comparison measuring the mathematical difference between two unique changes. The basis of this technique is that although the change that occurs in a measure may appear to tell one story, when juxtaposed with another change over the same time period, the true nature of the first change would be revealed.

One instance of using the difference-in-difference technique in this study involves the change in RASM from the peaked to the depeaked quarter. This difference is juxtaposed with the differences in RASM for the rest of the airline's network and the industry. Lagging behind these two comparison differences would show the depeaked airport underperformed, while the opposite would indicate depeaking may have influenced revenue growth. If an airline sees an increase in RASM, for example, it may not be as much as the increase that the industry had. Thus the difference between the differences would indicate slower growth, and lead to the conclusion that depeaking could cause underperformance in revenue.

This study also makes use of the difference-in-difference technique in evaluating on-time performance. The on-time statistics at a depeaked airport are measured for the month before and after depeaking. The difference between the two is taken to see the change over time. This difference is then compared to the difference in on-time statistics for the full airline network and the industry as a whole, similar to the RASM measurement. The difference between the depeaked airport difference and the airline or industry difference puts the first change into perspective.

3.5.9.2 Year-over-year Technique

Assessing whether the changes which occurred in the supply, demand, and operational results were unique to the depeaking year can be checked using a year-over-year assessment. There is no difference-in-difference for the same time period that can be performed for the supply data because no suitable comparison set is available since each airport is unique. Bogusch (2003) compared qualitatively the supply changes for depeaking to other hub airports for comparison, but did not do a quantitative control comparison. By using a year-over-year comparison, however, the same measurement can be made for the same time period over multiple years.

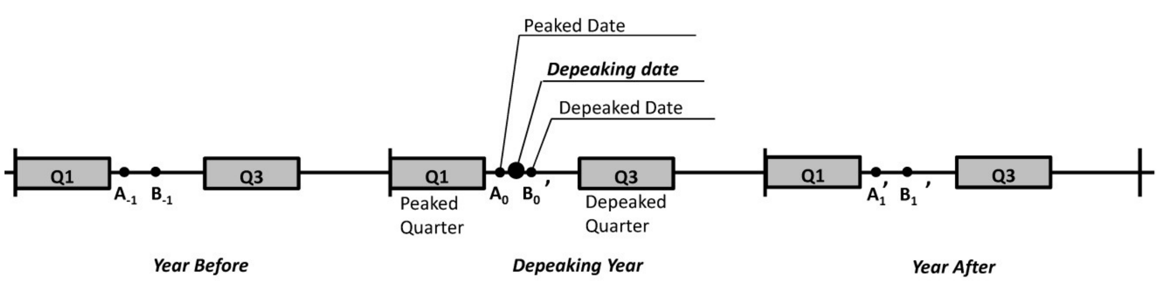

Figure 3.22 Location of time periods for year-over-year measurements.

As seen in Figure 3.22, dates similar to the peaked (A_0) and depeaked (B_0') dates are chosen from the year before (A_{-1} and B_{-1}) and year after (A_1' and B_1'), and the differences between the two dates in each of the three years are compared. Similarly, for demand, the change in the depeaking year (between quarters 1 and 3) is compared to the changes in the year before and the year after. Although not shown in the figure, the months used for the operational year-over-year measures would be the same months in all three years, with the changes between the pairs of months compared.

Using comparisons for the same time period in the surrounding years from the one of interest was done also in Bogusch's (2003) depeaking study. If one year stands out as different, then it is reasonable that another force influenced that change. This is can be applied for checking to see if supply differences occurred annually between the peak and depeak dates, or if a difference was unique to the depeaking year.

As an example, it could be seen that in the depeaking year there was an increase from the peak date to the depeaked date in the number of destinations served. This may lead one to believe that a component of airline's depeaking decision was to expand its network. When looking at the same difference in the measurement the year before (two peaked schedule dates) and the year after (two depeaked schedule dates), the same change may have occurred in the number of destinations served. When examined closely, it becomes evident that every year at the period of time when depeaking was performed, the airline expanded its network to capture seasonal travel destinations. Thus the year-over-year comparison can aid in revealing which changes were typical, and which changes could be associated with depeaking.

The year-over-year comparison is most useful for assessing the demand and operations changes. This technique is perhaps more important for demand and operations than supply because of the longer time periods over which the demand and operations data are measured: two quarters a half a year apart for demand and two months a month apart for operations, versus two dates just weeks apart for supply. The depeaked airport's change in RASM and operational changes in relation to the airline's and the industry's changes could be a typical situation, as opposed to a unique change in the depeaking year. The same underperformance or growth could have occurred year after year over the same times of the year. By assessing these changes over a longer period of time, it can be seen how depeaking really affected the revenue growth and operations at the airport.

3.5.11 Dwell Time and Airport Revenue

It is hypothesized that the longer airport passengers spend in the airport, the more likely they are to spend and the more money they will spend. Using the passenger survey data from the Port Authority of New York and New Jersey (PANYNJ) at its three major airports, the relationship between passenger dwell time and airport terminal revenue is examined. Regression models are used to explore which factors influence passenger spending.

In order to prepare variables of cost for comparison over time, the variables are adjusted for inflation. The variables which need adjusting are those that involve a monetary value such as price paid by passengers for food, beverage, and retail purchases. In addition, income must be adjusted for inflation. A price inflator (or deflator) is used to convert the historical prices and incomes to current U.S. dollars (Duval, 2012). To perform this conversion, it is necessary to use the Consumer Price Index (CPI), available from the Bureau of Labor Statistics (BLS)[9]. The CPI measures the changes in the price

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[9] ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

level of a collection of consumer goods and services. By using the CPI, one can measure the average change in time in the price consumers pay. Using the ratio of the CPI from two different years, one can convert what a good cost in the first year to what it would have cost in the second year.

In this study historical prices of food and beverage purchases at the PANYNJ airports are converted to present day purchases. The conversion is as follows:

$$Food\ \&\ Beverage\ Price\ _{Present} = Food\ \&\ Beverage\ Price\ _{Past} \times \frac{CPI_{Present}}{CPI_{Past}}$$

Similar conversions are used to convert all monetary values to a common year, which in this part of the study is 2011, as this is the most recent data available both from PANYNJ and BLS.

3.5.11.1 Regression Models

Several steps were used to develop regression models to predict consumer spending patterns as a function of the number of connecting passengers and/or passenger dwell times. General plots of the data are used to explore potential relationships and functional forms. Simple regression is then used to find the correlation between potential variables, and to better define relationships.

The purpose of the regression models is to analyze the amount of money spent on retail and food purchases at the airport. The dependent variable is the amount of money spent, which is reported by the PANYNJ as an average annual value from across all passenger surveys, for retail and food/beverage at each of Newark (EWR), New York

LaGuardia (LGA), and New York John F. Kennedy (JFK). The potential independent variables that are tested include the average dwell time for local passengers, the average dwell time for connecting passengers, the average dwell time for all passengers, the difference in dwell time between local and connecting passengers, the mean income of the passenger group, and the percent of connecting passengers.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter describes the results for the six case studies identified in the previous chapter. Each case study is first discussed individually in chronological order by its depeaking date, and includes a discussion of supply, demand, and on-time measures. These measures are interpreted within the larger context of major external events that may have impacted revenues (e.g. the dehubbing of an airport or a merger during the analysis period of a case). Each case is individually assessed to see if the changes it saw in the depeaking year were noteworthy compared to other years and in relation to rest of the industry. The case studies are assessed using multivariate statistical methods to evaluate the decision-making process of the airline in choosing spoke destinations to increase or decrease flight frequency.

Also included in this section are the results of the analysis on passenger dwell time and airport revenue. In addition, for depeaked hubs which had two hub carriers, the competitor's response to depeaking is reported.

4.2 American Airlines at Chicago O'Hare (ORD)

The first hub that depeaked in this study was ORD. In April 2002 American Airlines removed eight arrival and departure peaks from their schedule. This move was in response to the rising costs of operating the peaked schedule, coupled with the high market volatility in the post-9/11 market.

The financial outlook for American Airlines had become bleaker over the year prior. The airline had purchased the bankrupt Trans World Airlines (TWA) in the spring of 2001, and had inherited TWA's debt. American immediately dehubbed Saint Louis, TWA's former hub, already having two mid-American hubs in its network. After the merger, American immediately began losing money. The 9/11 terrorist attack's detrimental effect on the airline industry would bankrupt two major airlines in 2002, and put American at risk as well. One strategy American used to help avoid bankruptcy was depeaking hub airports in order to reduce costs: ORD in April and DFW later in November.

This case has the unique aspect that ORD serves as a hub airport for two major airlines. United Airlines also has a major hub operation at ORD, and thus this case is useful to assess how a competitor at a dual-hub responds to depeaking. Included in this section is a description of United's changes after American depeaked.

4.2.1 Data Periods Used and Input Parameters

American Airlines depeaked ORD on Sunday April 7, 2002. The date used to represent the peak schedule is Tuesday March 26, 2002. The date used to represent the depeaked schedule is Tuesday April 9, 2002.

Because American depeaked ORD just one week into the second quarter of 2002, the second quarter was used as the depeaked quarter for demand data. Although this assumption includes one week (out of 13 total weeks) of demand data in a peaked schedule, the alternative was to use demand data 3-6 months in the future to represent depeaking effects. The first quarter of 2002 is used as the peaked quarter for demand data. For operational measures, the peaked month used is March 2002; the depeaked month is May 2002.

For creating year-over-year measures, March 27, 2001 and April 10, 2001 were used as the supply comparison dates the year prior. March 25, 2003 and April 8, 2003 were used as the supply comparison dates for the year after depeaking. The first and second quarters of 2001 are used as the year prior demand comparison quarters, and the same quarters in 2003 are used for the year after. March 2001 and May 2001 are used for the year prior operational comparison months, and March 2003 and May 2003 are used for the year after.

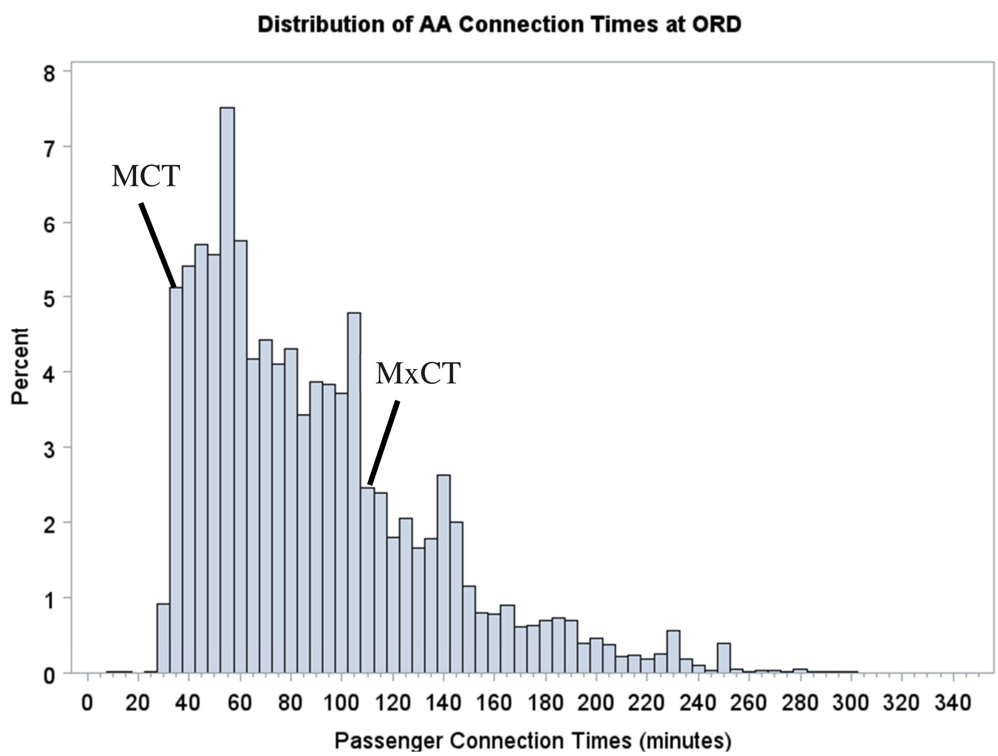

Figure 4.1 Connection time distribution for AA at ORD. MCT and MxCT are denoted.

The distribution of actual connection times made at ORD for passengers flying on American itineraries is shown in Figure 4.1. This distribution is from itineraries flown in June 2010. At that time, ORD was still operating under a depeaked schedule. The 5th and 75th percentiles, indicating the MCT and MxCT, are denoted in the figure. For this case, the MCT is 35 minutes and MxCT is 110 minutes.

4.2.2 Supply Results

The following section describes the supply-side results for American's depeaking of ORD, which includes data derived from the On-Time database. Table 4.1 summarizes the supply measures representing peaked and depeaked schedules that are discussed in this section.

Table 4.1 Summary of Supply Changes for American at ORD

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	23	14
Max. number of flight operations in a 15-minute interval	26	25
Number of flights flown into or out of hub	869	935
Total available seat miles flown into or out of hub	92,827,870	98,523,721
Number of destinations served from hub	96*	92*
Coefficient of variation in number of arr./dep. flights	124.5/132.3	84.9/86.0
Percentage of flights served by affiliate airline(s)	35.3%	34.9%
Percentage of flights served in peak period	73.3%	53.9%
Number of potential connections	16,806	16,904
Average connections per arriving flight	38.7	36.3
Maximum potential connections serving a market	18	18

*The four destinations that are removed are seasonal ski destinations.

4.2.2.1 General Supply

American Airlines' reproduced peaked schedule at ORD is shown in Figure 4.2 and the reproduced depeaked schedule in Figure 4.3.

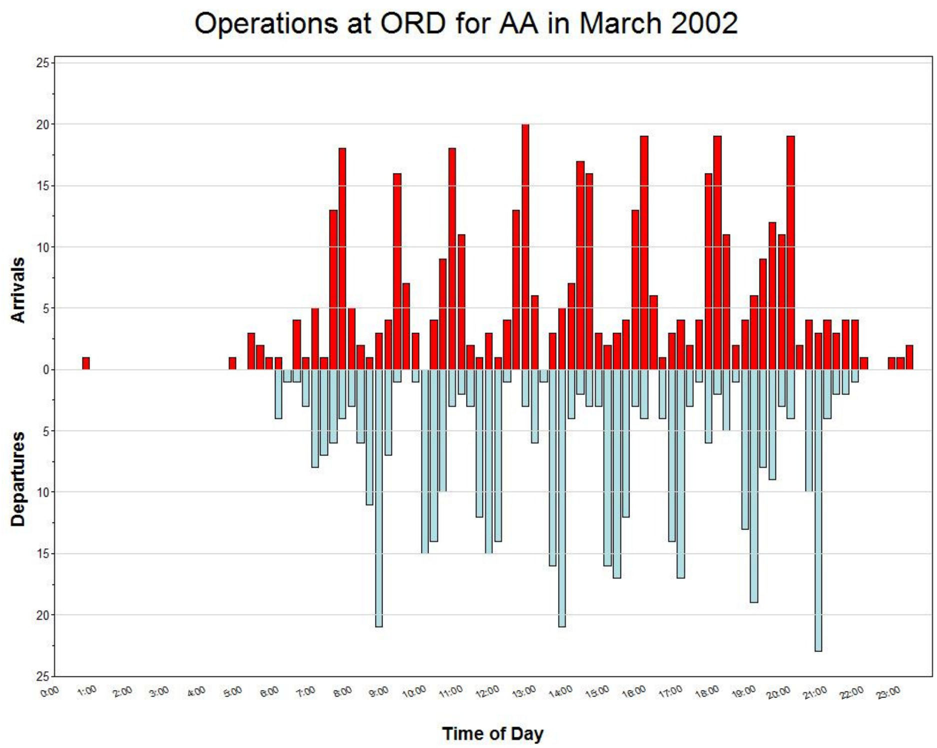

Figure 4.2 Peaked schedule for American at ORD.

The peaked schedule has eight arrival and departure peaks. The first arrival peak starts around 7:30 AM, and the first departure peak starts around 8:30 AM.

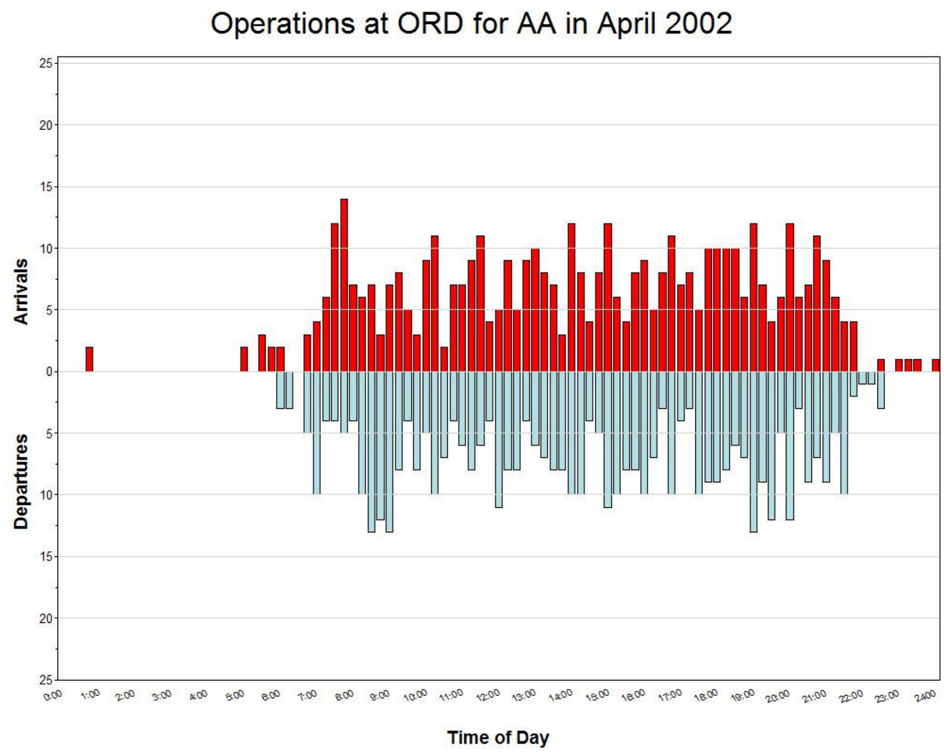

Figure 4.3 Depeaked schedule for American at ORD.

The maximum number of a single type of operations in a 15-minute period drops greatly from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 23, while in the depeaked schedule it is 14. The combined number of arrivals and departures in a 15-minute period does not decrease as much: in the peaked schedule the value is 26, while it drops to 25 in the depeaked schedule.

The distribution of American's operations at ORD is more spread out throughout the day, as seen in the density function plot shown in Figure 4.4. In this plot, the 15-minute periods are ranked in order of frequency. There are more 15-minute periods that have greater than zero operations in the depeaked schedule, in addition to having a more flat distribution. It is clear that busiest periods are much lower in the depeaked schedule, but the peaked schedule drops off sharply from its busiest periods.

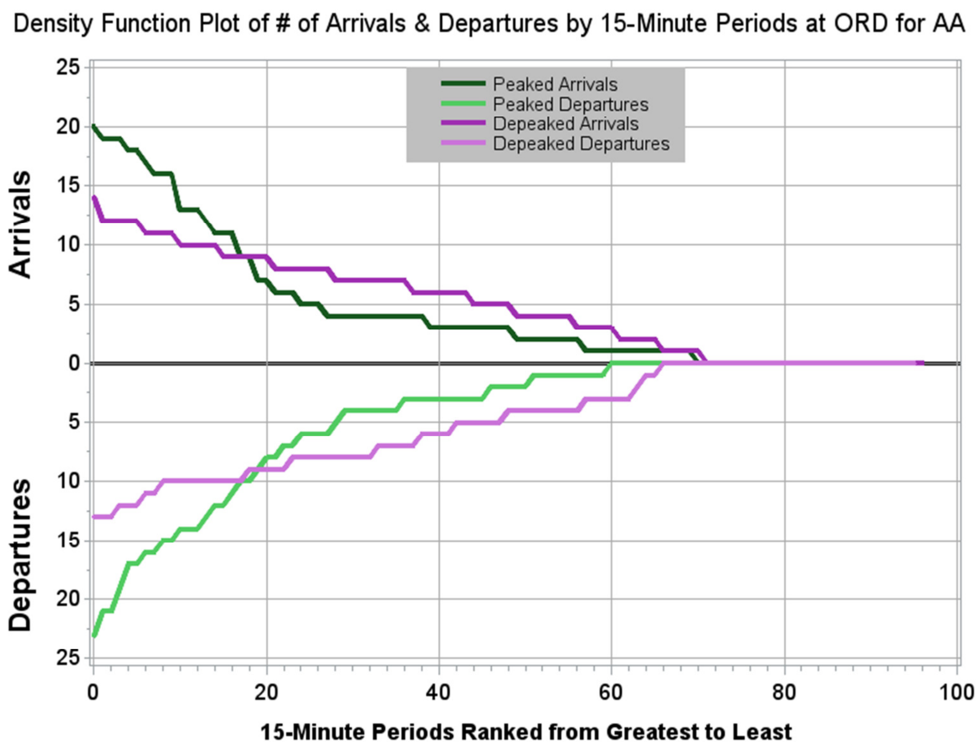

Figure 4.4 Density function plot of American operations at ORD.

Although the flights are more distributed throughout the day in the depeaked schedule, the total number of flights increased from the peaked schedule. In the peaked daily schedule in late March of 2002 American operated 869 flights out of Chicago O'Hare, and this increased to 935 flights by early April. American decreased the number of destinations served from ORD, from 96 to 92. These destinations, however, are seasonal ski destinations - American cut out flights to Burlington, Vermont; Eagle, Colorado; Yampa Valley, Colorado; and Jackson Hole Wyoming. Thus, to non-seasonal destinations, American retained its network. Due to the increased number of flights, daily ASMs increased as well, from just fewer than 93 million to over 98 million.

4.2.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines stays mostly constant from the peaked to the depeaked schedule, decreasing just slightly. This percentage is 35.3% in the peaked quarter and 34.9% in the depeaked quarter. This value is for the affiliate airline that reported on-time statistics to the On-Time database, which in early 2002 included American Eagle. As seen in Figure 4.5, American Eagle primarily operates in the banks of the schedule, although American Eagle certainly has a large number of flights outside the banks.

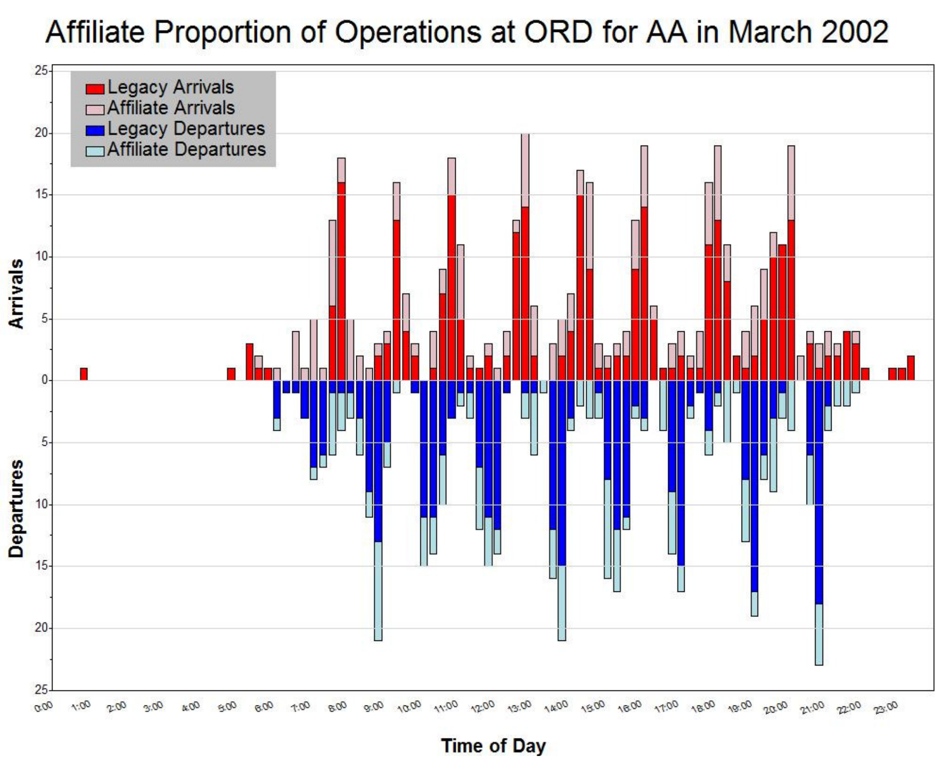

Figure 4.5 Affiliate airlines in the peaked schedule of American at ORD.

In the depeaked schedule shown in Figure 4.6, American Eagle operates at a consistent level throughout the day.

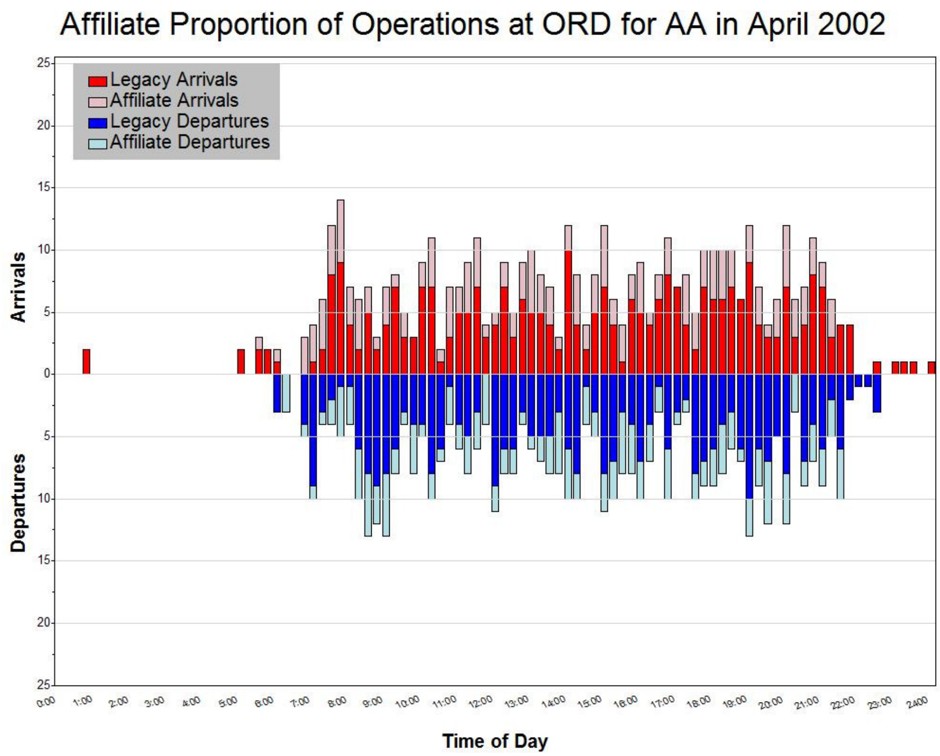

Figure 4.6 Affiliate airlines in the depeaked schedule of American at ORD.

4.2.2.3 Peak/Depeak Measurement

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 124.5, which drops to 84.9 in the depeaked schedule. The change for the departures goes from 132.3 to 86.0.

The peak and depeak percentage measures show a drop in the peaked nature of the schedule. In the peaked schedule, 73% of flights occur within the banks, highlighted in Figure 4.7. In the depeaked schedule, 54% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.8. This drop, combined with the changes in the coefficient of variation, both indicate a quantitative reduction in the peak level of the schedule.

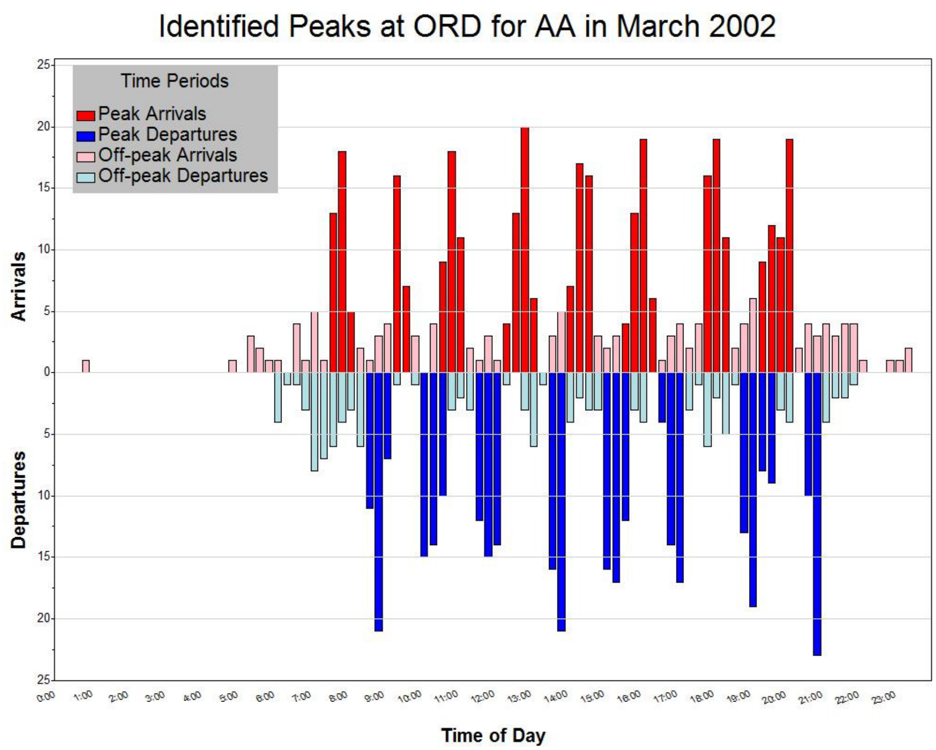

Figure 4.7 Identified banks in the peaked American schedule at ORD.

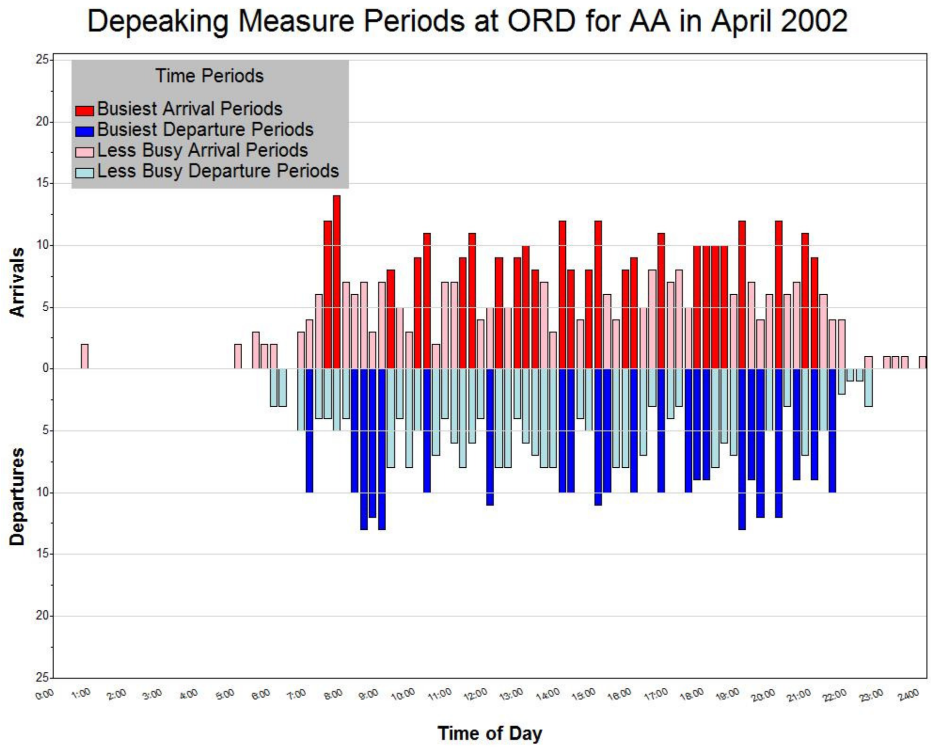

Figure 4.8 Busiest *n* 15-minute periods in the depeaked American schedule at ORD.

4.2.2.4 Connections

The number of connections increased slightly from the peaked to the depeaked schedule. The peak schedule has 16,806 potential connections from each arriving to departing flights within the MCT and MxCT for the given arriving flight. This value increases to 16,904 in the depeaked schedule. The average number of connections per arriving flight decreases however due to the increase in number of flights needed to make those connections, from 38.7 in the peaked schedule, to 36.3 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections stayed the same from the peaked to the depeaked schedule at 18. In both schedules, this market was between LaGuardia (LGA) and Dallas-Fort Worth.

4.2.2.5 Validation of Supply-Demand Time Decision

As discussed in subsection 3.4.7.2, schedules representing supply during the peaked (depeaked) periods in the quarters directly before (or after) the depeaking event were verified to be similar.

Table 4.2 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.3 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.2 Supply Measures Over Time for American's Peaked Schedule at ORD

Measure	1/8/02	1/15/02	1/29/02	2/12/02	2/19/02	3/5/02	3/19/02	3/26/02
Max. number of flight arrs. or deps. in 15-minute interval	22	22	22	22	22	24	23	23
Max. number of flight operations in 15-minute interval	26	26	26	26	26	27	27	26
Number of flights flown into or out of hub	861	852	849	878	835	851	875	869
Total available seat miles flown into or out of hub (000s)	79671	79023	78993	80553	78266	90653	91940	92828
Number of destinations served from hub	97	97	97	97	97	96	96	96
Coefficient of variation in number of arr./dep. flights	127.5/132.2	127.5/132.6	127.3/134.2	126.2/131.9	128.7/135.1	125.8/133.9	124.4/132.3	124.5/132.3
Percentage of flights served by affiliate airline(s)	37.4%	36.7%	36.6%	37.9%	35.9%	35.5%	37.7%	35.3%
Percentage of flights served in peak period	74.7%	75.5%	76.1%	70.5%	74.3%	72.2%	74.2%	73.3%
Number of potential connections	16969	16698	16520	17230	15743	16197	16980	16806
Average connections per arriving flight	39.6	39.4	39.0	39.4	37.7	38.3	38.7	38.7
Maximum potential connections serving a market	14	14	13	17	13	17	13	18

Table 4.3 Supply Measures Over Time for American's Depeaked Schedule at ORD

Measure	4/9/02	4/16/02	4/23/02	5/7/02	5/21/02	6/18/02	6/25/02
Max. number of flight arrs. or deps. in 15-minute interval	14	13	14	14	14	14	15
Max. number of flight operations in 15-minute interval	25	25	25	25	24	24	24
Number of flights flown into or out of hub	935	922	937	922	934	937	842
Total available seat miles flown into or out of hub (000s)	98524	97928	98798	99015	98983	995161	92365
Number of destinations served from hub	92	92	92	90	91	91	91
Coefficient of variation in number of arr./dep. flights	84.9/86.0	85.1/85.7	84.8/85.7	84.8/86.4	84.8/85.6	84.0/84.7	86.5/88.9
Percentage of flights served by affiliate airline(s)	34.9%	34.1%	34.2%	33.3%	34.8%	33.3%	32.9%
Percentage of flights served in peak period	53.9%	53.6%	53.6%	53.5%	53.8%	53.7%	55.5%
Number of potential connections	16904	16425	17015	16462	16960	16988	13594
Average connections per arriving flight	36.3	35.7	36.5	35.9	36.4	36.5	32.7
Maximum potential connections serving a market	18	17	20	20	20	23	14

4.2.3 Demand Results

The changes in demand and related parameters before and after the depeaking of ORD are shown in Table 4.4. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Just over 25 thousand average daily passengers traveled on American through ORD in the peaked schedule during the peaked quarter, and this increased to nearly 32 thousand during the depeaked quarter. Overall the revenue increased from the first to second quarter of 2002, from $4.7 million to $5.7 million. More importantly, even though ASMs increased, the RASM increased as well: from 5.11 cents per mile to 5.80 cents per mile.

Table 4.4 Summary of Demand and Revenue Changes for American at ORD

Measure	Peaked	Depeaked
Total passengers	25,413	31,836
Revenue ($)	4,746,042	5,712,689
Revenue per available seat mile (RASM) (cents per mile)	5.11	5.80
Percent connecting passengers	38.9%	34.4%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was 85, while 11 markets saw a decrease. RASM increased in 77 markets and decreased in 19.

Across the spokes of ORD there was an average decrease in connecting traffic from the spoke airports. 38.9% of passengers at ORD on American were connecting passengers under the peaked schedule, and 34.4% were connecting passengers under the depeaked schedule. At the spoke level, 20 spoke routes had an increase in the percentage of passengers on flights between ORD and the spoke that made connections. However, 76 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and ORD. It is clear that connecting traffic suffered after depeaking.

Revenue measures, much more so than supply measures, must be considered in terms of market conditions at the time. Across any time period, macroeconomic changes influence the revenue of a business, and this is much more poignant in the travel industry. Fares change and passenger numbers vary depending on the economy, seasons, and competition. Thus, the 0.69 cents per mile increase from the peaked to the depeaked period must be considered in the context of the rest of the airline's revenue and the industry during this period. Over this same time period, the entire American network saw a 1.01 cents per mile increase in RASM, including American's other hubs in Dallas and Miami. The industry as a whole saw a 1.18 cents per mile increase between these two quarters. American's revenue growth at ORD lagged behind the rest of American and the industry as a whole. It is thus possible that the depeaking of ORD could have influenced slower revenue growth.

4.2.4 On-Time Results

The operational effects of depeaking are shown in Table 4.5 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was an improvement in operations. There was an overall decrease in average delay per aircraft, with less delayed aircraft overall

Table 4.5 Summary of Operational Changes for American at ORD

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	13.3	6.8
Average departure delay for delayed aircraft (minutes)	51.3	40.7
Percentage of delayed departing aircraft	23.4%	14.3%
Total delay for delayed departing aircraft (minutes)	155,846	80,850
Average taxi-out time (minutes)	18.6	17.8
Average arrival delay for all aircraft (minutes)*	13.6	8.1
Average arrival delay for delayed aircraft (minutes)	55.2	46.2
Percentage of delayed arriving aircraft	22.1%	15%
Total delay for delayed arriving aircraft (minutes)	157,947	96,100
Average taxi-in time (minutes)	8.7	7.5

***Early arriving and early departing aircraft were assigned zero delay**

The improvement in operations, like demand, must be considered in context with what was occurring across the system. The peaked quarter was in the winter, while the depeaked quarter was in the spring, so that alone could account for the improvement in delay statistics.

What is seen is that the improvements at ORD for American in terms of departure delay were better than what seen across American's network and throughout the industry. Nearly 11 minutes of delay were removed from the ORD departing flights, whereas across American it was about 2 minutes. Meanwhile the industry actually saw an increase during this time period, seeing just over 2.5 more minutes of departure delay. Across the board, a lower percentage of aircraft saw departure delay, but the decrease for American at ORD after depeaking was the greatest reduction at 39%. The entire American network and the industry saw just a 23% drop in delayed departing aircraft over the same time period.

Arrival delay also saw a similar degree of improvement over the whole American route network and the industry. In terms of delay in minutes per arriving aircraft, the ORD operations saw a 16% decrease, while only a 3% decrease occurred across all of American's flights. The industry as a whole increased 4% during this same time period. As a percentage of aircraft that were delayed on arrival, ORD exceeded the American and industry averages. A decrease of 32% exceeded the network's and industry's decrease of about 20% each.

American's operations at ORD saw a greater improvement in operations than the rest of American's network and the industry. This is indicative of a possible influence by depeaking on operations, and could mean that depeaking in this case improved operations.

4.2.4.1 Operations for Dual-Hub Competitor

The ORD case provides an opportunity to assess the operations of a depeaking airline's competition because of its dual-hub status with American and United. Because American saw an improvement at ORD in its operations, it is possible that with reduced congestion American's main competitor United could have as well. It is important to know if depeaking has positive spillover effects for all airport operations, as it could potentially affect an airline's decision.

The operational effects for United before and after American's depeaking are shown in Table 4.6, created using statistics from the On-Time database. Using these aggregated measures, it is seen that between the peaked and depeaked months there was an improvement in operations. There was an overall decrease in average delay per aircraft, with less delayed aircraft overall

Table 4.6 Summary of Operational Changes for United at ORD

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	7.6	5.2
Average departure delay for delayed aircraft (minutes)	48.6	45.6
Percentage of delayed departing aircraft	13.2%	9.6%
Total delay for delayed departing aircraft (minutes)	64,568	45,027
Average taxi-out time (minutes)	18.2	19.2
Average arrival delay for all aircraft (minutes)*	10.1	7.2
Average arrival delay for delayed aircraft (minutes)	49.0	41.7
Percentage of delayed arriving aircraft	17.8%	14.2%
Total delay for delayed arriving aircraft (minutes)	87,350	60,848
Average taxi-in time (minutes)	7.6	7.4

***Early arriving and early departing aircraft were assigned zero delay**

Just like with American's operations, the improvement in United's operations needs to be considered in the context with what was occurring across the system. Thus United's operations are compared to the rest of United's network and the industry overall, the latter being the same statistics American was compared to in the previous subsection.

United at ORD did have improvements in operations as compared to the rest of United's network and the industry. In terms of minutes of delay for delayed aircraft, United saw a decrease of 6% and 15% for departing and arriving flights, respectively. These figures outperformed United as a whole, an improvement of 2% and 4% for arriving and departing flights, respectively, and the industry, which gained delay for both measures. United's ORD operations did not see as great of an improvement in terms of the proportion of aircraft which were delayed. Its 27% less delayed departures and 20% less delayed arrivals were not as good of improvements as United overall (34% and 27% improvements) and were slightly better or on par with the industry (23% and 20% improvements).

United's operational benefits over the depeaking period are good, but the airline did not see as great of an operational improvement as American. The operations of American had a greater degree of improvement than United across the comparison measures. Thus it is seen that although the depeaking airline's competitor saw operational improvements, the depeaking airline's gains were to a larger degree.

It appears that United's operations at ORD for the most part saw a greater improvement in operations than the rest of United's network and the industry. The airline saw operational benefits because of American's depeaking, but American saw a larger improvements. Thus it is likely that a depeaking airline sees the bulk of the operational benefits when it depeaks its hub, although the competitors are also likely to see benefits.

4.2.5 Dual-Hub: United Airlines' Response

ORD is a dual-hub airport, with both American's and United's hubbing operations. When American depeaked, United had the option to move some of its flights into peak time periods in which American had previously concentrated its flights.

The initial schedule United was operating at ORD was a heavily peaked schedule, as seen in Figure 4.9. There are 10 arrival and departure peaks. The schedule's peak measurements indicate a peaked schedule, with a peak percentage of 80.5% and coefficients of variation for arrivals and departures of 140.6 and 131.8. Based on these values, United's schedule at the time before depeaking was more concentrated into banks than the schedule American would depeak.

The United measurements for the peaked date, as well as the preceding months before depeaking and the months after American depeaked are shown in Table 4.7. United had a fairly consistent schedule in terms of peak measurements and connections per arriving flights. One measure unique to the dual-hub competitor that is not seen for the depeaking airline is the percentage of flights operated by the competitor during the time of the depeaking airline's banks. Thus, for this case, it is a measurement of the percentage of flights in United's schedule which were flown during the American banks.

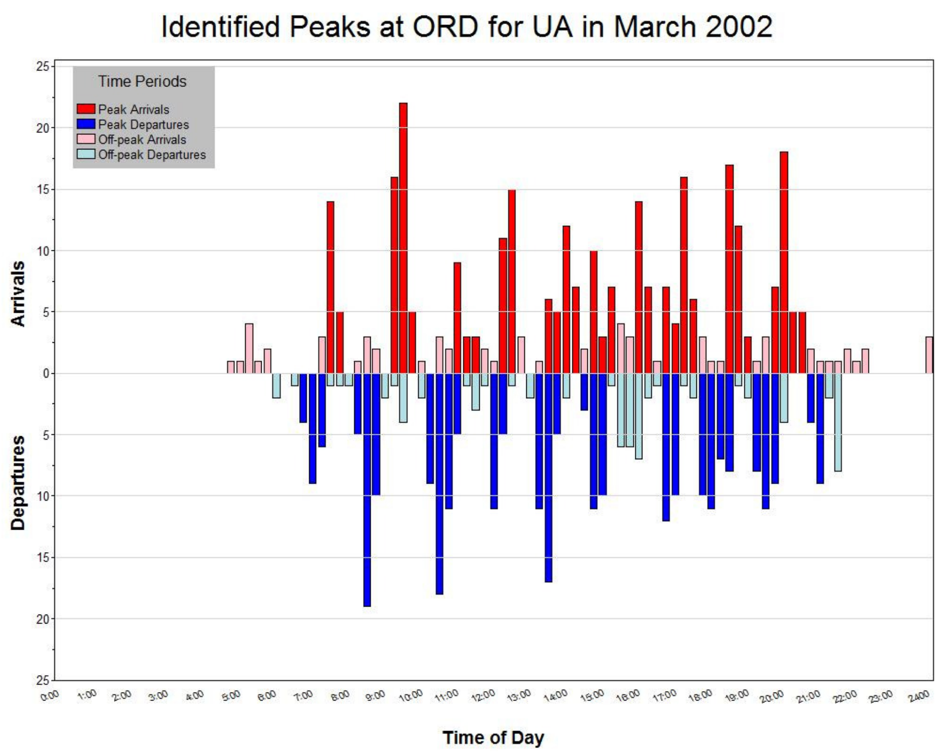

Figure 4.9 Identified banks in the United schedule at ORD.

Table 4.7 Summary of Supply Changes for United at ORD

Measure	Dec. 18 2001	Feb. 26 2002	Mar. 26 2002	Apr. 9 2002	May 14 2002	Jul. 9 2002
Coefficient of variation in # of arr.	150.5	140.5	140.6	130.0	128.3	96.8
Coefficient of variation in # of dep.	133.0	133.2	131.8	137.7	135.9	128.9
Percentage of flights in peak period	79.9%	77.9%	80.5%	69.4%	70.1%	77.2%
Percentage of flights in AA banks	51.3%	51.3%	51.4%	48.2%	47.7%	42.1%
Number of potential connections	9255	9815	10015	10045	9917	12158
Average connections per arriving flight	28.7	29.8	29.7	29.5	29.0	30.6
Max. potential connections in a market	18	20	21	19	18	27

After American's depeaking on April 7, 2002, United's peak level in its schedule reduced for some time. Although the peak level ultimately increased back to its former levels by three months after depeaking, the coefficients of variation did not, particularly that for arrivals. Meanwhile, United managed to increase its number of potential connections per arriving flight, and the number of connections in its most important markets increased as well (as indicated by the maximum potential connections in a given market). This could have occurred because United increased the number of peaks from 10 arrival and departure banks to 11 arrival banks and 12 departure banks. The schedule for United three months after American's depeaking is shown in Figure 4.10.

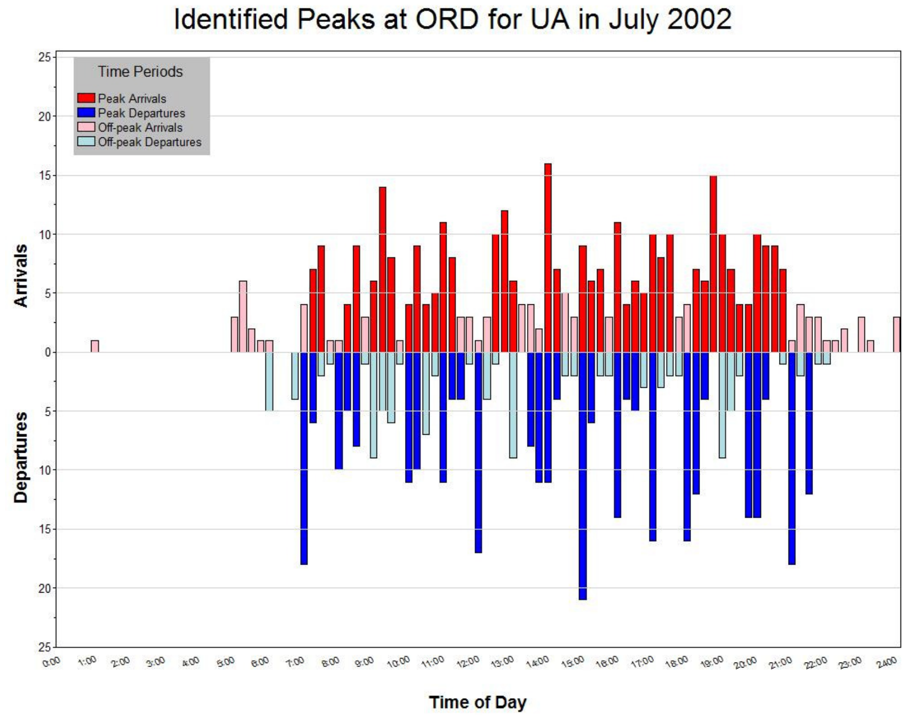

Figure 4.10 Identified banks in the United schedule at ORD, 3 months after.

The decision by United to increase the number of banks, while reducing their peak level, helped United increase their number of connections per arriving flight. United did not, however, move their flights to the times of day in which American was operating their flights. Instead, they moved flights away from those times. As seen in Table 4.7, United reduced the percentage of flights operated in American's banks (and later bank shadows), from 51% during American's peak period, to 42% by three months later. Figures 4.11 and 4.12 show the American banks overlaid on United's peaked date schedule and three months after schedule.

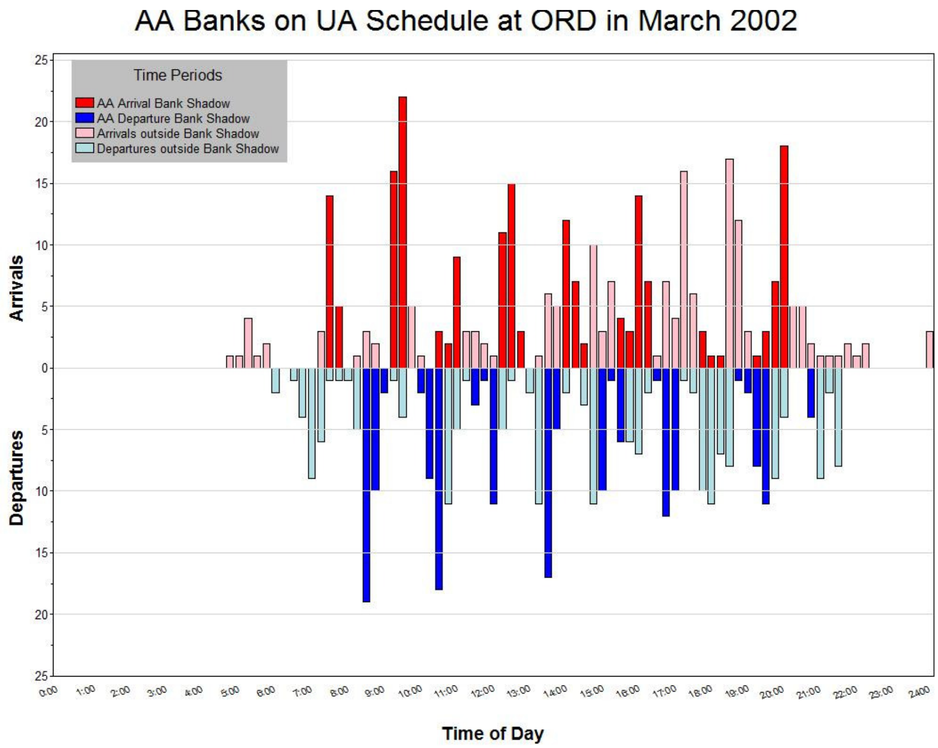

Figure 4.11 American's banks overlaid on United's peaked date schedule.

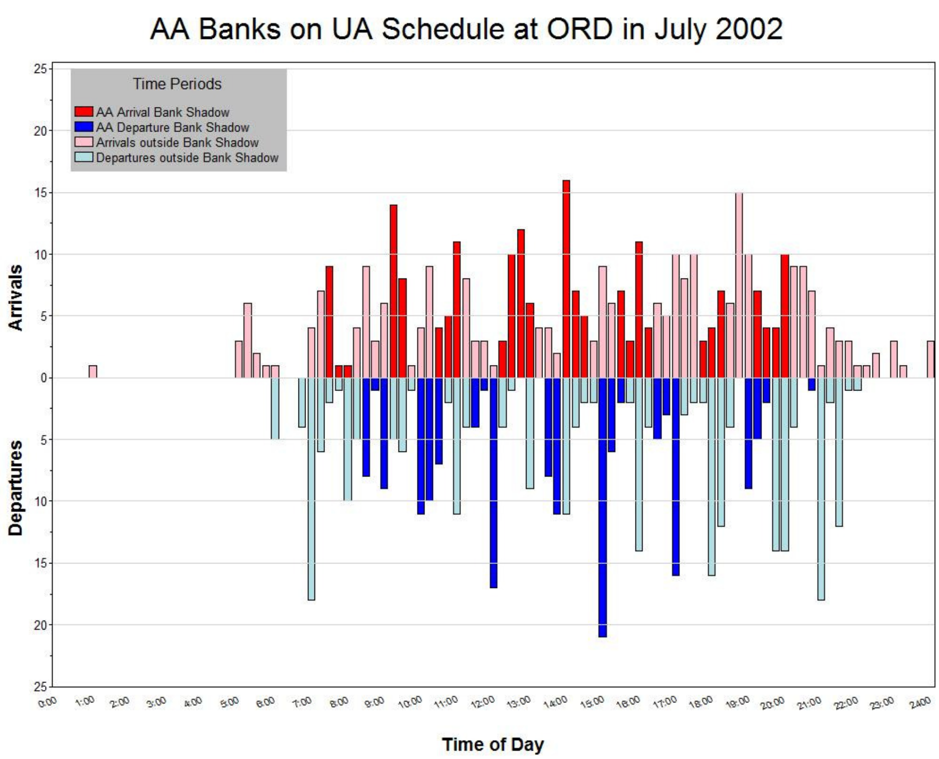

Figure 4.12 American's banks overlaid on United's 3-months-later schedule

It appears that in some ways United found ways to create more connections in their schedule to counter American's reduction in connections per arriving flight. This did not appear to include though, the shifting of flights to make use of the time slots American once dominated.

4.2.6 Predicting Changes in Supply

Employing the use of a regression model, analysis was performed on the ORD case study to assess the decision-making process American used in determining how to depeak their schedule. Analysis is done at the spoke level, such that all data is summarized for a spoke airport destination that was served by American during the depeaking period.

Table 4.8 Regression Model Results for Change in Flights at ORD

Variable	Coefficient	t-stat	p > |t|
Intercept	-0.2840	-0.69	0.492
Connecting Passengers	0.0039	3.34	0.001
Connecting Fare	0.0131	1.93	0.057
Distance to Spoke Airport	-0.0015	-2.50	0.014
Spoke is hub for AA*	-2.4871	-2.76	0.007
Spoke is hub for another airline*	0.8275	2.56	0.012

***Indicator variable (1 = yes)**

The dependent variable, defined as the change in the number of flights on the route between ORD and a spoke, was associated with some of the variables listed in Table 4.8. The variables include the number of connecting passengers, the fare for connecting passengers, the distance to ORD from the spoke airport, and whether the spoke airport is a hub for American or for another airline. Four of these variables are significant at the

95% confidence level, while the connecting fare is significant at the 90% confidence level. The adjusted R^2 for the model is 0.176.

This model did not pass the normality assumption, but passed the linearity and homoscedasticity assumptions. The normal probability plot in Figure 4.13 shows a bowed portion in the plot, indicating that there could be excessive skewness. To check to see if the model holds up, it was checked against a count model with the same parameters.

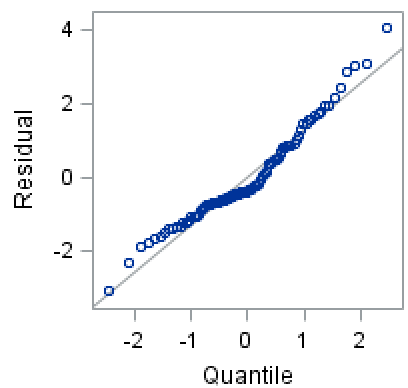

Figure 4.13 Normal probability plot for ORD case. The bowed shape indicates excessive skewness.

The count model results provided the same directional results as the regression model with the exception of connecting passengers. That ORD is an important mid-continental hub in American's network, the connections that are made are critical for having a successful network. It must be noted, however, of the three major connecting hubs in this study (ORD, DFW, and ATL), ORD has the highest percentage of local traffic. 61% of ORD's passenger traffic for American is locally originating, compared to 53% for DFW and 46% for ATL. Thus American is focused on capturing local originating traffic, likely because of United operating a hub out of the same airport. Thus, although connecting traffic is significant in the model, it is likely not as important of a factor in depeaking ORD due to the volume of originating traffic at ORD.

American's strategy for depeaking ORD, as determined by the model's results, shows a focus on boosting revenue from high-value connecting traffic, with less frequency to farther away spokes. In addition, American went after competitor's hubs, without prioritizing their own. ORD only dropped frequency to five airports. The greatest increases occurred at competitor hubs with high priced connecting tickets. These included Houston (IAH), Newark (EWR), and Minneapolis (MSP). Other high priced connecting tickets that were not hubs included Fayetteville, AR (XNA), Boston (BOS), and Austin (AUS). Airports which are also hubs for American did not gain flights, as Miami (MIA) lost flights and Dallas/Fort Worth (DFW) maintained frequency. The distance factor's role mainly caused farther away spokes to lose frequency or stay constant. Airports like Tucson (TUS), Orange County (SNA), San Jose, Puerto Rico (SJU), and San Jose, CA (SJC) did not receive gains to ORD on American. Meanwhile spokes which gained flights were less than 1000 miles from ORD, including the greatest gain at Indianapolis (IND).

In summary, the strategy American employed at ORD to expand frequency focused on going after other airlines' hubs, targeting high value connecting traffic, and mostly excluding spoke airports far from ORD. The airline mostly added flights to spokes, and only took away frequency from a few. Thus, when American depeaked ORD, they did not refocus operations, but rather boosted to destinations where they wanted to pursue growth, and felt growth would be profitable.

4.2.7 Assessing Depeaking and Effects

The supply and demand results over the depeaking period show changes that likely could have been due to depeaking. To get a better understanding as to whether the changes that occurred were likely due to depeaking as opposed to being a typical change for that time of the year, year-over-year measures were calculated. The percentage change between the peaked and depeaked dates is calculated, and also for the year before and year after on similar dates.

For the ORD case, it is evident that much of the supply changes were due to depeaking. Table 4.9 shows schedule measures and reports a percentage change associated with each year. For example, in the case of American, depeaking occurred in 2002. March 26, 2002 was used as the representative Tuesday peaked schedule and April 9, 2002 was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2002 shows the change in schedule measures between these two dates. The process is repeated for two dates each in the years 2001 and 2003, using representative Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2001 change is between two peaked schedules and the 2003 change is between two depeaked schedules. Thus only the 2002 change is for changes that occurred between different schedule types.

Table 4.9 Supply Year-Over-Year Changes for American at ORD

Measure	2001				2002				2003			
	3/27	4/10	Δ	%	3/26	4/9	Δ	%	3/25	4/10	Δ	%
Max. number of flight arrs. or deps. in a 15-minute interval	25	22	-3	-12%	23	14	**-9**	**-39%**	14	14	0	0%
Max. number of flight operations in a 15-minute interval	27	24	-3	-11%	26	25	-1	-4%	21	21	0	0%
Number of flights flown into or out of hub	922	883	-39	-4%	869	935	**66**	**8%**	915	873	-42	-5%
Total available seat miles flown into or out of hub (000s)	86503	84946	-1557	-2%	92828	98524	**5696**	**6%**	90625	88793	-1831	-2%
Number of destinations served from hub	90	88	-2	-2%	96	92	-4	-4%	92	88	-4	-4%
Coefficient of variation in number of arrivals	116.9	120.8	3.9	3%	124.5	84.9	**-39.6**	**-32%**	82.6	82.9	0.3	0%
Coefficient of variation in number of departures	132.9	129.2	-3.7	-3%	132.3	86	**-46.3**	**-35%**	81.6	82.1	0.5	1%
Percentage of flights served by affiliate airline(s)	35.3%	33.1%	-2.2%	-6%	35.3%	34.9%	-0.4%	-1%	40.9%	39.8%	-1.1%	-3%
Percentage of flights served in peak period	78.3%	77.5%	-0.8%	-1%	73.3%	53.9%	**-19.4%**	**-26%**	51.8%	52.0%	0.2%	0%
Number of potential connections	17546	16143	-1403	-8%	16806	16904	**98**	**1%**	16079	14509	-1570	-10%
Average connections per arriving flight	38.1	36.7	-1.4	-4%	38.7	36.3	-2.4	-6%	35.3	33.4	-1.8	-5%
Maximum potential connections serving a market	24	25	1	4%	18	18	0	0%	26	22	-4	-15%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages represent changes most evident by American's depeaking. From the year-over-year data, it is evident that depeaking involved a reduction in the number of flights flown in a given period and the creation of a more even distribution of flights (as evidenced by the reduction in the coefficients of variation and reduction in peak percentage). Depeaking thus allowed American to increase the number of flights flown in the schedule, increase the ASMs, and maintain potential connections in the schedule.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases, because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus RASM is used in comparison still with the RASM of the airline network and for the industry.

One measurement which is useful in terms of demand in measuring it year-over-year is the percentage of connecting passengers. Surprisingly, despite the increase in potential connections in the schedule, the percent of connecting passengers in 2002 decreased 12%, while in 2001 and 2003 it increased, 2% and 3% respectively. Depeaking may have actually led to a decrease in connecting traffic, despite the relative increase in connections.

The change in RASM for American's ORD schedule lagged behind the rest of American and industry in the depeaking year. This underperformance seems to be tied to the depeaking change, as without a change in schedule, American's ORD RASM was ahead or on par with the rest of the network and industry, as seen in Table 4.10.

Table 4.10 RASM Year-Over-Year Changes for American at ORD

Measure	2001				2002				2003			
	Q1	**Q2**	**Δ**	**%**	**Q1**	**Q2**	**Δ**	**%**	**Q1**	**Q2**	**Δ**	**%**
RASM for Depeaked Airport	7.17	7.94	0.77	11%	5.11	5.80	0.69	14%	5.30	6.20	0.90	17%
RASM for Airline Network	8.53	8.74	0.21	2%	5.98	6.99	1.01	17%	6.19	7.18	0.99	16%
RASM for Industry	9.87	10.28	0.41	4%	7.95	9.13	1.18	15%	8.17	9.63	1.46	18%

Operationally, American saw an improvement in operations at ORD year-over-year, as seen in Table 4.11. For departure delay there was an improvement in the depeaking year that was greater than the rest of American's network and the industry, which outperformed that which occurred in the years before and after. Percent of delayed departures also saw a greater improvement in the depeaking year in relation to the comparative measures than in the surrounding years. Arrival delay improved in the depeaking year compared to the industry and the rest of the American network, while in the years before and after arrival delay worsened at ORD. For the percentage of delayed arrivals, there was a big improvement in the depeaking year when compared using the difference-in-difference method, and this improvement was much greater than the year after's improvement (the year before saw a worsening in relation to the industry and network). Overall, ORD saw all four operational measures notably improve in the depeaking year.

Table 4.11 Operations Year-Over-Year Changes for American at ORD

Measure	2001				2002				2003			
	Mar	May	Δ	%	Mar	May	Δ	%	Mar	May	Δ	%
Dep. Delay Depeaked Airport	48.7	51.5	2.8	6%	51.3	40.7	-10.6	-21%	49.2	50.2	1	2%
Dep. Delay Airline Network	56.4	52.6	-3.8	-7%	54.1	52.2	-1.9	-4%	52.7	55.1	2.4	5%
Dep. Delay Industry	50.7	48.2	-2.5	-5%	45.8	47.5	1.7	4%	49.4	50.1	0.7	1%
% Delayed Dep. Depeaked Airport	22.4	22.4	0	0%	23.4	14.3	-9.1	-39%	15.8	13.2	-2.6	-16%
% Delayed Dep. Airline Network	18.8	15.5	-3.3	-18%	15.4	11.8	-3.6	-23%	10.3	10.7	0.4	4%
% Delayed Dep. Industry	19	13.9	-5.1	-27%	16.6	12.8	-3.8	-23%	12.5	10.9	-1.6	-13%
Arr. Delay Depeaked Airport	49.8	55.3	5.5	11%	55.2	46.2	-9	-16%	57.9	62.2	4.3	7%
Arr. Delay Airline Network	52.6	49.2	-3.4	-6%	50.6	48.9	-1.7	-3%	50.7	51.5	0.8	2%
Arr. Delay Industry	48.3	45.7	-2.6	-5%	44.2	46	1.8	4%	47.4	47.4	0	0%
% Delayed Arr. Depeaked Airport	20.7	21.8	1.1	5%	22.1	15	-7.1	-32%	19.7	16.6	-3.1	-16%
% Delayed Arr. Airline Network	22.5	19.6	-2.9	-13%	19.8	15.8	-4	-20%	13.6	15.2	1.6	12%
% Delayed Arr. Industry	22	16.9	-5.1	-23%	20.2	16.3	-3.9	-19%	15.9	14.3	-1.6	-10%

American appears to have considerable changes from depeaking, and ones that provided positive results in terms of cutting cost and getting more use out of their operations. They increased ASM and flights while reducing their gate and staff needs by spreading out the flights. Oddly, they were able to increase potential connections, but connecting passenger traffic reduced. This may be due to lack of coordination between scheduling and revenue management decisions, e.g. the schedule was constructed to allow for higher numbers of connecting passengers but the revenue management system may have been expecting the same number of local and connecting passengers as in the past. The airline saw notable improvements in operations when examined against comparative measures in the depeaking year and assessed year-over-year.

4.2.8 Summary

The need to cut cost drove the decision to make big supply changes that completely altered the schedule at ORD. American spread operations out throughout the day, and thus reduced the need for gates and staff. Despite this change, American was able to increase the number of flights and ASMs in the schedule, which boosted the overall number of connections. Because American added flights, there were only a few spokes which lost frequency. The decision on how to restructure the schedule and add flights focused on targeting high value connecting traffic. The additions occurred mostly for spokes closer to Chicago and reinforced frequency in markets in which the airline wanted to pursue growth, including markets served by competitor’s hubs.

The effects of these changes were mixed for American. Operationally the airline saw improvements in delay and taxi times. American reduced the percentage of flights that experienced delays out of ORD. American was unable to maintain their revenue stream with the changes. The airline also saw a drop in the connecting percentage of the passenger traffic despite the focus on maintaining valuable connections in depeaking. American’s prime competitor, United, did not respond with major schedule changes and kept a mostly consistent schedule, although United did change their schedule to increase potential connections. United saw an improvement in operations, but it did not match the level to which American was able to cut delay.

4.3 American Airlines at Dallas/Fort Worth (DFW)

American Airlines depeaked their second major mid-continental hub, DFW, in October of 2002. American Airlines removed nine arrival and departure peaks from their schedule. This move, like the ORD depeaking, was in response to the rising costs of operating the peaked schedule, coupled with the high market volatility in the post-9/11 market and the losses from acquiring TWA. Depeaking DFW aided American in avoiding bankruptcy.

DFW served as a hub airport for two major airlines during the depeaking period. Delta Air Lines also had a hub operation at DFW until 2005, and thus this case is useful to assess how a competitor at a dual-hub responds to depeaking. Included in this section is a description of Delta's changes after American depeaked.

4.3.1 Data Periods Used and Input Parameters

American Airlines depeaked DFW on Friday November 1, 2002. The date used to represent the peak schedule is Tuesday October 22, 2002. The date used to represent the depeaked schedule is Tuesday November 5, 2002.

American depeaked DFW in the middle of the fourth quarter of 2002, so the representative peaked quarter is the third quarter of 2002. The representative depeaked quarter is the first quarter of 2003. The peaked month used for operational measures is October 2002; the depeaked month is November 2002.

For creating year-over-year measures, October 23, 2001 and November 6, 2001 were used as the supply comparison dates the year prior. October 21, 2003 and November 4, 2003 were used as the supply comparison dates for the year after depeaking. The third quarter of 2001 and the first quarter of 2002 are used as the year prior demand comparison quarters, and the third quarter of 2003 and the first quarter of 2004 are used for the year after. October 2001 and November 2001 are used for the year prior operational comparison months, and October 2003 and November 2003 are used for the year after.

The distribution of actual connection times made at DFW for passengers flying on American itineraries is shown in Figure 4.14. This distribution is from itineraries flown in June 2010. At that time, DFW was still operating under a depeaked schedule. The 5th and 75th percentiles, indicating the MCT and MxCT are denoted in the figure. For this case, the MCT is 40 minutes and the MxCT is 105 minutes.

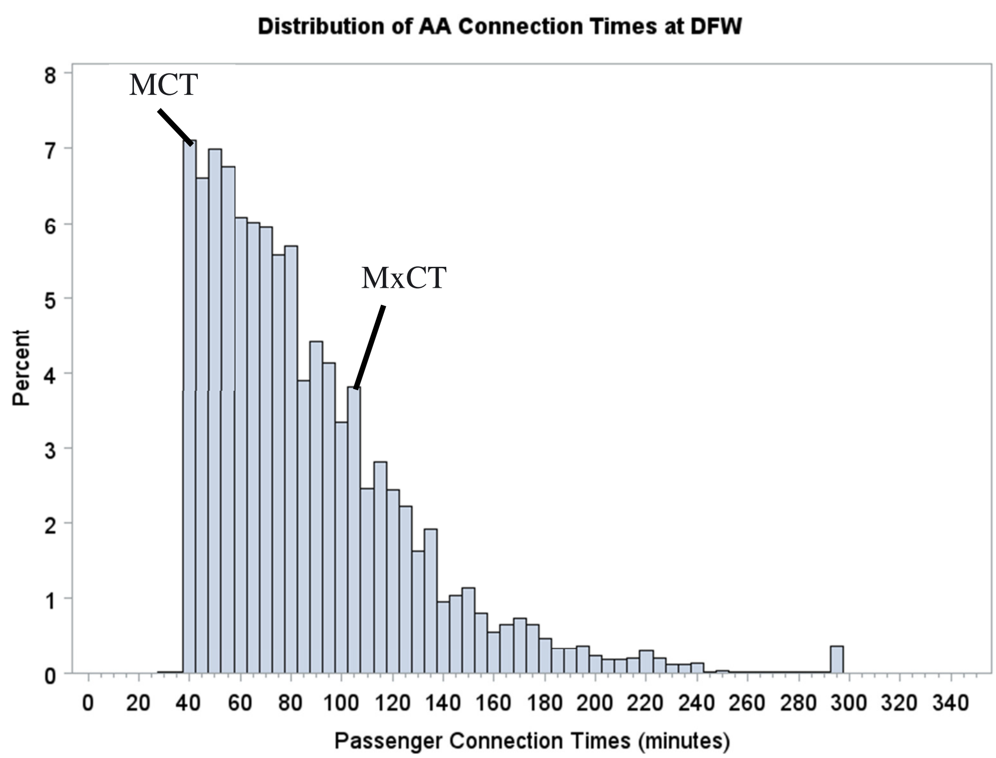

Figure 4.14 Connection time distribution for AA at DFW. MCT and MxCT are denoted.

4.3.2 Supply Results

The following section describes the supply-side results for American's depeaking of DFW, which includes data derived from the On-Time database. Table 4.12 summarizes the supply measures representing peaked and depeaked schedules that are discussed in this section.

Table 4.12 Summary of Supply Changes for American at DFW

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	48	21
Max. number of flight operations in a 15-minute interval	49	34
Number of flights flown into or out of hub	1,270	1,245
Total available seat miles flown into or out of hub	131,767,721	127,660,919
Number of destinations served from hub	105	105
Coefficient of variation in number of arr./dep. flights	141.7/176.4	88.4/86.8
Percentage of flights served by affiliate airline(s)	32.5%	33.6%
Percentage of flights served in peak period	82.7%	53.5%
Number of potential connections	35,513	26,743
Average connections per arriving flight	55.9	43.1
Maximum potential connections serving a market	14	15

4.3.2.1 General Supply

American Airlines' reproduced peaked schedule at DFW is shown in Figure 4.15 and the reproduced depeaked schedule in Figure 4.16.

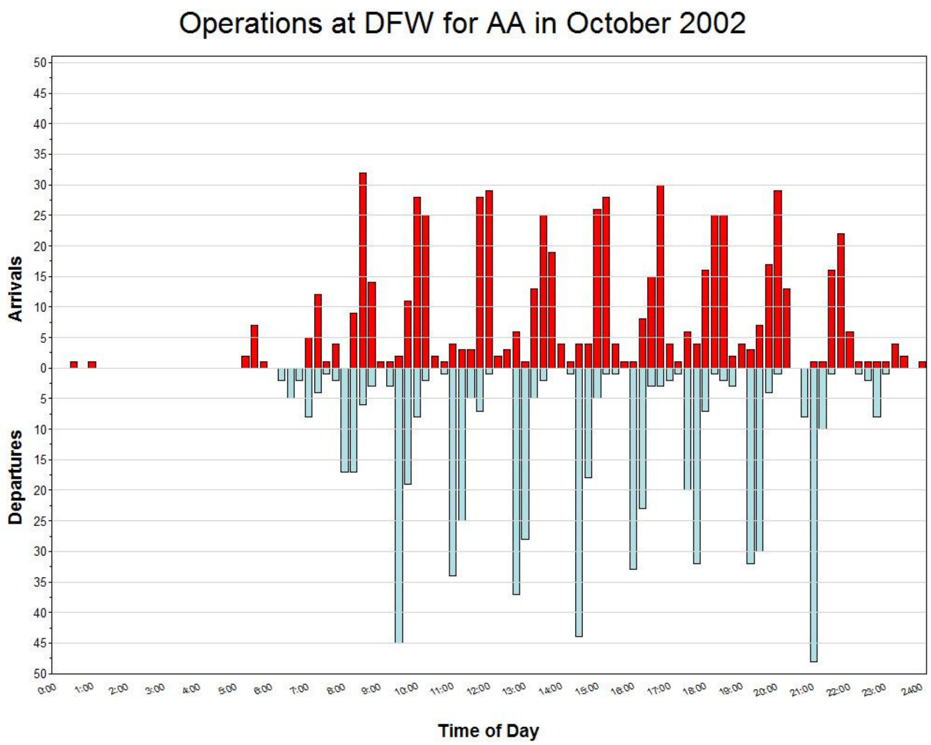

Figure 4.15 Peaked schedule for American at DFW.

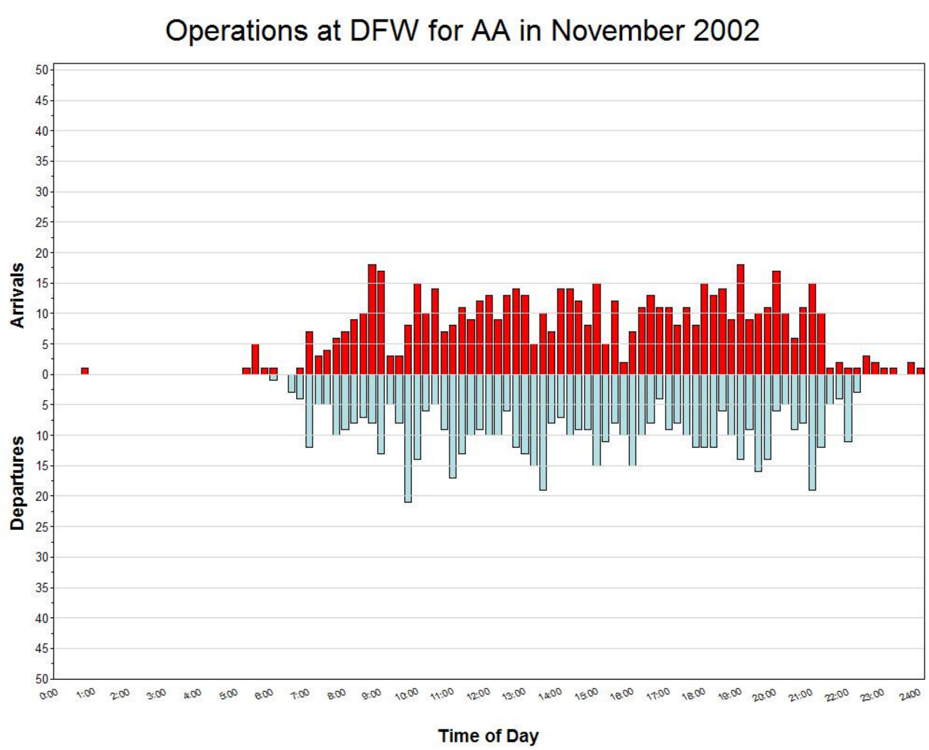

Figure 4.16 Depeaked schedule for American at DFW.

The maximum number of operations in a 15-minute period drops greatly from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 48, while in the depeaked schedule it is 21. The combined number of arrivals and departures in a 15-minute period in the peaked schedule is 49, while it drops to 34 in the depeaked schedule.

The distribution of American's operations at DFW is more spread out throughout the day, as seen in the density function plot shown in Figure 4.17. In this plot, the 15-minute periods are ranked in order of frequency. There are more 15-minute periods that have greater than zero operations in the depeaked schedule, in addition to having a less steeply sloped distribution. It is clear that busiest periods are much lower in the depeaked schedule, but the peaked schedule drops off sharply from its busiest periods. It is also clear that the departures have a much greater magnitude and compactness in operations.

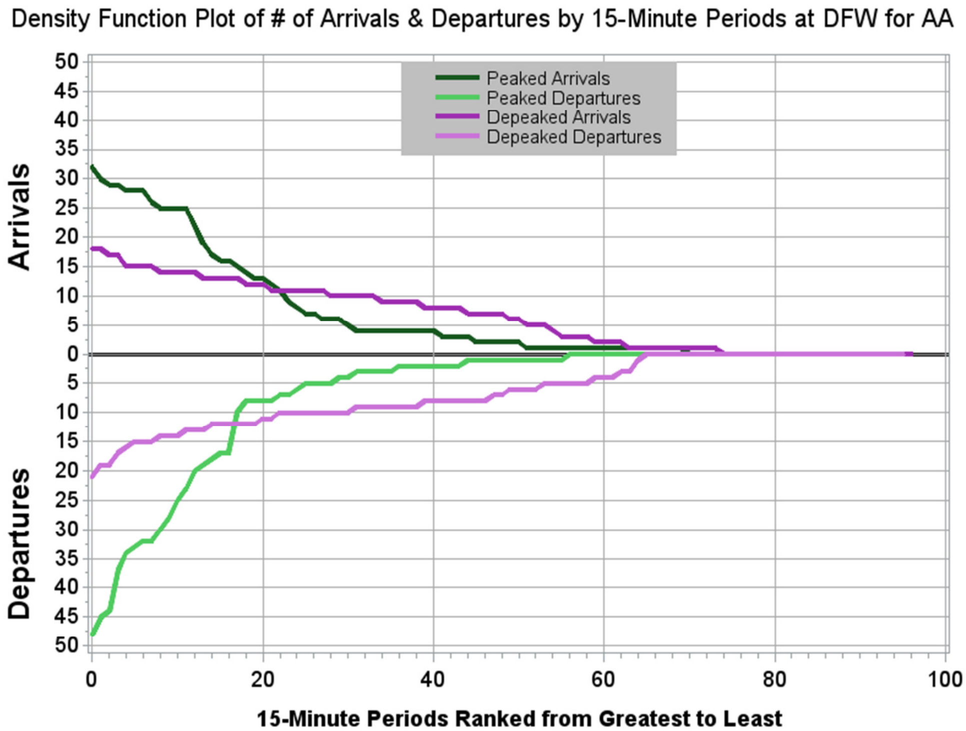

Figure 4.17 Density function plot of American operations at DFW.

In the depeaked schedule, American slightly decreased the total number of flights from the peaked schedule. In the peaked daily schedule in late October of 2002 American operated 1,270 flights out of DFW, and this dropped to 1,245 flights by early November. American retained the same set of destinations in their network from DFW under the depeaked schedule. Due to the decreased number of flights, daily ASMs decreased as well, from just fewer than 132 million to under 128 million.

4.3.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines stays mostly constant from the peaked to the depeaked schedule, increasing just slightly. This percentage is 32.5% in the peaked quarter and 33.6% in the depeaked quarter. This value is for the affiliate airline that reported on-time statistics to the On-Time database, which in early 2002 included American Eagle. As seen in Figure 4.18, American Eagle primarily operates in the banks of the schedule, although American Eagle certainly has a large number of flights outside the banks. In the depeaked schedule shown in Figure 4.19, American Eagle operates at a consistent level throughout the day.

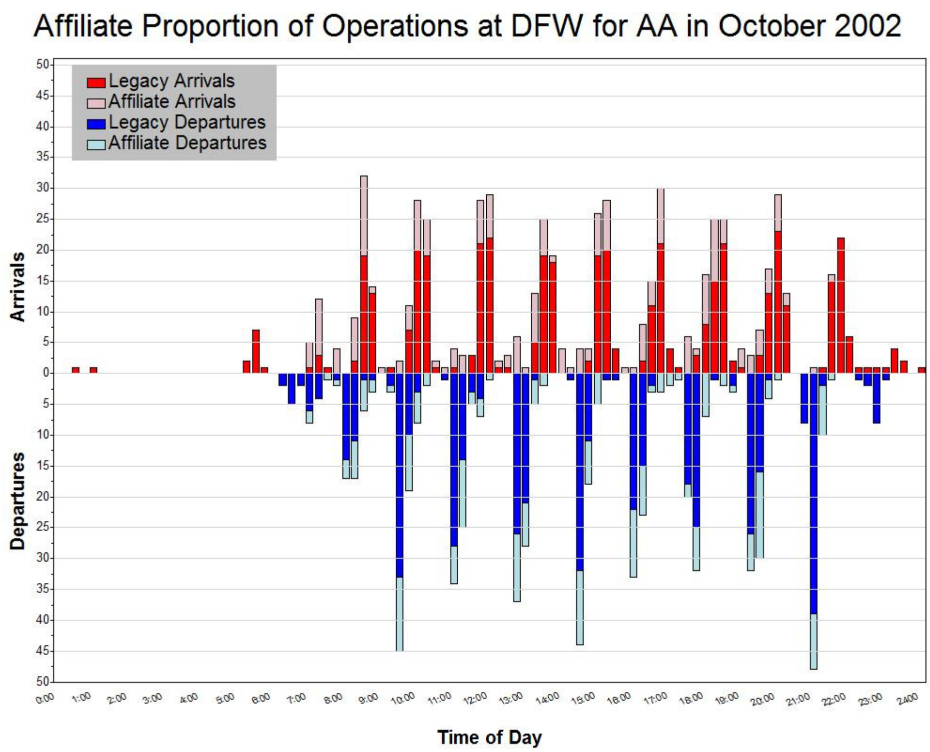

Figure 4.18 Affiliate airlines in the peaked schedule of American at DFW.

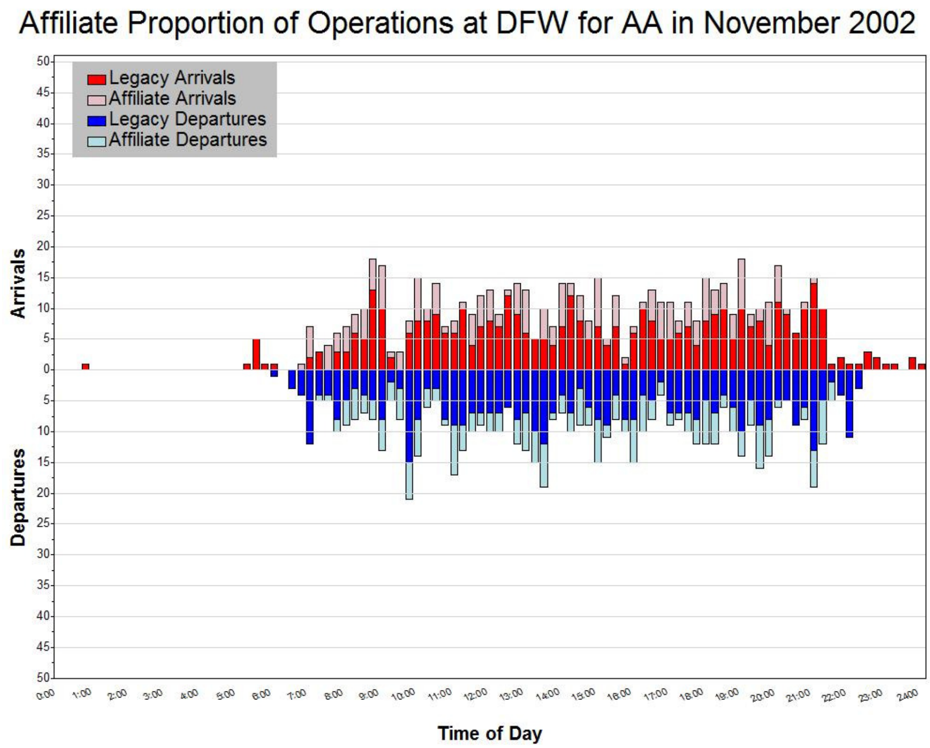

Figure 4.19 Affiliate airlines in the depeaked schedule of American at DFW.

4.3.2.3 Peak/Depeak Measures

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 141.7, which drops to 88.4 in the depeaked schedule. The change for the departures is even greater, dropping from 176.4 to 86.8.

The peak and depeak percentage measures show a drop in the peaked nature of the schedule. In the peaked schedule, 83% of flights occur within the banks, highlighted in Figure 4.20. In the depeaked schedule, 53% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.21. This drop, combined with the changes in the coefficient of variation, both indicate a quantitative reduction in the peak level of the schedule.

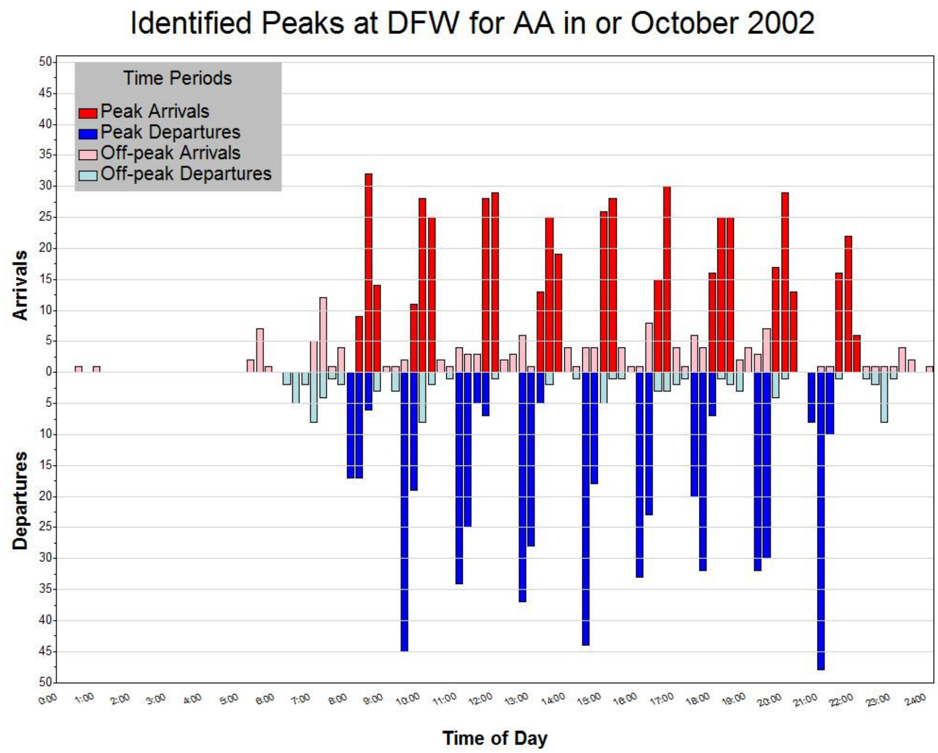

Figure 4.20 Identified banks in the peaked American schedule at DFW.

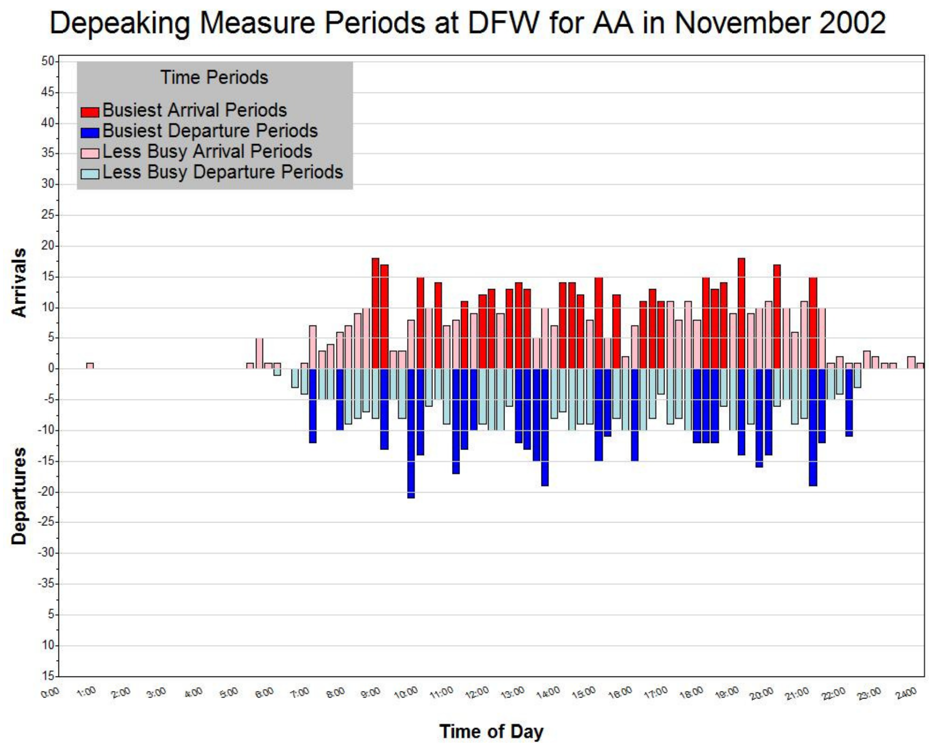

Figure 4.21 Busiest *n* 15-minute periods in the depeaked American schedule at DFW.

4.3.2.4 Connections

The number of connections decreased greatly from the peaked to the depeaked schedule. The peak schedule has 35,513 potential connections from each arriving to departing flights within the MCT and MxCT for the given arriving flight. This value decreases to 26,743 in the depeaked schedule. The average number of connections per arriving flight also decreases considerably. The number of connections per arriving flights operated is 55.9 in the peaked schedule, but drops to 43.1 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections increased slightly from 14 in the peaked schedule to 15 in the depeaked schedule. In the peaked schedule, 14 connections existed from LGA to LAX, from ORD to Shreveport (SHV), and from Tulsa (TUL) to ORD. In the depeaked schedule, 15 connections existed daily between TUL to ORD.

4.3.2.5 Validation of Supply-Demand Time Decision

The schedule on the peaked date (or depeaked date) supply data was verified as being similar to the schedule used in the peaked quarter (or depeaked quarter) for the analysis.

Table 4.13 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.14 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.13 Supply Measures Over Time for American's Peaked Schedule at DFW

Measure	7/16/02	7/30/02	8/13/02	8/27/02	9/10/02	9/24/02	10/1/02	10/8/02	10/22/02
Max. # of flight arrs. or deps. in 15-min. interval	49	49	47	47	47	47	47	47	48
Max. # of flight operations in 15-min. interval	51	53	50	50	51	50	49	49	49
Number of flights flown into or out of hub	1285	1281	1271	1214	1165	1282	1258	1267	1270
Total avail. seat mi. flown into or out of hub (000s)	136692	136674	136514	131295	118995	134725	130741	133024	131768
Number of destinations served from hub	109	108	109	109	108	108	106	106	105
Coefficient of variation in # of arr./dep. flights	142.5/176.2	142.0/176.8	139.2/175.3	138.8/174.5	150.9/178.6	140.6/174.2	140.4/177.8	140.4/176.9	141.7/176.4
Percentage of flights served by affiliate airline(s)	30.5%	30.4%	31.1%	31.4%	34.9%	32.8%	32.9%	32.3%	32.5%
Percentage of flights served in peak period	83.4%	82.8%	81.0%	77.4%	81.9%	78.3%	78.1%	78.9%	82.7%
Number of potential connections	36477	36181	35303	32485	32173	36083	34773	35198	35513
Average connections per arriving flight	56.8	56.7	55.7	53.6	55.1	56.5	55.5	55.8	55.9
Maximum potential connections serving a market	15	15	14	14	13	15	15	15	14

Table 4.14 Supply Measures Over Time for American's Depeaked Schedule at DFW

Measure	11/5/02	11/19/02	12/3/02	12/17/02	1/7/03	1/28/03	2/11/03	3/4/03	3/25/03
Max. # of flight arrs. or deps. in 15-min. interval	21	21	20	20	22	22	20	19	20
Max. # of flight operations in 15-min. interval	34	35	36	34	38	37	37	36	37
Number of flights flown into or out of hub	1245	1261	1240	1267	1226	1201	1217	1214	1219
Total avail. seat mi. flown into or out of hub (000s)	127661	128899	129054	132516	123736	121043	122889	124782	125768
Number of destinations served from hub	105	105	106	109	108	107	107	107	107
Coefficient of variation in # of arr./dep. flights	88.4/86.8	88.8/86.4	87.6/88.7	85.1/86.0	87.5/85.7	88.2/85.7	88.3/86.2	87.6/87.6	86.2/87.4
Percentage of flights served by affiliate airline(s)	33.6%	33.8%	32.3%	32.8%	33.7%	33.0%	32.9%	32.1%	31.8%
Percentage of flights served in peak period	53.5%	53.6%	53.7%	52.2%	53.2%	53.3%	53.6%	53.5%	53.1%
Number of potential connections	26743	27275	26357	27509	25879	24818	25435	25532	25424
Average connections per arriving flight	43.1	43.4	42.6	43.5	42.5	41.4	42.0	42.2	41.8
Maximum potential connections serving a market	15	16	14	14	13	11	14	11	14

4.3.3 Demand Results

The changes in demand and related parameters before and after the depeaking of DFW are shown in Table 4.15. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Around 43 thousand average daily passengers traveled on American through DFW in the peaked schedule during the peaked quarter, and this decreased to about 38 thousand during the depeaked quarter. Overall the revenue decreased from the third quarter of 2001 to the first quarter of 2002, from $8.4 million to $7.8 million. Most important though is that RASM decreased over this period for flights flying through DFW: from 6.35 cents per mile to 6.13 cents per mile.

Table 4.15 Summary of Demand and Revenue Changes for American at DFW

Measure	Peaked	Depeaked
Total passengers	43,142	37,608
Revenue ($)	8,366,379	7,831,576
Revenue per available seat mile (RASM) (cents per mile)	6.35	6.13
Percent connecting passengers	46.6%	47.3%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was only 30, compared to the 75 markets that saw decreases. RASM increased in 38 markets, and decreased in 67.

Across the spokes of DFW there was an average increase in connecting traffic from the spoke airports. 46.6% of passengers at DFW on American were connecting passengers under the peaked schedule and 47.3% were connecting passengers under the depeaked schedule. At the spoke level, 61 spoke routes had an increase in the percentage of passengers on flights between DFW and the spoke that made connections. Only 44 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and DFW. It is clear that connecting traffic benefited from depeaking due to American's depeaking.

The revenue measures were compared to what was occurring for the airline during the same time period, as well as across the industry. From the peaked to the depeaked quarter, there was a 0.22 cents per mile decrease in RASM. Over this same time period, the entire American network saw only a 0.06 cents per mile decrease in RASM, including American's other depeaked hub at ORD. The industry as a whole saw a 0.18 cents per mile increase between these two quarters, and thus American's RASM at DFW lagged behind the industry by 0.40 cents per mile. It is thus possible that the depeaking of ORD could have influenced slower revenue growth.

4.3.4 On-Time Results

The operational effects of depeaking are shown in Table 4.16 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was an improvement in operations. There was an overall decrease in average delay per aircraft, with less delayed aircraft overall as a percentage of all aircraft. Delay decreased for both departures and arrivals over this period, and taxi-out and taxi-in times saw reductions.

Table 4.16 Summary of Operational Changes for American at DFW

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	6.8	4.9
Average departure delay for delayed aircraft (minutes)	47.6	39.3
Percentage of delayed departing aircraft	12.2%	10%
Total delay for delayed departing aircraft (minutes)	111,913	70,177
Average taxi-out time (minutes)	19.6	15.7
Average arrival delay for all aircraft (minutes)*	7.5	5.3
Average arrival delay for delayed aircraft (minutes)	47.4	47.5
Percentage of delayed arriving aircraft	12.9%	8.9%
Total delay for delayed arriving aircraft (minutes)	117,262	75,966
Average taxi-in time (minutes)	11.8	10.6

***Early arriving and early departing aircraft were assigned zero delay**

These operational improvements were not seen across American's system overall nor at the industry level, indicating that American's operations at DFW may have seen improvement due to depeaking. Although the departure delay for delayed aircraft decreased for American at DFW, it increased from 51.1 to 51.9 minutes for the rest of the network and from 45.2 to 46.5 minutes industry-wide. The percentage of delayed departures was higher at DFW for American than the rest of American's network, but while DFW saw an improvement by 2.2 percentage points, American as a whole got worse by a tenth of a percentage point. The industry improved, but at a slower rate than DFW.

American's aircraft at DFW saw nearly the same amount of delay from the peaked to the depeaked schedule. Meanwhile, over the same period, the rest of American's network had an increase in arrival delay by almost 2.5 minutes, and industry saw an increase by 1.2 minutes. A similar situation occurred with the percent of arriving aircraft which were delayed. American's DFW depeaked operations were 4 percentage points better than the peaked operations, which surpassed the improvements seen network-wide, 0.7 percentage points, and industry-wide, 0.8 percentage points.

American's depeaking of DFW caused an overall improvement in operational delay from the peaked to the depeaked period, even when compared to the normalizing measures. The differences in the measures from the peaked to depeaked schedule indicated a faster rate of improvement at DFW than the rest of American's network and the industry. Thus, there is reason to believe depeaking played some role in improving operations at DFW.

4.3.5 Dual-Hub: Delta Air Lines' Response

The dual-hub status of DFW lasted until Delta dehubbed in December 2005, but during American's 2002 depeaking, Delta still was operating a hub out of DFW. Unlike the near equal size hubbing operations at ORD for American and United, Delta's hubbing operations at DFW were considerably smaller than American's.

The initial schedule Delta was operating at ORD was concentrated into several peaks, with very little traffic in between, as seen in Figure 4.22. The figure has the same scale as American's schedule reproduction figures, to be able to visually compare the differences in the schedules. Delta's schedule had five arrival and six departure peaks. The schedule's peak measurements indicate a peaked schedule, with a peak percentage of 81.3% and coefficients of variation for arrivals and departures both of 201.3. Based on these values, Delta's schedule at the time before depeaking was very concentrated into banks, much more than American's, but at a smaller scale.

The Delta measurements for the peaked date, October 22, 2002, as well as the preceding months before depeaking and the months after American depeaked are shown in Table 4.17. Delta had a fairly consistent schedule in terms of peak measurements and connections per arriving flights. Like the ORD case, there is a measurement of the percentage of flights in Delta's schedule which were flown during the American banks.

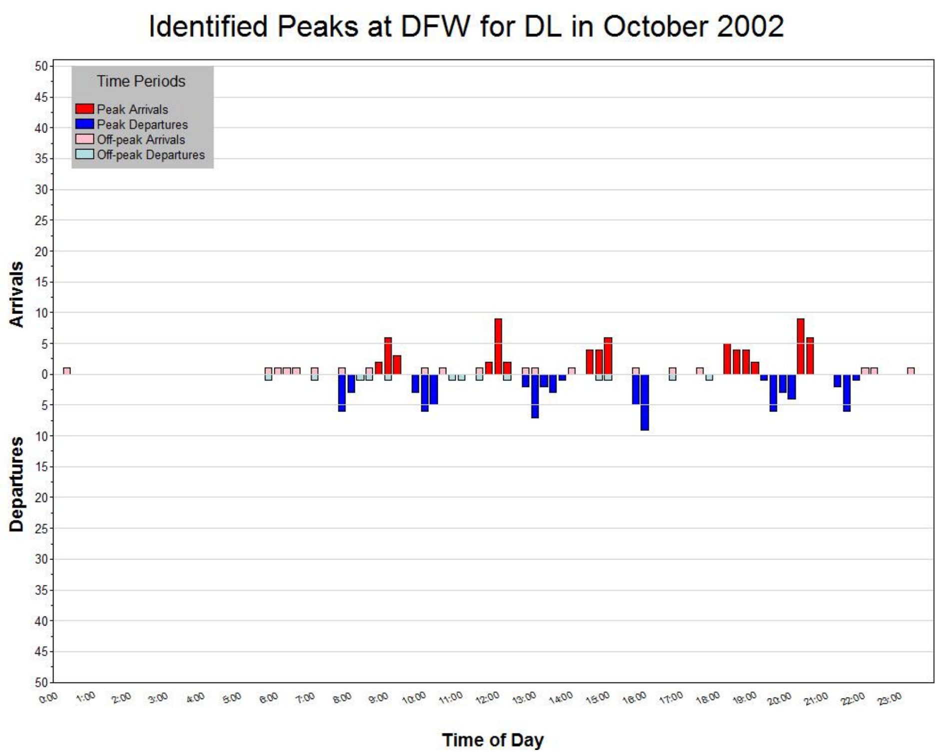

Figure 4.22 Identified banks in the Delta schedule at DFW

Table 4.17 Summary of Supply Changes for Delta at DFW

Measure	Jul. 23 2002	Sep. 24 2002	Oct. 22 2002	Nov. 5 2002	Dec. 10 2002	Feb. 11 2003
Coefficient of variation in # of arr.	203.9	201.3	201.3	201.3	201.3	202.9
Coefficient of variation in # of dep.	198.5	203.3	201.3	201.3	221.8	226.1
Percentage of flights in peak period	83.0%	81.0%	81.3%	81.3%	83.3%	84.5%
Percentage of flights in AA banks	42.7%	47.1%	46.6%	46.6%	43.5%	44.1%
Number of potential connections	881	869	898	899	859	819
Average connections per arriving flight	10.1	10.0	10.3	10.3	9.9	10.1
Max. potential connections in a market	5	5	5	5	4	3

Delta's schedule, after American's depeaking, saw practically no changes as compared to the peaked schedules. Delta maintained a similar level of peaking, and a similar level of flights within the schedule where American's banks were operating. The schedule for Delta three months after American's depeaking is shown in Figure 4.23. Potential connections also stayed consistent.

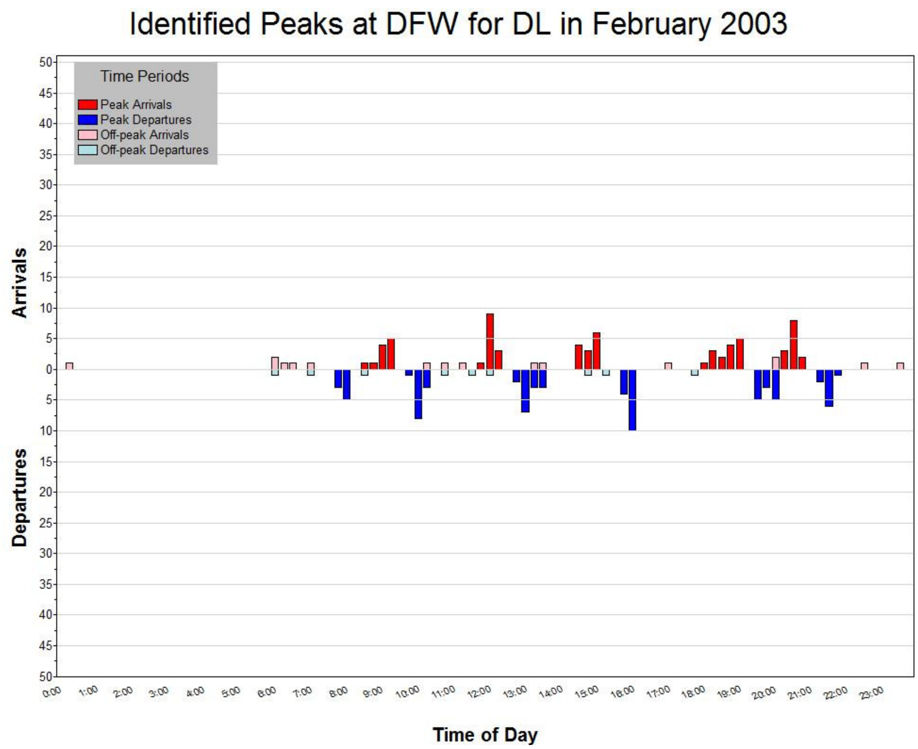

Figure 4.23 Identified banks in the Delta schedule at DFW, 3 months after.

Delta's operations in relation to American's banks are shown in Figures 4.24 and 4.25. As noted before, there was no noticeable shift into or out of American's banks or bank shadows.

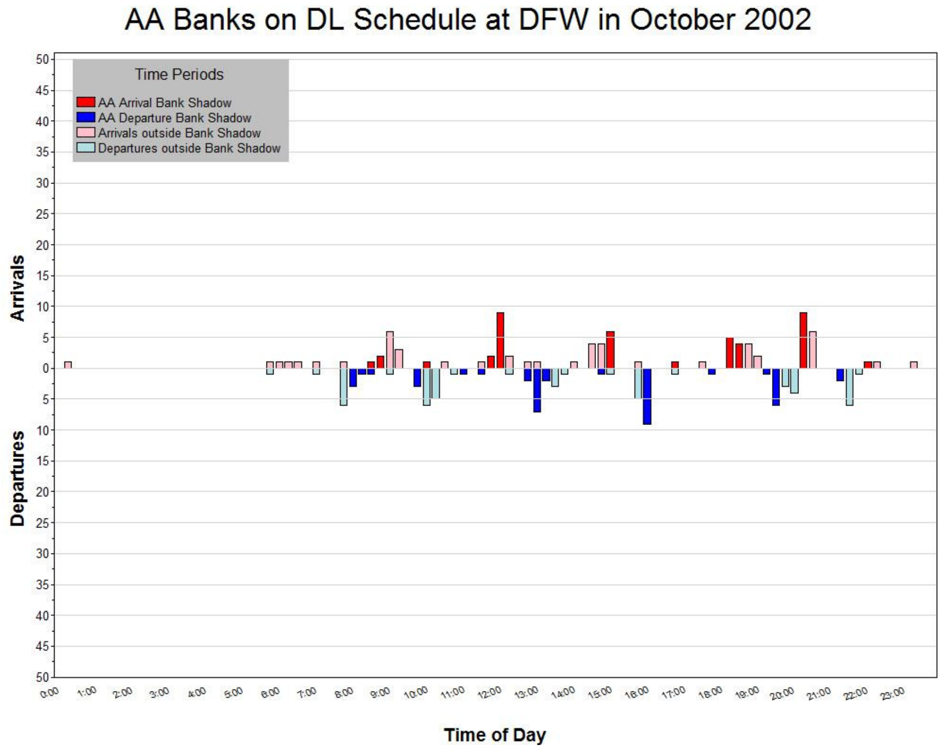

Figure 4.24 American's banks overlaid on Delta's peaked date schedule.

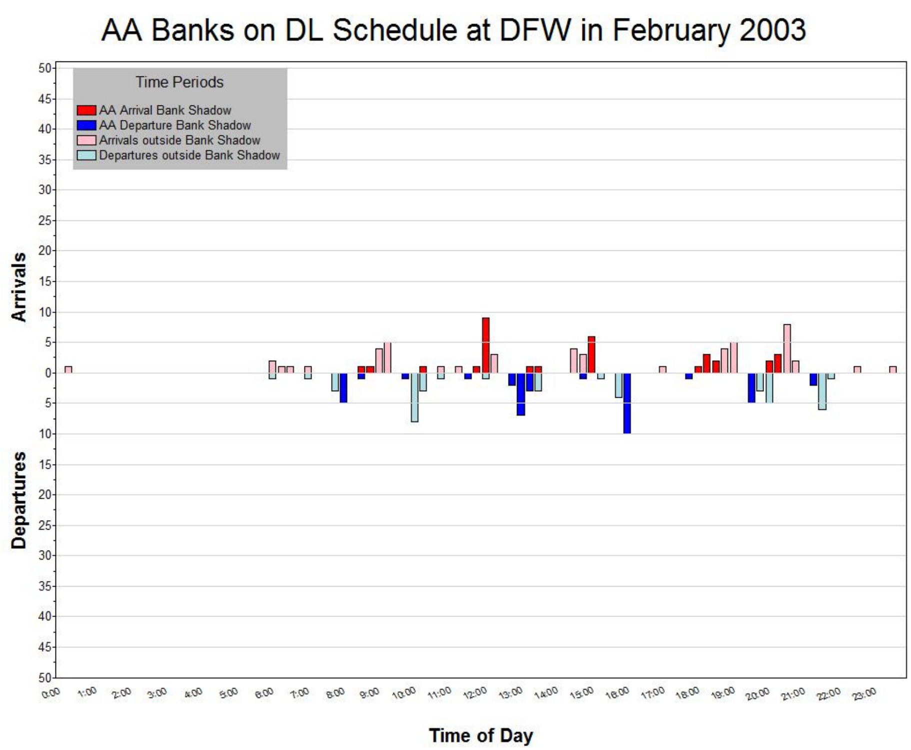

Figure 4.25 American's banks overlaid on Delta's 3-month-later schedule.

The evidence supports that American's primary competitor at DFW, Delta, did not alter its schedule in response to American's depeaking.

4.3.6 Predicting Changes in Supply

Analysis was performed on the DFW case study to assess the decision-making process American used in determining how to depeak their schedule using a regression model. The analysis at the spoke level makes use of data that is summarized for all spoke airports destination that were served by American during the depeaking period.

Table 4.18 Regression Model Results for Change in Flights at DFW

Variable	Coefficient	t-stat	p > |t|
Intercept	1.229	2.20	0.030
Connecting Passengers	0.0012	2.63	0.010
Log of # of flights in peaked schedule	-0.6690	-2.88	0.005
RASM	7.2704	2.39	0.019
AA is the largest carrier in the market*	-0.9299	-1.91	0.059

***Indicator variable (1 = yes)**

The dependent variable, defined as the change in the number of flights on the route between DFW and a spoke, was found to be well predicted by the variables listed in Table 4.18. The variables include the number of connecting passengers, the log of the number of flights to the spoke in the peaked schedule, the RASM on the route, and whether American had the most flights on the route between DFW and the spoke. Three of these variables are significant at the 95% confidence level, while the largest carrier indicator variable is significant at the 90% confidence level. The adjusted R^2 for the model is 0.095.

This model did not pass the normality assumption, but passed the linearity and homoscedasticity assumptions. The normal probability plot in Figure 4.26 shows a bowed portion in the plot, indicating that there could be excessive skewness. A count model was used to verify the directionality of the results held from the regression model.

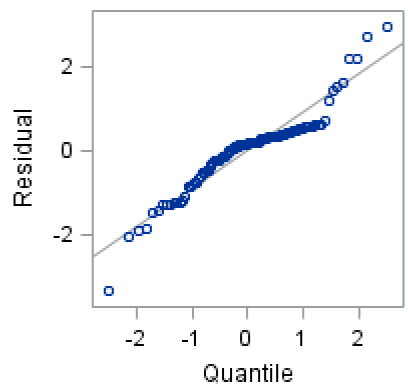

Figure 4.26 Normal probability plot for DFW case. The bowed shape indicates excessive skewness.

In the count model, it was found that all the variables in the regression model have the same direction. This gave assurance that the regression model was performing as it should, and thus the results were suitable for interpretation.

American Airlines' strategy for depeaking DFW, as determined by the results of the regression model showed a focus on high-value connections. The DFW hub is a critical mid-continental hub along with ORD, and thus connections from spokes to major coastal destinations are critical. American increased frequency to routes which had high levels of connecting passengers on routes where there was a lower frequency. Cities such as Cincinnati (CVG), Greensboro (GSO), and Greenville/Spartanburg (GSP) are examples. Service was cut to low connecting passenger cities that had high frequency, such as Shreveport (SHV), Memphis (MEM), San Francisco (SFO), Minneapolis (MSP), and Denver (DEN). Frequency was also added to routes that had high RASM including Lubbock (LBB), San Antonio (SAT), and Amarillo (AMA), even though frequency was already high to these spokes. Markets in which American was not the biggest airline, such as CVG and ATL, were targeted by American, while all spoke cities which lost frequency were destinations in which American dominated. In these markets, low RASM was common, including Honolulu (HNL), Grand Rapids (GRR), Little Rock (LIT), Newark (EWR), and Columbus (CMH).

In summary, American's strategy at DFW can be described as pulling out of high frequency markets where American already dominated but RASM was low. These inefficient markets did not prove to be worth the number of flights American was giving them. Instead, American focused on maintaining valuable hub connections where RASM was higher, and going after markets where they were not the largest airline.

4.3.7 Assessing Depeaking and Effects

The supply and demand results over the depeaking period show changes that likely could have been due to depeaking. To get a better understanding as to whether the changes that occurred were likely due to depeaking as opposed to being a typical change for that time of the year, year-over-year measures were calculated. The percentage change between the peaked and depeaked dates is calculated, and also for the year before and year after on similar dates.

For the DFW case, it is evident that much of the supply changes were due to depeaking. Table 4.19 shows schedule measures and reports a percentage change associated with each year. In the case of American, depeaking occurred in 2002. October 22, 2002 was used as the representative Tuesday peaked schedule and November 5, 2002 was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2002 shows the change in schedule measures between these two dates. The process is repeated for two dates each in the years 2001 and 2003, using representative Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2001 change is between two peaked schedules and the 2003 change is between two depeaked schedules. Thus only the 2002 change is for changes that occurred between different schedule types.

Table 4.19 Supply Year-Over-Year Changes for American at DFW

Measure	2001				2002				2003			
	10/23	11/6	Δ	%	10/22	11/5	Δ	%	10/21	11/4	Δ	%
Max. number of flight arrs. or deps. in a 15-minute interval	44	44	0	0%	48	21	**-27**	**-56%**	21	25	4	19%
Max. number of flight operations in a 15-minute interval	45	46	1	2%	49	34	**-15**	**-31%**	37	40	3	8%
Number of flights flown into or out of hub	1127	1145	18	2%	1,270	1,245	**-25**	**-2%**	1219	1277	58	5%
Total available seat miles flown into or out of hub (000s)	121694	119368	-2326	-2%	131768	127661	-4107	-3%	126692	135855	9163	7%
Number of destinations served from hub	107	106	-1	-1%	105	105	0	0%	104	105	1	1%
Coefficient of variation in number of arrivals	156.5	155.6	-0.9	-1%	141.7	88.4	**-53.3**	**-38%**	86.7	89.6	2.9	3%
Coefficient of variation in number of departures	177.8	186.7	8.9	5%	176.4	86.8	**-89.6**	**-51%**	88.2	93.9	5.7	6%
Percentage of flights served by affiliate airline(s)	33.9%	34.2%	0.3%	1%	32.5%	33.6%	1.1%	3%	32.7%	29.8%	-2.9%	-9%
Percentage of flights served in peak period	83.1%	85.2%	2.1%	3%	82.7%	53.5%	**-29.2%**	**-35%**	53.6%	55.5%	1.9%	4%
Number of potential connections	29871	31771	1900	6%	35513	26743	**-8770**	**-25%**	25423	28317	2894	11%
Average connections per arriving flight	52.9	55.5	2.7	5%	55.9	43.1	**-12.8**	**-23%**	41.8	44.4	2.6	6%
Maximum potential connections serving a market	12	14	2	17%	14	15	1	7%	15	14	-1	-7%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages represent changes most evident by American's depeaking. From the year-over-year data, it is evident that depeaking involved a reduction in the number of flights flown in a given period and the creation of a more even distribution of flights (as evidenced by the reduction in the coefficients of variation and reduction in peak percentage). Depeaking allowed American to decrease the number of flights flown in the schedule. The consequence of depeaking the tight banks was a big loss of potential connections, both gross and per arriving flight.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases, because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus RASM is used in comparison still with the RASM of the airline network and for the industry.

One measurement which is useful in terms of demand in measuring it year-over-year is the percentage of connecting passengers. Surprisingly, despite the decrease in potential connections in the schedule, the increase in the percent of connecting passengers in 2002 is similar to the percentage increases in 2001 and 2003 – all between one and three percent. Depeaking did not shift the types of passengers flying through DFW.

The change in RASM for American's DFW schedule lagged behind the rest of American and industry in the depeaking year. This was also the case in the year prior, but in the year after the RASM change was on par with that occurring elsewhere. As seen in

Table 4.20, the drop in RASM in the depeaking year may not be entirely tied to the depeaking of the schedule, since it lagged behind in other years as well.

Table 4.20 RASM Year-Over-Year Changes for American at DFW

Measure	2001/2				2002/3				2003/4			
	Q3	Q1	Δ	%	Q3	Q1	Δ	%	Q3	Q1	Δ	%
RASM for Depeaked Airport	6.94	6.34	-0.30	-4%	6.35	6.13	-0.22	-3%	6.65	7.02	0.37	6%
RASM for Airline Network	7.71	9.50	1.79	23%	8.36	8.54	0.18	2%	6.64	7.25	0.61	9%
RASM for Industry	9.72	10.00	0.28	3%	6.33	6.27	-0.06	-1%	9.01	9.32	0.31	3%

American saw an improvement in all operational measures in the depeaking year, but when compared year-over-year the arriving aircraft measures do not show a notable change from the surrounding years, as seen in Table 4.21. The average arrival delay in the depeaking year improved compared to the rest of American's network and the industry, but this improvement also occurred in the year after to the same degree. The percentage of delayed arriving aircraft saw an improvement in the depeaking year, but a similar improvement occurred in the year before. In terms of departure delay, there was an improvement in the depeaking year in relation to the comparative measures, and this improvement was not seen in the years before and after where departure delay worsened comparatively. For the percentage of delayed aircraft, the improvement in the depeaking year was greater when compared to the network and industry in the depeaking year than in the year before and year after.

Table 4.21 Operations Year-Over-Year Changes for American at DFW

Measure	2001				2002				2003			
	Oct	Nov	Δ	%	Oct	Nov	Δ	%	Oct	Nov	Δ	%
Dep. Delay Depeaked Airport	39.4	43.1	3.7	9%	47.6	39.3	-8.3	-17%	37.5	45	7.5	20%
Dep. Delay Airline Network	43.4	47.6	4.2	10%	51.1	51.9	0.8	2%	49.2	53.1	3.9	8%
Dep. Delay Industry	43.2	44.4	1.2	3%	45.2	46.5	1.3	3%	48.4	50.8	2.4	5%
% Delayed Dep. Depeaked Airport	21.9	17.3	-4.6	-21%	12.2	10	-2.2	-18%	9	14.5	5.5	61%
% Delayed Dep. Airline Network	17.1	13.4	-3.7	-22%	9.3	9.4	0.1	1%	8.2	16.4	8.2	100%
% Delayed Dep. Industry	13.5	12.5	-1	-7%	11.4	10.8	-0.6	-5%	9.7	13.8	4.1	42%
Arr. Delay Depeaked Airport	45.8	48.6	2.8	6%	47.4	47.5	0.1	0%	51.2	50.7	-0.5	-1%
Arr. Delay Airline Network	45.1	44.2	-0.9	-2%	44.8	47.2	2.4	5%	43.8	51.8	8	18%
Arr. Delay Industry	43.6	42.8	-0.8	-2%	41.7	42.9	1.2	3%	43.9	47.5	3.6	8%
% Delayed Arr. Depeaked Airport	14.9	12.6	-2.3	-15%	12.9	8.9	-4	-31%	7.5	12.5	5	67%
% Delayed Arr. Airline Network	16.8	16.3	-0.5	-3%	13.1	12.4	-0.7	-5%	11.2	22.1	10.9	97%
% Delayed Arr. Industry	13.8	14.2	0.4	3%	14.8	14	-0.8	-5%	12.7	18.5	5.8	46%

American appears to have had considerable changes from depeaking, particularly in areas that allowed the airline to cut cost through the removal of gates and staff. This came at a cost of lost potential connections, but the drop in RASM was not necessarily attached to the depeaking because the year prior was also an underperforming year in relation to the comparison measures. Operationally, when compared year-over-year, American saw an improvement for departure delay, but arrival delay did not see a notable improvement.

4.3.8 Summary

DFW was the second airport American depeaked in 2002. The supply changes were substantial, as the airline dropped its level of operations per 15-minute period by a considerable degree. The result was a flat schedule that allowed the airline to cut costs through the use of less gates and a reduction in staff and equipment. The airline also removed flights throughout the schedule. Many flights were removed in markets in which American dominated in market share, operated a high number of flights, but had a low RASM. American's depeaking strategy with respect to DFW was thus distinct from its ORD strategy and focused more on cutting low RASM flights versus adding connections to competitor hubs. Despite these moves by American, DFW's other hub operator Delta did not make a noteworthy change in its schedule in response.

The drop in supply at DFW came at the expense of potential connections. Without the busy banks in their schedule, it was not possible for American to maintain the high connectivity which they had been operating with. Despite the loss in connections, though, American did not have slower revenue growth in 2002 more so than in other years when comparing to the rest of American and the industry. It did, however, see a considerable improvement in operations, reducing delay and the percentage of delayed aircraft in relation to comparable measures.

4.4 Delta Air Lines at Atlanta (ATL)

In January 2005 Delta Air Lines removed ten arrival and departure peaks from their schedule in Atlanta (ATL). Delta's depeaking happened about a year after the SARS crisis, which affected a large portion of international travel for the industry. It also occurred amongst a series of bankruptcies during the end of 2004 through 2005, including Delta's in September 2005.

The airline in 2005 was implementing a number of cost-cutting measures, including depeaking, but was unable to avoid bankruptcy. Delta had expanded its Atlanta operations and closed its hub at DFW in 2005, to focus its energy at its largest hub operation. The dehubbing of DFW actually took place on the same date of ATL's depeaking. Delta would later reduce its operations in Cincinnati as well. In order to help avoid bankruptcy, the pilots of Delta took a pay cut. At the end of the summer of 2005, Delta sold its connection carrier to SkyWest Airlines. Despite all these changes, Delta was unable to avoid bankruptcy.

This case has the aspect that ATL serves as a hub airport for two major airlines. AirTran Airways also has a major hub operation at ATL, and thus this case is useful to assess how a low-cost competitor at a dual-hub responds to depeaking. AirTran does not have a banked schedule. Included in this section is a description of AirTran's changes after Delta depeaked.

Because ATL was depeaked on the same day that DFW was dehubbed, this case is carefully inspected when analyzing changes in the network. Any Delta markets which had had connections at DFW before it was dehubbed are excluded from the network analysis.

4.4.1 Data Periods Used and Input Parameters

Delta Air Lines depeaked ATL on Monday January 31, 2005. The date used to represent the peak schedule is Tuesday January 25, 2005. The date used to represent the depeaked schedule is Tuesday February 8, 2005.

Delta depeaked ATL in the middle of the first quarter of 2005, so the representative peaked quarter is the fourth quarter of 2004. The representative depeaked quarter is the second quarter of 2005. The peaked month used for operational measures is January 2005; the depeaked month is February 2005.

For creating year-over-year measures, January 27, 2004 and February 10, 2004 were used as the supply comparison dates the year prior. January 24, 2006 and February 7, 2006 were used as the supply comparison dates for the year after depeaking. The fourth quarter of 2003 and the second quarter of 2004 are used as the year prior demand comparison quarters, and the fourth quarter of 2005 and the second quarter of 2006 are used for the year after. January 2004 and February 2004 are used for the year prior operational comparison months, and January 2006 and February 2006 are used for the year after.

The distribution of actual connection times made at ATL for passengers flying on Delta itineraries is shown in Figure 4.27. This distribution is from itineraries flown in June 2010. At that time, ATL was operating under a peaked schedule with twelve daily banks. The 5^{th} and 75^{th} percentiles, indicating the MCT and MxCT are denoted in the figure. For this case, the MCT is 39 minutes and the MxCT is 93 minutes.

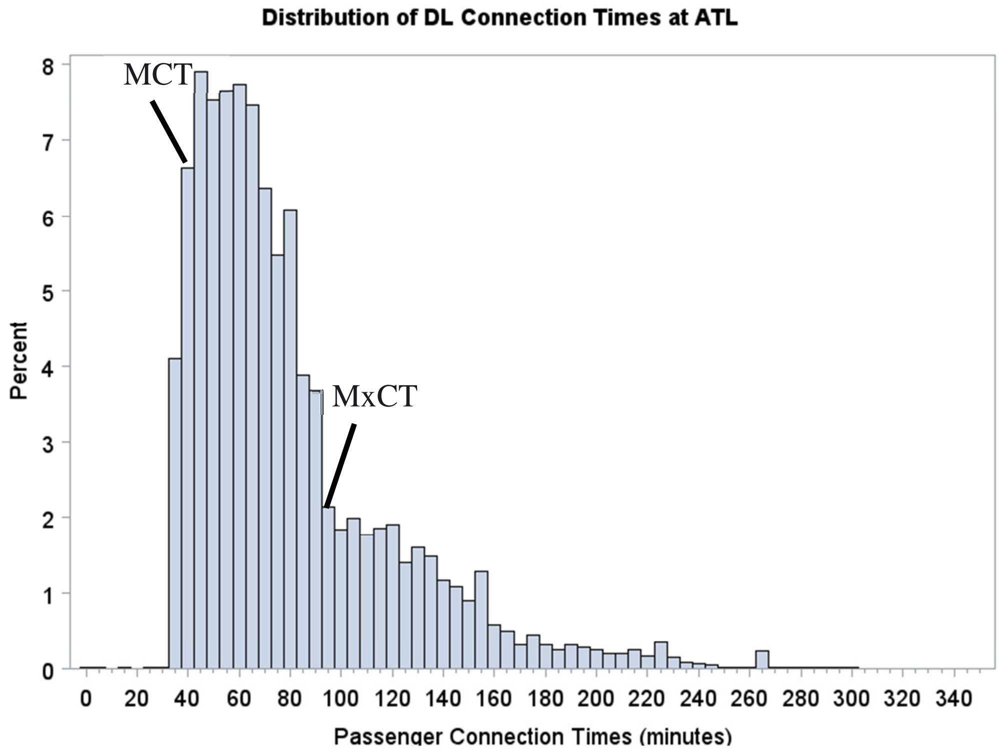

Figure 4.27 Connection time distribution for DL at ATL. MCT and MxCT are denoted.

4.4.2 Supply Results

The following section describes the supply-side results for Delta's depeaking of ATL, which includes data derived from the On-Time database. Table 4.22 summarizes the supply measures representing peaked and depeaked schedules that are discussed in this section.

Table 4.22 Summary of Supply Changes for Delta at ATL

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	33	20
Max. number of flight operations in a 15-minute interval	54	38
Number of flights flown into or out of hub	1742	1856
Total available seat miles flown into or out of hub	160,342,865	172,866,078
Number of destinations served from hub	144	146
Coefficient of variation in number of arr./dep. flights	86.6/94.5	68.9/70.6
Percentage of flights served by affiliate airline(s)	34.3%	33.8%
Percentage of flights served in peak period	71.5%	60.8%
Number of potential connections	45,866	45,425
Average connections per arriving flight	52.7	49.2
Maximum potential connections serving a market	12	13

4.4.2.1 General Supply

Delta Air Lines' reproduced peaked schedule at ATL is shown in Figure 4.28 and the reproduced depeaked schedule in Figure 4.29.

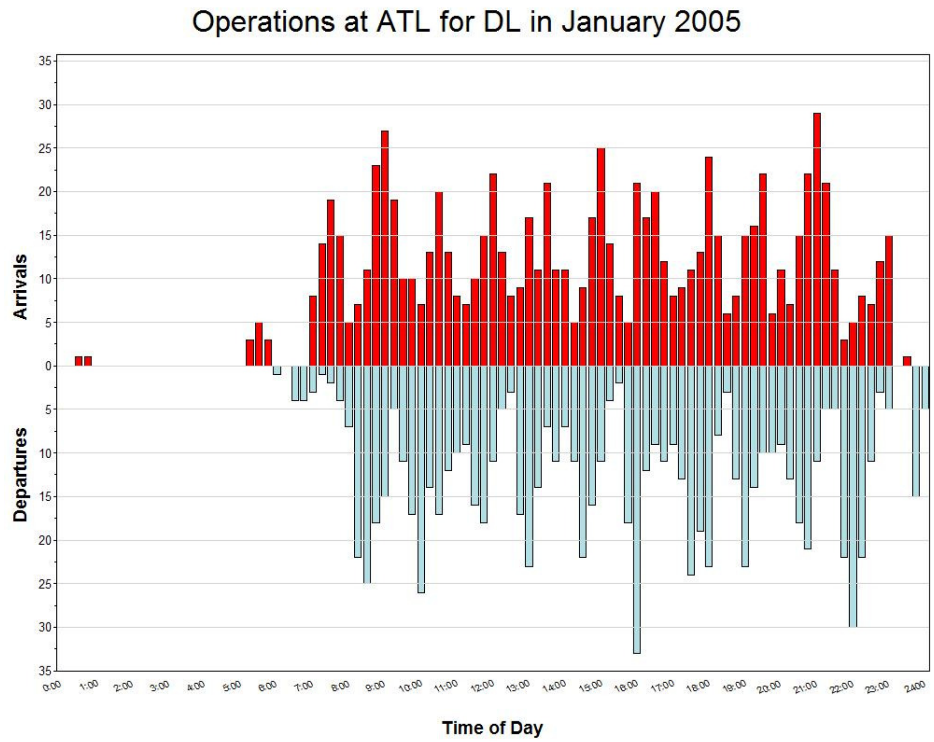

Figure 4.28 Peaked schedule for Delta at ATL.

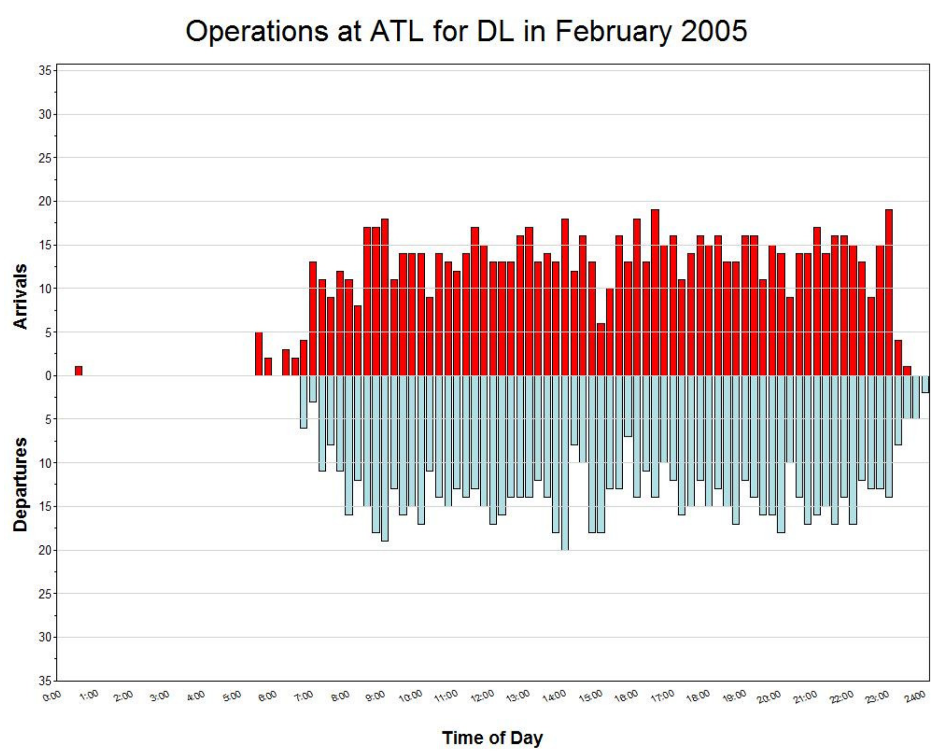

Figure 4.29 Depeaked schedule for Delta at ATL.

The maximum number of operations in a 15-minute period drops greatly from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 33, while in the depeaked schedule it is 20. The combined number of arrivals and departures in a 15-minute period in the peaked schedule is 54, while it drops to 38 in the depeaked schedule.

The distribution of Delta's operations at ATL is more spread out throughout the day, as seen in the density function plot shown in Figure 4.30. In this plot, the 15-minute periods are ranked in order of frequency. Delta operated both schedules over the same length of time in a day, encompassing the same number of 15-minute periods to operate both schedules, but the depeaked schedule has a much more even distribution of both arrivals and departures. It is clear that busiest periods are much lower in the depeaked schedule, especially for the top twenty busiest periods, but the peaked schedule drops off sharply from its busiest periods.

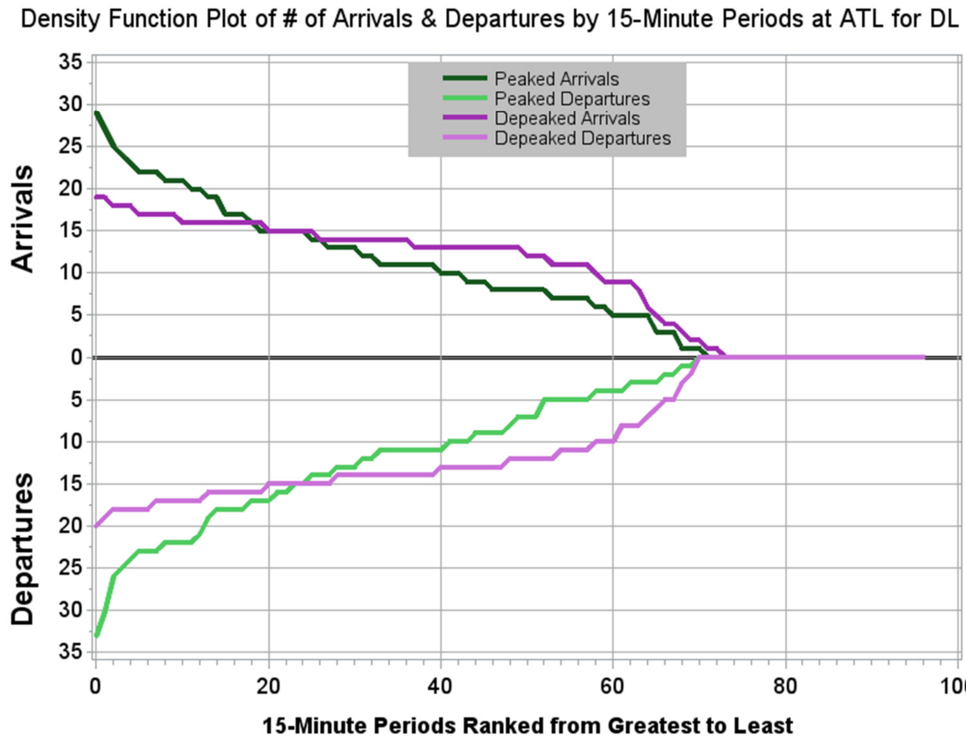

Figure 4.30 Density function plot of Delta operations at ATL.

Although the activity is more spread out in the depeaked schedule, the total number of flights increased from the peaked schedule. In the peaked daily schedule in late January of 2005 Delta operated 1,742 flights out of Atlanta, and this increased to 1,856 flights by early February. Delta also added two destinations to their network under the depeaked schedule: Kalamazoo/Battle Creek International Airport (AZO) and Long Island MacArthur Airport (ISP). Due to the increased number of flights, daily ASMs increased as well, from just over 160 million to nearly 173 million.

4.4.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines stays near constant from the peaked to the depeaked schedule. This percentage is 34.3% for the affiliate airlines in the peaked schedule and 33.8% in the depeaked schedule. This value is for affiliates that reported on-time statistics to the On-Time database, which in early 2005 primarily included Atlantic Southeast Airlines. As seen in Figure 4.31, the affiliate airlines primarily operate in the banks of the schedule, although the affiliate certainly has a large number of flights outside the banks. In the depeaked schedule shown in Figure 4.32, the affiliate airlines operate at a consistent level throughout the day.

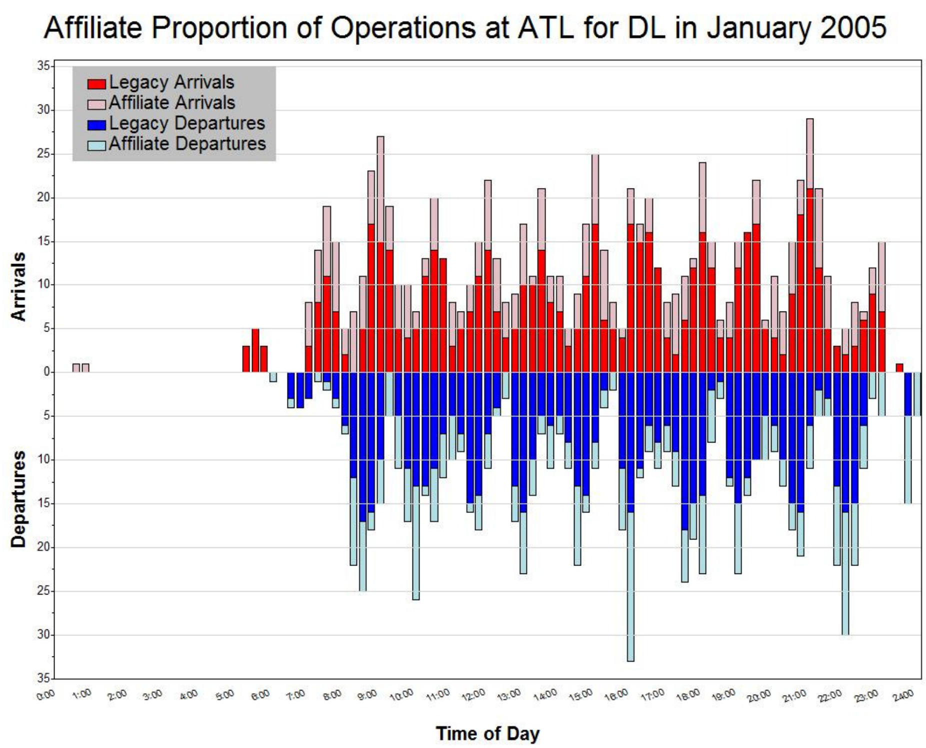

Figure 4.31 Affiliate airlines in the peaked schedule of Delta at ATL.

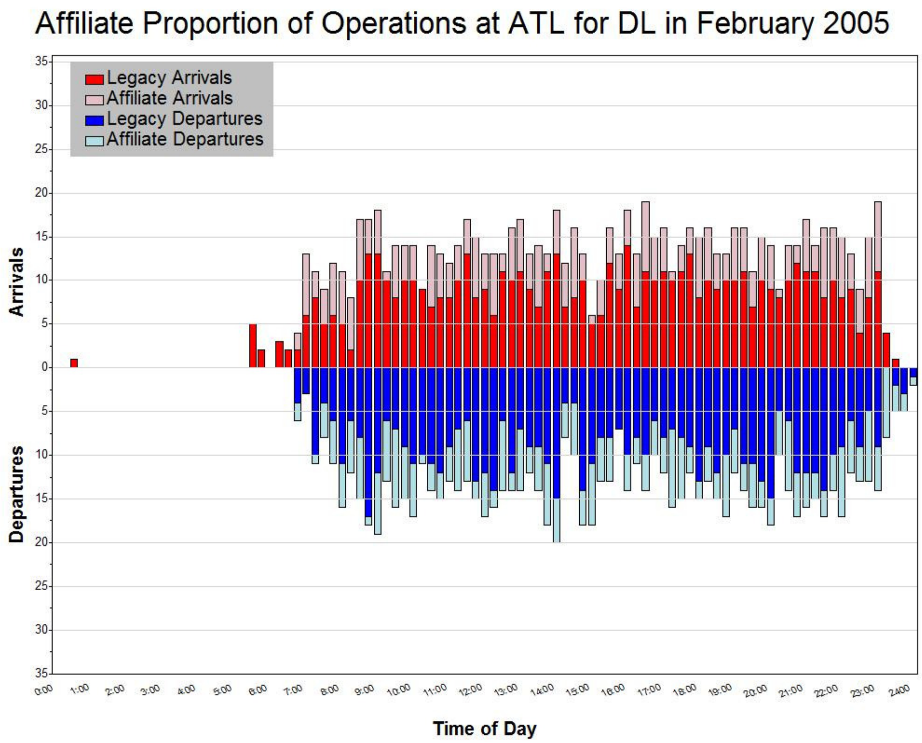

Figure 4.32 Affiliate airlines in the depeaked schedule of Delta at ATL.

4.4.2.3 Peak/Depeak Measures

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 86.6, which drops to 68.9 in the depeaked schedule. The change for the departures goes from 94.5 to 70.6.

The peak and depeak percentage measures show a drop in the peaked nature of the schedule. In the peaked schedule, 72% of flights occur within the banks, highlighted in Figure 4.33. In the depeaked schedule, 61% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.34. This drop, combined with the changes in the coefficient of variation, both indicate a quantitative reduction in the peak level of the schedule.

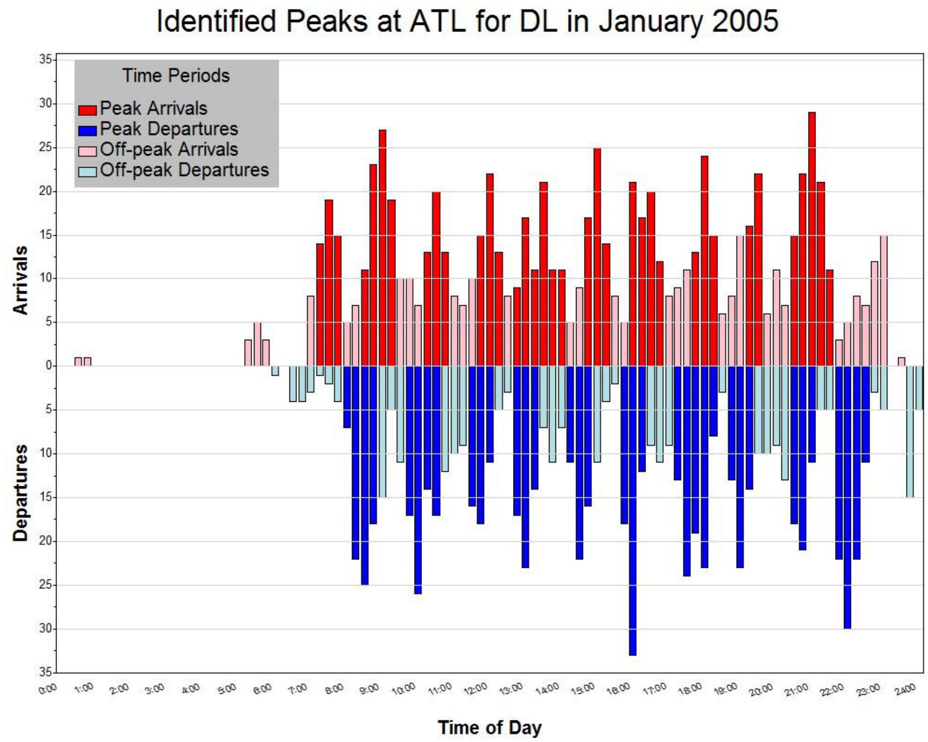

Figure 4.33 Identified banks in the peaked Delta schedule at ATL.

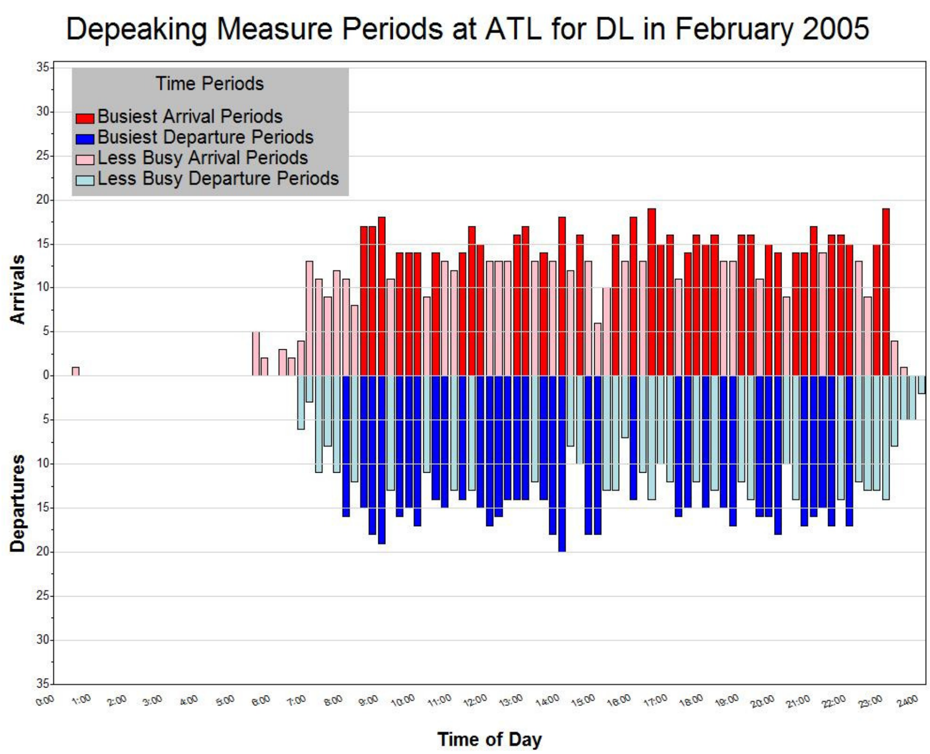

Figure 4.34 Busiest *n* 15-minute periods in the depeaked Delta schedule at ATL.

4.4.2.4 Connections

The number of connections decreases very slightly from the peaked to the depeaked schedule. The peak schedule has 45,866 potential connections from each arriving flight to departing flights within the MCT and MxCT for the given arriving flight. This value decreases to 45,425 in the depeaked schedule. This change, however, occurs even though there is an increase in the number of flights overall. The average number of connections per arriving flight operated is 52.7 in the peaked schedule, and drops to 49.2 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections increased from 12 to 13 potential connections from the peaked to the depeaked schedule. In the peaked schedule, 12 connections existed from Washington (DCA) to Tampa (TPA), EWR to TPA, and Baltimore-Washington (BWI) to TPA. In addition there were also 12 possible connections from Washington (IAD) to Washington (DCA), but this is disregarded because the two airports are in the same city. In the depeaked schedule, 13 possible connections existed daily from Boston (BOS) to LGA, but this connection to be made through ATL because of BOS and LGA are close geographically, as compared to the distance to ATL. Thus, the busiest connection for cities not in the same region is 12 connections in the depeaked schedule from DCA to DFW, LGA to Orlando (MCO), BOS to MCO, PHL to Fort Lauderdale (FLL), and PHL to MCO.

4.4.2.5 Validation of Supply-Demand Time Decision

The schedule on the peaked date (or depeaked date) was verified as being similar to the schedule used in the peaked quarter (or depeaked quarter) for the analysis. Table 4.23 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.24 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.23 Supply Measures Over Time for Delta's Peaked Schedule at ATL

Measure	10/5/04	10/19/04	11/2/04	11/16/04	11/30/04	12/14/04	12/28/04	1/11/05	1/25/05
Max. # of flight arrs. or deps. in 15-min. interval	34	34	33	33	34	33	33	33	33
Max. # of flight operations in 15-min. interval	46	45	47	44	47	55	53	54	54
Number of flights flown into or out of hub	1786	1683	1747	1755	1727	1764	1719	1741	1742
Total avail. seat mi. flown into or out of hub (000s)	154495	151224	157099	157558	158083	160880	160763	158341	160343
Number of destinations served from hub	140	141	141	142	142	143	145	144	144
Coefficient of variation in # of arr./dep. flights	92.4/95.6	95.1/97.2	91.9/97.1	91.8/97.4	92.8/97.7	89.2/94.9	88.8/94.2	87.5/94.4	86.6/94.5
Percentage of flights served by affiliate airline(s)	35.9%	35.0%	34.6%	35.2%	33.5%	34.4%	33.7%	35.3%	34.3%
Percentage of flights served in peak period	75.0%	74.2%	73.8%	74.0%	75.3%	69.0%	73.1%	70.5%	71.5%
Number of potential connections	48813	43790	47027	47423	46089	47374	45068	45977	45866
Average connections per arriving flight	54.8	52.0	53.9	54.0	53.2	53.7	52.2	53.2	52.7
Maximum potential connections serving a market	14	13	13	13	12	12	12	13	12

Table 4.24 Supply Measures Over Time for Delta's Depeaked Schedule at ATL

Measure	2/8/05	2/22/05	3/8/05	3/22/05	4/19/05	5/3/05	5/17/05	6/7/05	6/21/05
Max. # of flight arrs. or deps. in 15-min. interval	20	20	21	19	21	21	22	19	21
Max. # of flight operations in 15-min. interval	38	37	40	37	39	38	39	36	40
Number of flights flown into or out of hub	1856	1862	1788	1658	1905	1940	1920	1787	1843
Total avail. seat mi. flown into or out of hub (000s)	172866	174440	161912	165334	174132	176235	174775	168055	170172
Number of destinations served from hub	146	146	146	145	146	148	148	150	150
Coefficient of variation in # of arr./dep. flights	68.9/70.6	69.5/70.6	69.9/70.9	70.3/73.9	69.4/70.9	70.0/70.1	70.5/70.5	70.3/70.7	70.5/71.7
Percentage of flights served by affiliate airline(s)	33.8%	32.4%	34.8%	31.4%	33.7%	35.6%	35.2%	34.0%	34.5%
Percentage of flights served in peak period	60.8%	61.3%	61.1%	62.9%	61.3%	60.5%	60.9%	61.7%	61.9%
Number of potential connections	45425	45554	42321	37084	48203	50015	49138	42709	45321
Average connections per arriving flight	49.2	49.4	46.9	45.0	50.8	51.7	51.4	48.4	49.4
Maximum potential connections serving a market	13	13	12	12	13	13	13	12	12

4.4.3 Demand Results

The changes in demand and related parameters before and after the depeaking of ATL are shown in Table 4.25. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Just over 85.5 thousand average daily passengers traveled on Delta through ATL in the peaked schedule during the peaked quarter, and this increased to over 90.5 thousand during the depeaked quarter. Overall the revenue increased from the fourth quarter of 2004 to second quarter of 2005, from $14.6 million to $16.5 million. More importantly, the RASM increased as well: from 9.12 cents per mile to 9.54 cents per mile.

Table 4.25 Summary of Demand and Revenue Changes for Delta at ATL

Measure	Peaked	Depeaked
Total passengers	85,578	90,515
Revenue ($)	14,627,088	16,497,380
Revenue per available seat mile (RASM) (cents per mile)	9.12	9.54
Percent connecting passengers	54.3%	53.8%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was 121, while 25 markets saw a decrease. RASM increased in 92 markets, and decreased in 54.

Across the spokes of ATL there was an average decrease in connecting traffic from the spoke airports. 54.3% of passengers at ATL on Delta were connecting passengers under the peaked schedule, which decreased to 53.8% under the depeaked schedule. At the spoke level, 61 spoke routes had an increase in the percentage of passengers on flights between ATL and the spoke that made connections. However, 85 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and ATL. It is clear that connecting traffic reduced slightly after depeaking.

The 0.42 cents per mile increase in RASM from the peaked to the depeaked period looks successful, but must be considered in terms of the rest of the airline's revenue and the industry during this period. Over this same time period, the entire Delta network saw a 1.39 cents per mile increase in RASM, including Delta's other hubs such as Cincinnati and Salt Lake City. The industry as a whole saw a 1.92 cents per mile increase between these same two quarters. Delta's revenue growth at ATL lagged behind the rest of Delta by nearly a cent per mile, while it was behind the industry as a whole by 1.5 cents. It is thus possible that the depeaking of ATL could have influenced slower revenue growth.

4.4.4 On-Time Results

The operational effects of depeaking are shown in Table 4.26 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was a slight improvement in operations in terms of departures, while arrival delay slightly increased. Taxi-out times decreased, while taxi-in times essentially remained the same.

Table 4.26 Summary of Operational Changes for Delta at ATL

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	12.9	11.9
Average departure delay for delayed aircraft (minutes)	49.4	50.5
Percentage of delayed departing aircraft	23.1%	21.4%
Total delay for delayed departing aircraft (minutes)	286,540	275,908
Average taxi-out time (minutes)	19.2	18.5
Average arrival delay for all aircraft (minutes)*	14.9	16.2
Average arrival delay for delayed aircraft (minutes)	53.9	55.8
Percentage of delayed arriving aircraft	24.9%	26.7%
Total delay for delayed arriving aircraft (minutes)	334,424	380,031
Average taxi-in time (minutes)	11.8	11.9

***Early arriving and early departing aircraft were assigned zero delay**

Evaluating the Delta depeaking and its effect on its operations requires comparing to the rest of the airline's on-time statistics and the industry's as well. What is seen is that the operations at Delta were outperformed by the rest of Delta and the industry.

While the departure delay increased for Delta at ATL, in the rest of its network it decreased. The industry also saw a decrease during this time period. Although the percentage of departing aircraft that were delayed decreased for Delta at ATL, a reduction of 7%, this was less than the improvement across Delta, 13%, and in the industry, 19%.

Arrival delay was worse than departure delay for Delta. While at ATL both arrival and departure times and the percentage of aircraft delayed increased over the period, Delta as a whole and the industry both saw decreases in both of these measures.

Delta did not see an improvement in operations after it depeaked. Depeaking at Atlanta did not appear to provide operations benefits.

4.4.5 Dual-Hub: AirTran's Response

AirTran operates a hub alongside Delta at ATL. Unlike the ORD and DFW cases though, this dual-hub example is with a low-cost competitor that does not operate a peaked schedule. AirTran's continuous operations were in place before and after Delta changed from a peaked schedule.

The initial schedule AirTran was operating at ATL was a continuous schedule during most of the day, with higher levels of operations (which could be described as peaks) in the morning and evening high-demand travel periods. This operational set-up is seen in Figure 4.35. The figure has the same scale as Delta's schedule reproduction figures, to be able to visually compare the differences in the schedules. AirTran's schedule has two small peaks each in the morning and evening time periods. The AirTran measurements for the peaked date, as well as the preceding months before depeaking and the months after Delta depeaked are shown in Table 4.27. AirTran had a fairly consistent schedule in terms of the coefficient of variation, although the connections per arriving flight increases three months after Delta depeaked. Also included in the table is a measurement of the percentage of flights in AirTran's schedule which were flown during the Delta banks.

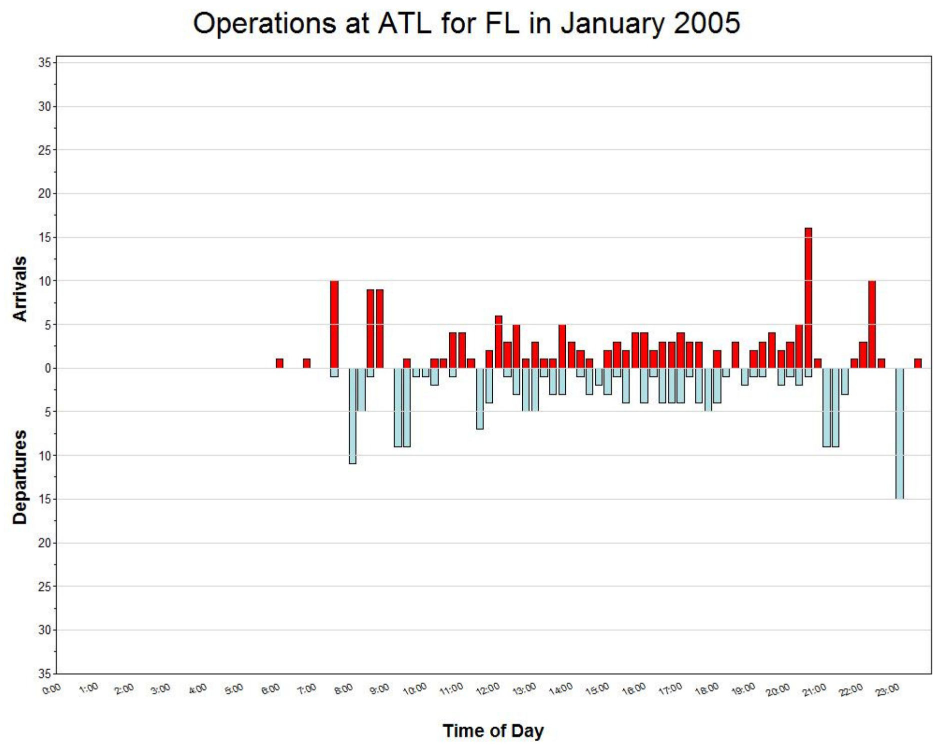

Figure 4.35 AirTran schedule at ATL

Table 4.27 Summary of Supply Changes for AirTran at ATL

Measure	Oct. 19 2004	Dec. 14 2004	Jan. 25 2005	Feb. 8 2005	Mar. 8 2005	May 10 2005
Coefficient of variation in # of arr.	156.1	162.9	157.4	156.2	161.9	147.0
Coefficient of variation in # of dep.	163.1	168.4	163.9	159.3	160.7	154.9
Percentage of flights in peak period	n/a	n/a	n/a	n/a	n/a	n/a
Percentage of flights in AA banks	57.9%	56.1%	56.1%	56.6%	57.5%	58.4%
Number of potential connections	1815	1844	1751	1635	1882	2314
Average connections per arriving flight	20.9	21.2	20.1	18.8	21.6	26.6
Max. potential connections in a market	8	7	6	6	6	6

The schedule for AirTran three months after Delta's depeaking is shown in Figure 4.36.

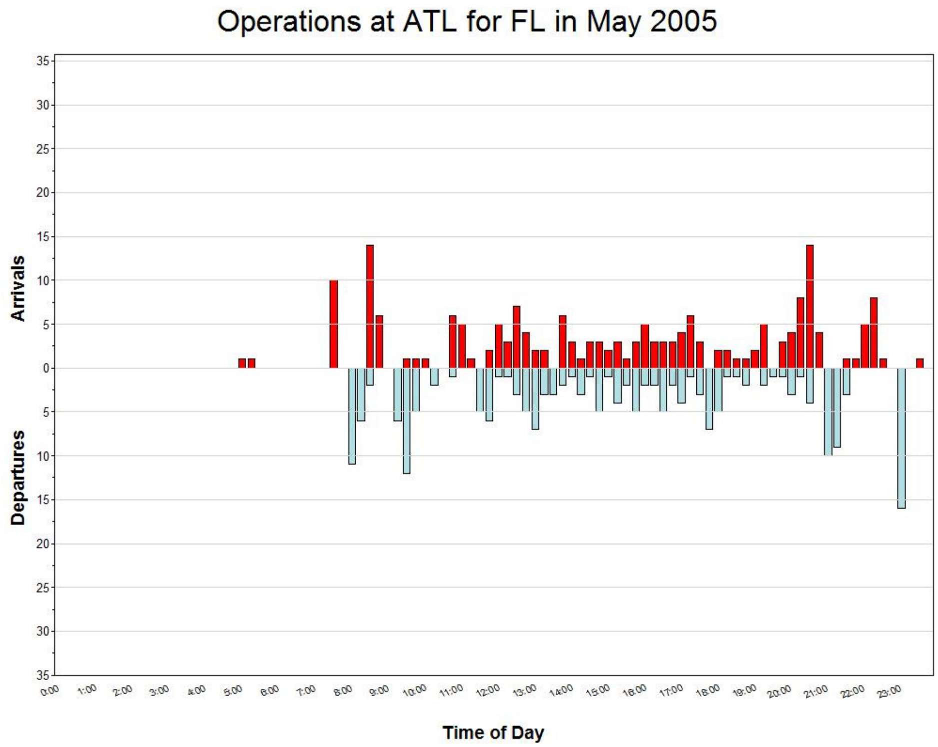

Figure 4.36 AirTran schedule at ATL, 3 months after.

AirTran's operations in relation to Delta's banks are shown in Figures 4.37 and 4.38. There is a consistent level of operations for AirTran in the time periods in which Delta operated its banks. The percentage of operations varies between 56 and 59 percent.

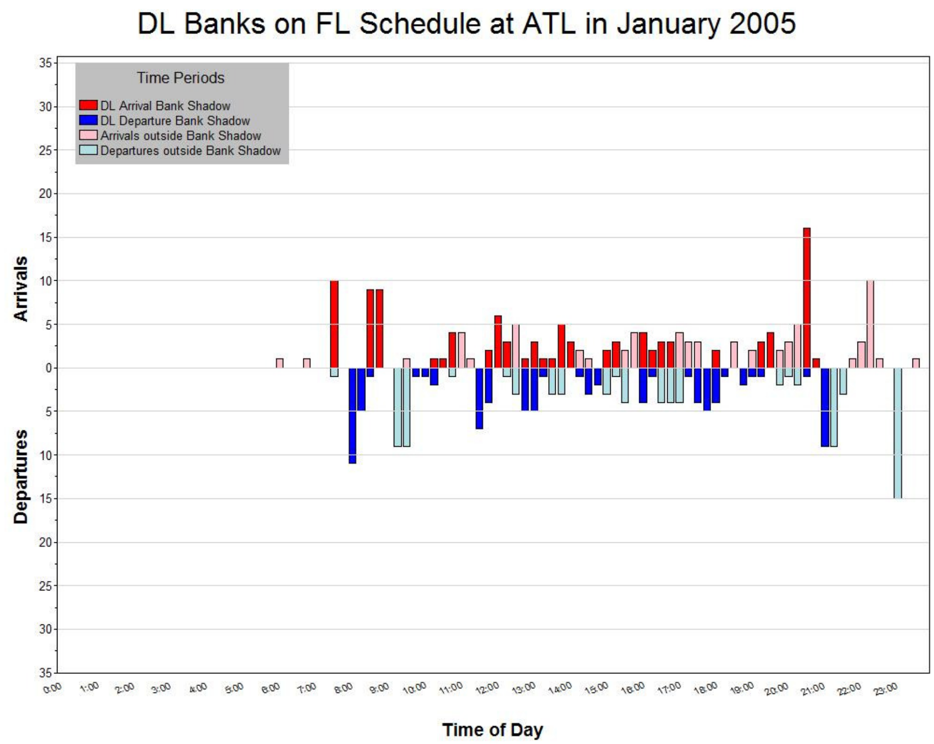

Figure 4.37 Delta's banks overlaid on AirTran's peaked date schedule.

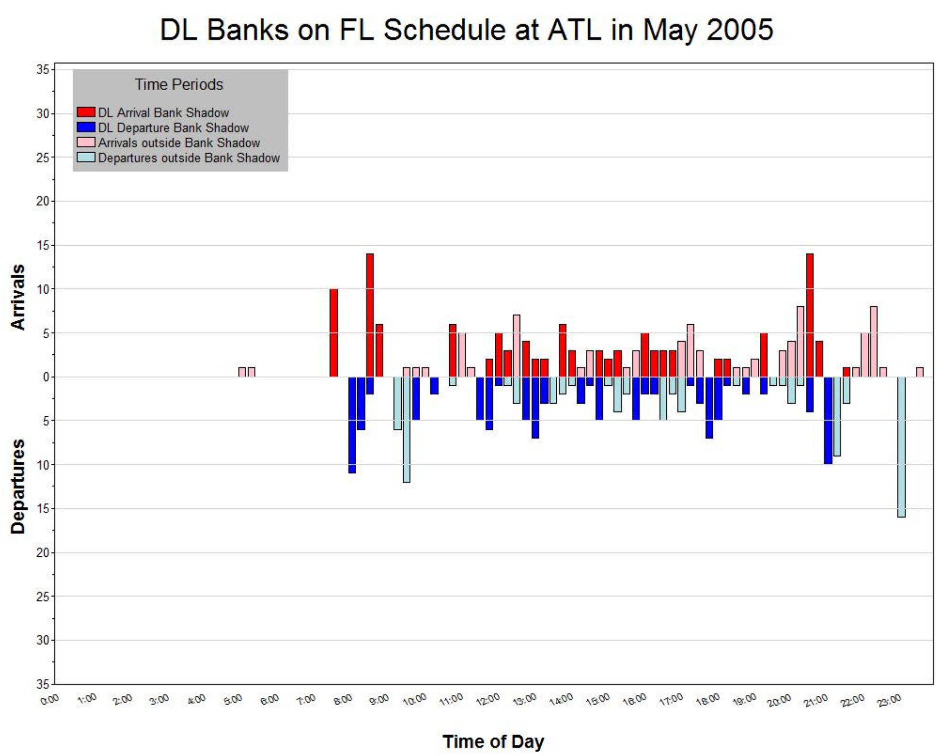

Figure 4.38 Delta's banks overlaid on AirTran's 3-months-later schedule.

The evidence supports that Delta's primary competitor at ATL, AirTran, altered the schedule to provide more connections per flight in response to Delta's depeaking.

4.4.6 Predicting Changes in Supply

Being able to predict the change in flight frequency at ATL after depeaking through a regression model helps to determine what Delta's decision-making process was when making the new schedule. The analysis at the spoke level makes use of data that is summarized for all spoke airports destination that were served by Delta during the depeaking period.

The dependent variable, defined as the change in the number of flights on the route between ATL and a spoke, was found to be well predicted by the variables listed in Table 4.28. The variables include the number of connecting passengers, the connecting fare for connecting passengers for the portion of the route that was from the spoke to ATL, the distance to the spoke airport from ATL, and the number of flights already operated from ATL to the spoke. All of these variables are significant at the 99% confidence level or greater. The adjusted R^2 for the model is 0.195.

Table 4.28 Regression Model Results for Change in Flights at ATL

Variable	Coefficient	t-stat	p > |t|
Intercept	1.0666	1.37	0.173
Connecting Passengers	0.0031	5.49	< 0.001
Connecting Fare	0.0287	2.79	0.006
Distance to Spoke Airport	-0.0027	-3.36	< 0.001
# of Flights in Peaked Schedule	-0.2731	-5.48	0.001

This model passed all three tests for the normality, linearity, and homoscedasticity assumptions. The normal probability plot in Figure 4.39 shows a straight line of residuals falling close to the diagonal line in the plot, indicating that the distribution is normal. The regression was still checked against a count model and the direction of the variables were the same as those in the regression model, providing assurance that the fit was appropriate.

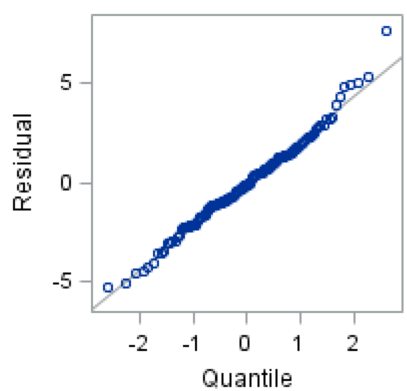

Figure 4.39 Normal probability plot for ATL case.

Delta Airlines' strategy for depeaking ATL, as determined by the results of the regression model showed a focus on connections, especially for spokes that did not already have high frequency. Spokes farther from ATL also received drops in frequency. The greatest increase in frequency was to Boston (BOS), which had a high level of connecting traffic at a high fare. BOS already had a high frequency, and it was pushed higher by Delta in depeaking. As a comparison of a high frequency spoke, flights to Washington-Dulles was reduced substantially, due likely to its low connecting traffic and connecting passenger fare. Even though Boston was farther away, the connection piece was a big factor.

Other spokes which saw increases in flight frequency, and already had high frequency, with high levels of connecting traffic included Fort Lauderdale (FLL), Orlando (MCO), Norfolk (ORF), Fort Myers (RSW), Hartford (BDL), and Birmingham (BHM). As a comparison, spokes with high frequency but lower connecting traffic that lost flights were to Houston (HOU), Chattanooga (CHA), Mobile (MOB), and Jackson, MS (JAN). In addition, many of these latter cities had low connecting fares as compared to the former cities.

Low frequency spoke airports are seen to have mostly have increases. Airports in Peoria, IL (PIA), Outagamie, WI (ATW), Scranton, PA (AVP), Key West (EYW), and the Golden Triangle Airport in Mississippi (GTR). Many of these passengers connected onwards to other spoke cities.

The distance component of the regression is best seen in the airports which lost frequency with Delta, including Orange County (SNA), San Francisco, Oakland (OAK), and Los Angeles (LAX). A large portion of this traffic was for non-stop flights to Atlanta.

In summary, Delta's strategy at ATL can be described as focusing on maintain valuable hub connections and decreasing traffic to high-frequency destinations. There was a strong focus on pulling up low frequency markets that would provide high connecting traffic at the ATL hub. High frequency routes with high connecting traffic gained flights, while those that were dominated by direct passengers, particularly from farther distances, lost flights. A competitive factor was not seen for Delta, perhaps because it has a stronghold on its Atlanta operations, with only some competition from low-cost carrier AirTran.

4.4.7 Assessing Depeaking and Effects

The supply and demand results over the depeaking period show changes that likely could have been due to depeaking. In order to have a better understanding as to whether the changes that occurred were likely due to depeaking as opposed to being a typical change for that time of the year, year-over-year measures were calculated. The percentage change between the peaked and depeaked dates is calculated, and also for the year before and year after on similar dates.

For the ATL case, it is evident that much of the supply changes were due to depeaking. Table 4.29 shows schedule measures and reports a percentage change associated with each year. In the case of Delta, depeaking occurred in 2005. January 25, 2005 was used as the representative Tuesday peaked schedule and February 8, 2005 was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2005 shows the change in schedule measures between these two dates. The process is repeated for two dates each in the years 2004 and 2006, using representative Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2004 change is between two peaked schedules and the 2006 change is between two depeaked schedules. Thus only the 2005 change is for changes that occurred between different schedule types.

Table 4.29 Supply Year-Over-Year Changes for Delta at ATL

Measure	2004				2005				2006			
	1/27	**2/10**	**Δ**	**%**	**1/25**	**2/8**	**Δ**	**%**	**1/24**	**2/7**	**Δ**	**%**
Max. number of flight arrs. or deps. in a 15-minute interval	29	30	1	3%	33	20	**-13**	**-39%**	25	29	4	16%
Max. number of flight operations in a 15-minute interval	48	47	-1	-2%	54	38	**-16**	**-30%**	46	43	-3	-7%
Number of flights flown into or out of hub	1649	1713	64	4%	1742	1856	**114**	**7%**	1453	1495	42	3%
Total available seat miles flown into or out of hub (000s)	146912	149830	2918	2%	160343	172,866	**12523**	**8%**	126782	129475	2694	2%
Number of destinations served from hub	142	142	0	0%	144	146	2	1%	153	154	1	1%
Coefficient of variation in number of arrivals	92.6	93.5	0.9	1%	86.6	68.9	**-17.7**	**-20%**	84.2	84.4	0.2	0%
Coefficient of variation in number of departures	99.5	97.4	-2.1	-2%	94.5	70.6	**-23.9**	**-25%**	89.6	89.7	0.1	0%
Percentage of flights served by affiliate airline(s)	35.1%	36.1%	1.0%	3%	34.3%	33.8%	-0.5%	-1%	41.0%	41.5%	0.5%	1%
Percentage of flights served in peak period	75.0%	74.6%	-0.4%	-1%	71.5%	60.8%	**-10.7%**	**-15%**	71.7%	71.5%	-0.2%	0%
Number of potential connections	41638	45437	3799	9%	45866	45425	**-441**	**-1%**	30063	31623	1560	5%
Average connections per arriving flight	50.8	53.1	2.3	5%	52.7	49.2	**-3.5**	**-7%**	41.2	42.3	1.1	3%
Maximum potential connections serving a market	13	13	0	0%	12	13	**1**	**8%**	10	10	0	0%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages are considered to be important changes that are likely due to Delta's depeaking decision. From the year-over-year data, it is evident that depeaking involved a reduction in the number of flights flown in a given period and the creation of a more even distribution of flights (as evidenced by the reduction in the coefficients of variation and reduction in peak percentage). At the same time, Delta was able to increase flights and ASMs. These changes resulted though in a reduction in potential connections.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases, because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus RASM is used in comparison still with the RASM of the airline network and for the industry.

One measurement which is useful in terms of demand in measuring it year-over-year is the percentage of connecting passengers. Surprisingly, despite the decrease in potential connections in the schedule, the percent of connecting passengers in 2005 did not deviate much from the changes seen across the same time periods in 2004 and 2006. It was in fact between the two comparison years in terms of percent change. In order of year the percent change was 1%, -1%, and -3%.

The change in RASM for Delta's ATL schedule lagged behind the rest of Delta and the industry in all three years. The underperformance in the depeaking year, however, lagged behind Delta and the industry by a greater margin, as seen in Table 4.30. Thus it is possible that depeaking hindered revenue growth, and caused RASM to increase more slowly than it would have if Delta had maintained their schedule.

Table 4.30 RASM Year-Over-Year Changes for Delta at ATL

Measure	2003/4				2004/5				2005/6			
	Q4	Q2	Δ	%	Q4	Q2	Δ	%	Q4	Q2	Δ	%
RASM for Depeaked Airport	9.94	10.57	0.63	6%	9.12	9.54	0.42	5%	11.82	13.08	1.26	11%
RASM for Airline Network	10.53	11.93	1.40	13%	10.19	11.58	1.39	14%	12.30	15.18	2.88	23%
RASM for Industry	9.26	10.45	1.19	13%	9.49	11.41	1.92	20%	10.31	13.40	3.09	30%

Delta did not see any notable improvements year-over-year in terms of operations after depeaking ATL, as seen in Table 4.31. Although operations appeared to lag behind the rest of Delta's network and the industry in the depeaking year, there were no notable changes across all four measures when comparing Delta's operations against the comparative measures in the year before and the year after. Thus in the years before and after, Delta's Atlanta operations also generally lagged behind the rest of Delta's network and the industry.

Table 4.31 Operations Year-Over-Year Changes for Delta at ATL

Measure	2004				2005				2006			
	Jan	Feb	Δ	%	Jan	Feb	Δ	%	Jan	Feb	Δ	%
Dep. Delay Depeaked Airport	45.1	50.4	5.3	12%	49.4	50.5	1.1	2%	54.9	44.3	-10.6	-19%
Dep. Delay Airline Network	50.2	52.1	1.9	4%	52.1	50.9	-1.2	-2%	57.6	47.8	-9.8	-17%
Dep. Delay Industry	52.6	49.3	-3.3	-6%	53.7	50.4	-3.3	-6%	53.1	51	-2.1	-4%
% Delayed Dep. Depeaked Airport	17.5	28.4	10.9	62%	23.1	21.4	-1.7	-7%	22	22	0	0%
% Delayed Dep. Airline Network	16.3	20.5	4.2	26%	20.8	18.1	-2.7	-13%	18.5	18	-0.5	-3%
% Delayed Dep. Industry	17.8	16.5	-1.3	-7%	21.4	17.4	-4	-19%	17.6	19.8	2.2	13%
Arr. Delay Depeaked Airport	49.5	56.3	6.8	14%	53.9	55.8	1.9	4%	65.2	52	-13.2	-20%
Arr. Delay Airline Network	47.1	50	2.9	6%	50.6	48.9	-1.7	-3%	55.6	45.8	-9.8	-18%
Arr. Delay Industry	50.6	46.9	-3.7	-7%	52.9	48.7	-4.2	-8%	51.9	49.7	-2.2	-4%
% Delayed Arr. Depeaked Airport	21.8	35.8	14	64%	24.9	26.7	1.8	7%	24.4	25.5	1.1	5%
% Delayed Arr. Airline Network	21	25.1	4.1	20%	24.3	22.3	-2	-8%	21.2	22	0.8	4%
% Delayed Arr. Industry	22.8	21.1	-1.7	-7%	25.2	20.9	-4.3	-17%	19.7	22.9	3.2	16%

Delta's schedule change was beneficial from a cost perspective, and by comparing the change to the years before and after, it is clear that the shift in supply was related to depeaking. Despite the loss in potential connections, however, connecting traffic varied in roughly the same manner that it did in other years. Revenue saw a decline from the schedule changes, as the RASM over the depeaking period grew slower than the industry and the rest of Delta, and relatively slower than the years before and after. In terms of operations, there were no notable changes year-over-year for Delta.

4.4.8 Summary

Delta's depeaking of ATL was not as successful as other case studies. Revenue was negatively affected over the depeaking period, while operations did not improve. When depeaking operations, Delta sought to maintain valuable connections, particularly for low frequency markets that provided high levels of connecting traffic. Destinations farther from Atlanta with more direct traffic lost frequency. The airline made considerable changes in its supply, and created a more continuous schedule, with large reductions in the number of flights in the busiest 15-minute periods. Simultaneous to the flattening of the schedule, the airline increased flights and ASMs, but despite the depeaking strategy, this did not aid in preserving connections. Delta lost a substantial number of potential connections through depeaking, particularly in the measurement of the number of connections were available for each arriving flight.

The supply changes at ATL influenced a drop in RASM when compared to other years and the industry. This could be tied to the loss of connections when the banks were removed. The loss of connections in the schedule, despite Delta's focus on connecting traffic in depeaking, resulted in no noteworthy change in the percentage of connecting passengers. Delta's loss in revenue did not even come with an improvement in operations like other cases, as Delta saw delay in its schedule stay similar to surrounding years. To counter Delta's depeaking, AirTran increased its potential connections in its schedule, which happened a few months after Delta depeaked.

4.5 US Airways at Philadelphia (PHL)

In February 2005, US Airways removed seven arrival and departure peaks from their schedule in Philadelphia (PHL). US Airway's depeaking of PHL occurred several months after its second bankruptcy, during a period where many airlines were declaring bankruptcy. The airline, however, did not keep to the depeaking experiment. In September of 2005, just seven months after depeaking, US Airways reinstitute a peaked schedule at PHL.

US Airways had one of the most chaotic half decades of any major U.S. airline. Immediately after 9/11, the airline scrapped its no-frills airline-within-an-airline Metrojet, and closed its hub operations at Baltimore-Washington International. Post-9/11, US Airways underwent the bankruptcy process twice. They were the first airline to declare bankruptcy after the economic downturn caused by the terrorist attacks, in August of 2002. US Airways made many cost reduction efforts and received a government loan to stabilize its budget, but the airline declared bankruptcy again in September of 2004. Later in 2004, US Airways dehubbed its Pittsburgh operations; a couple of months later the airline depeaked PHL. Later in the year after depeaking, US Airways merged with America West Airlines, a reverse takeover by the Phoenix-based airline (America West purchased US Airways but retained the latter's name).

Because PHL was repeaked months after it was depeaked, this case has a section briefly discussing why the airline may have repeaked. The analysis on repeaking was outside the scope of this study, so limited attention is given to this topic.

The PHL case study does not have any affiliate airlines in the reproduced schedule as all four of the affiliate airlines flying for US Airways did not report to the

On-Time database during this time period. Unlike other potential case studies that were excluded from analysis because of this situation, this case had clear evidence of depeaking with just the mainline carrier's flights. For this reason, this case was retained for the full analysis.

4.5.1 Data Periods Used and Input Parameters

US Airways depeaked PHL on Sunday February 6, 2005. The date used to represent the peak schedule is Tuesday February 1, 2005. The date used to represent the depeaked schedule is Tuesday February 15, 2005.

US Airways depeaked PHL in the middle of the first quarter of 2005, so the representative peaked quarter is the fourth quarter of 2004. The representative depeaked quarter is the second quarter of 2005. The peaked month used for operational measures is January 2005; the depeaked month is March 2005.

For creating year-over-year measures, February 3, 2004 and February 24, 2004 were used as the supply comparison dates the year prior. January 31, 2006 and February 14, 2006 were used as the supply comparison dates for the year after depeaking. The fourth quarter of 2003 and the second quarter of 2004 are used as the year prior demand comparison quarters, and the fourth quarter of 2005 and the second quarter of 2006 are used for the year after. January 2004 and March 2004 are used for the year prior operational comparison months, and January 2006 and March 2006 are used for the year after.

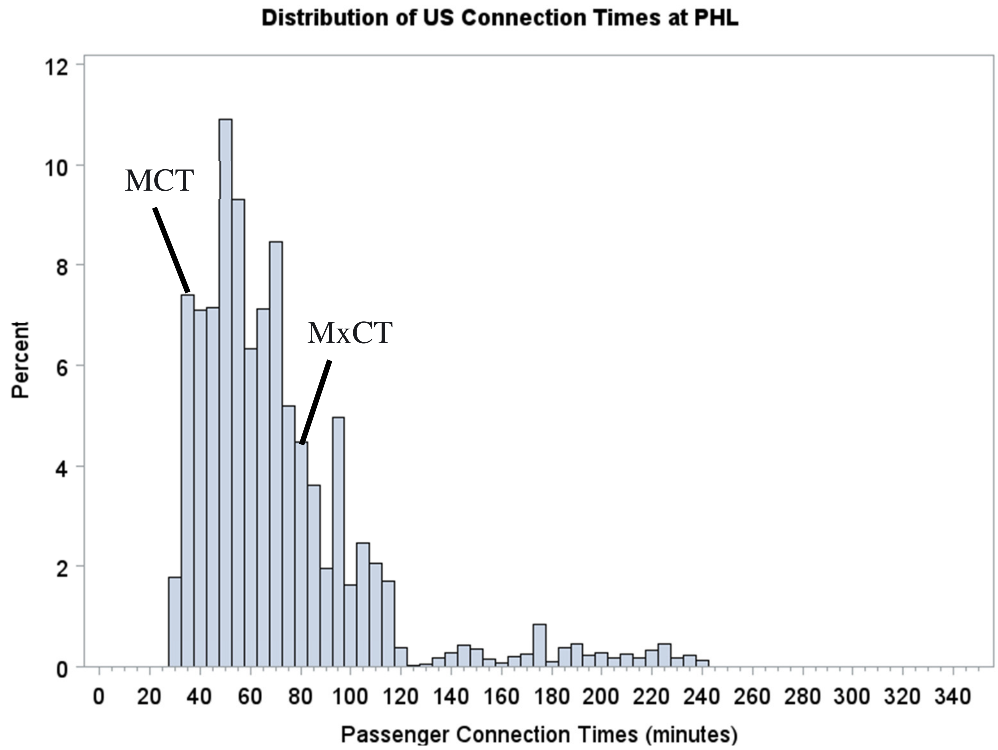

Figure 4.40 Connection time distribution for US at PHL. MCT and MxCT are denoted.

The distribution of actual connection times made at PHL for passengers flying on US Airways itineraries is shown in Figure 4.40. This distribution is from itineraries flown in June 2010. At that time, PHL was operating under a peaked schedule with eight daily banks. The 5th and 75th percentiles, indicating the MCT and MxCT are denoted in the figure. For this case, the MCT is 34 minutes and the MxCT is 82 minutes.

4.5.2 Supply Results

The following section describes the supply-side results for US Airways' depeaking of PHL, which includes data derived from the On-Time database. Table 4.32 summarizes the supply measures representing peaked and depeaked schedules that are discussed in this section.

Table 4.32 Summary of Supply Changes for US Airways at PHL

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	14	12
Max. number of flight operations in a 15-minute interval	14	13
Number of flights flown into or out of hub	448	439
Total available seat miles flown into or out of hub	46,531,047	49,646,130
Number of destinations served from hub	51	47
Coefficient of variation in number of arr./dep. flights	131.6/142.8	102.3/105.8
Percentage of flights served by affiliate airline(s)	n/a	n/a
Percentage of flights served in peak period	79.5%	64.9%
Number of potential connections	3,373	2,408
Average connections per arriving flight	15.0	10.9
Maximum potential connections serving a market	9	11

4.5.2.1 General Supply

US Airways' reproduced peaked schedule at PHL is shown in Figure 4.41 and the reproduced depeaked schedule in Figure 4.42.

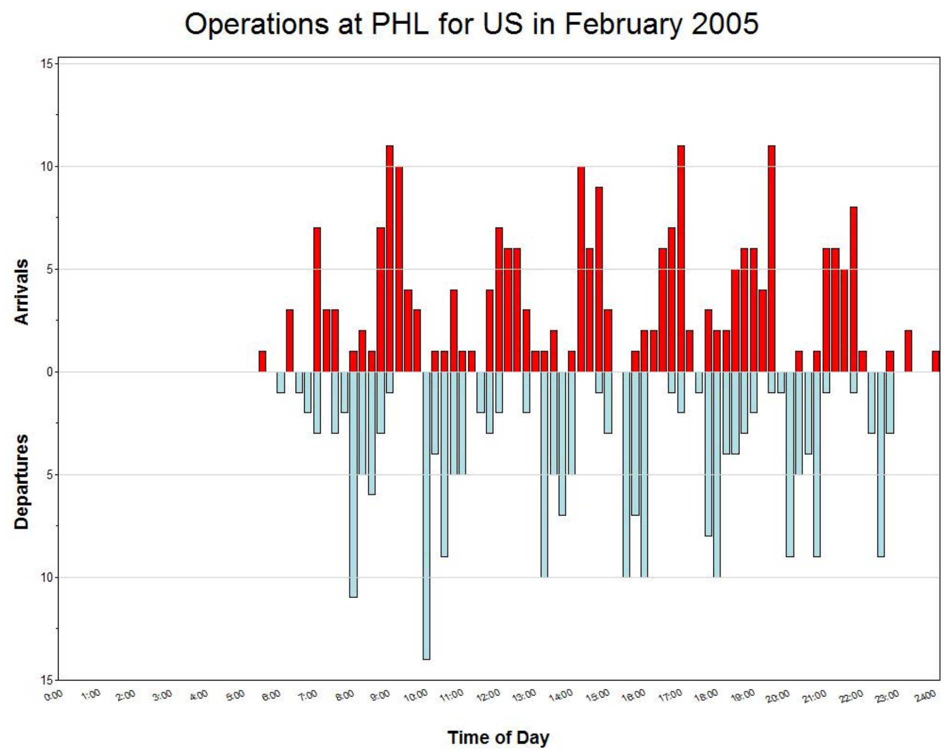

Figure 4.41 Peaked schedule for US Airways at PHL.

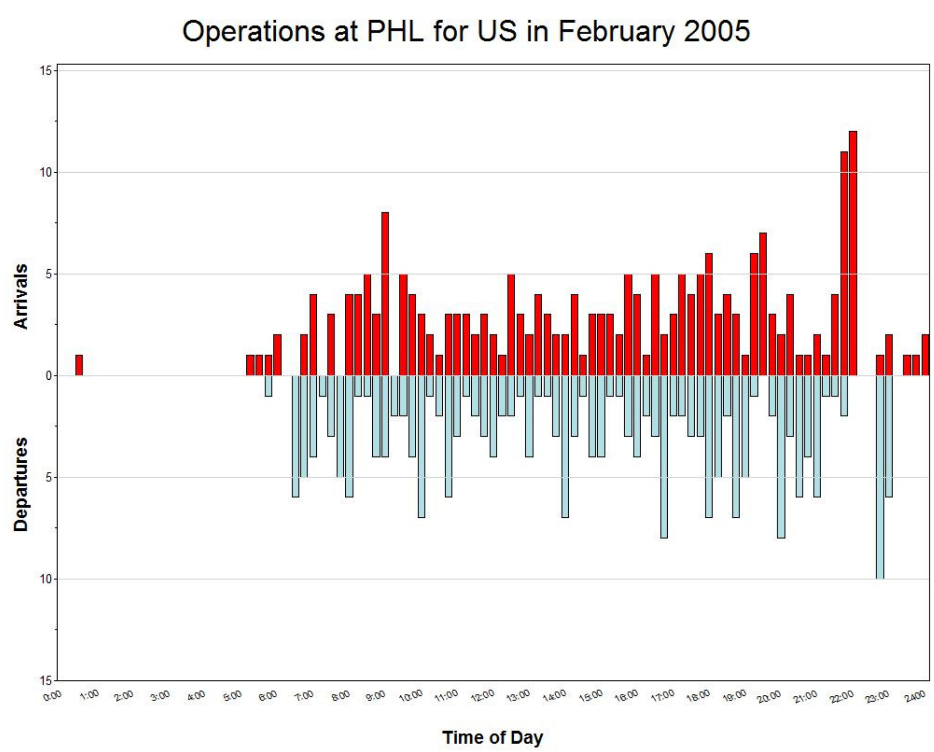

Figure 4.42 Depeaked schedule for US Airways at PHL.

The maximum number of operations in a 15-minute period drops from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 14, while in the depeaked schedule it is 12. The combined number of arrivals and departures in a 15-minute period in the peaked schedule is 14, and drops to 13 in the depeaked schedule.

The distribution of US Airways' operations at PHL is slightly more spread out throughout the day, as seen in the density function plot shown in Figure 4.43. In this plot, the 15-minute periods are ranked in order of frequency. What is seen, particularly with the arrivals, is that the distributions in the depeaked periods are not much flatter than in the peaked schedule. However, beyond the top two or three periods, the depeaked schedule does show more evenness as compared to the peaked schedule's operations. In addition, US Airways operated across more 15-minute periods in the depeaked schedule, showing a greater usage of infrastructure throughout the day.

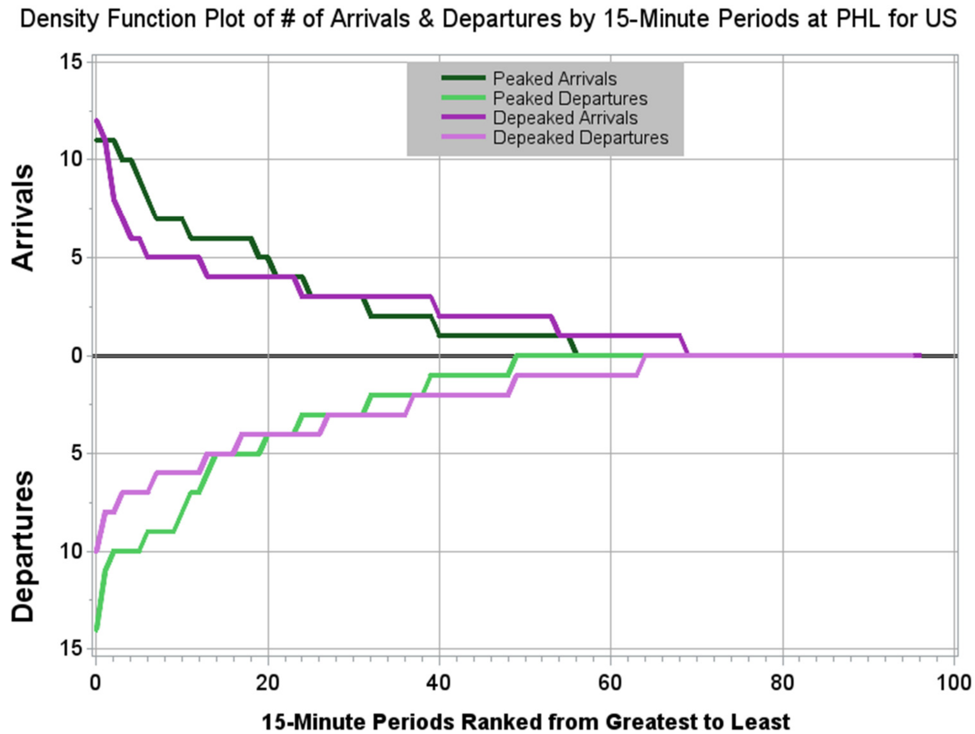

Figure 4.43 Density function plot of US Airways operations at PHL.

In the depeaked schedule, US Airways essentially maintained the same number of flights from the peaked schedule. In the peaked daily schedule in the beginning of February of 2002 US Airways operated 448 flights out of PHL, and this dropped only slightly to 439 flights by two weeks later. Although the number of flights stayed relatively the same, US Airways cut five destinations and added one on the mainline routes. Service was cut to Allentown/Bethlehem, PA; Detroit; Harrisburg, PA; Minneapolis; and Greensboro, NC. At the same time, service was added to Charleston, SC. Despite the number of flights dropping just slightly, ASMs increased from 47 million to 50 million.

4.5.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines is not applicable in this case since none of the affiliate airlines flying for US Airways during this time period had enough revenue to be required to report to the On-Time database. The affiliate airlines included: PSA Airlines, Piedmont Airlines, Chautauqua Airlines, and Mesa Airlines.

4.5.2.3 Peak/Depeak Measures

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 131.6, which drops to 102.3 in the depeaked schedule. The coefficient of variation for the departures drops from 142.8 to 105.8.

The peak and depeak percentage measures show a drop in the peaked nature of the schedule. In the peaked schedule, 79% of flights occur within the banks, highlighted in Figure 4.44. In the depeaked schedule, 65% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.45. This drop, combined with the changes in the coefficient of variation, both indicate a quantitative reduction in the peak level of the schedule.

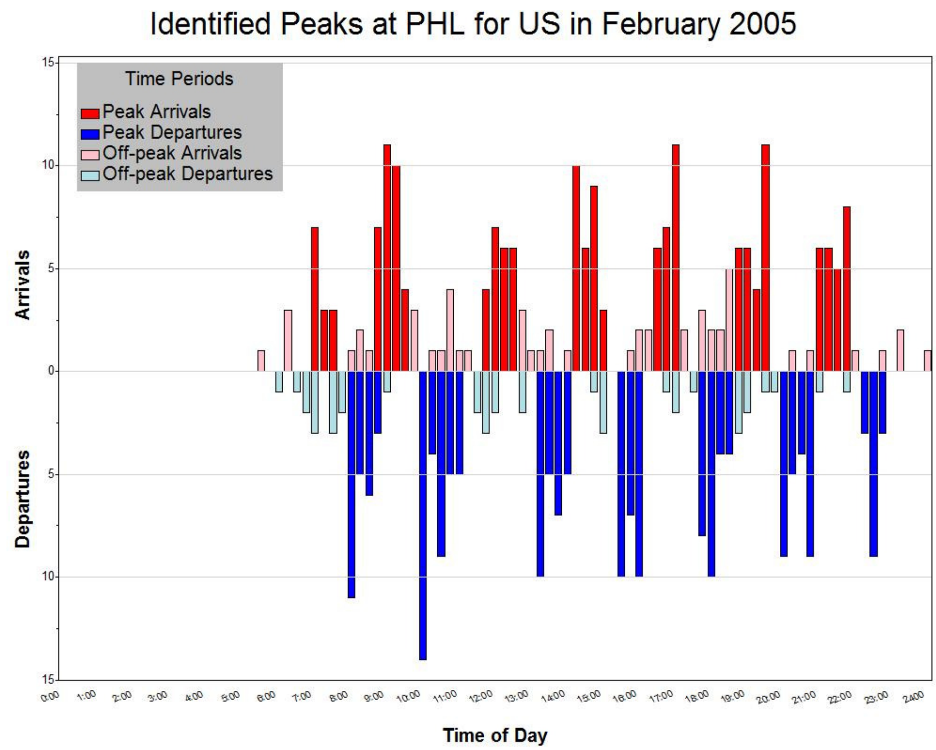

Figure 4.44 Identified banks in the peaked US Airways schedule at PHL.

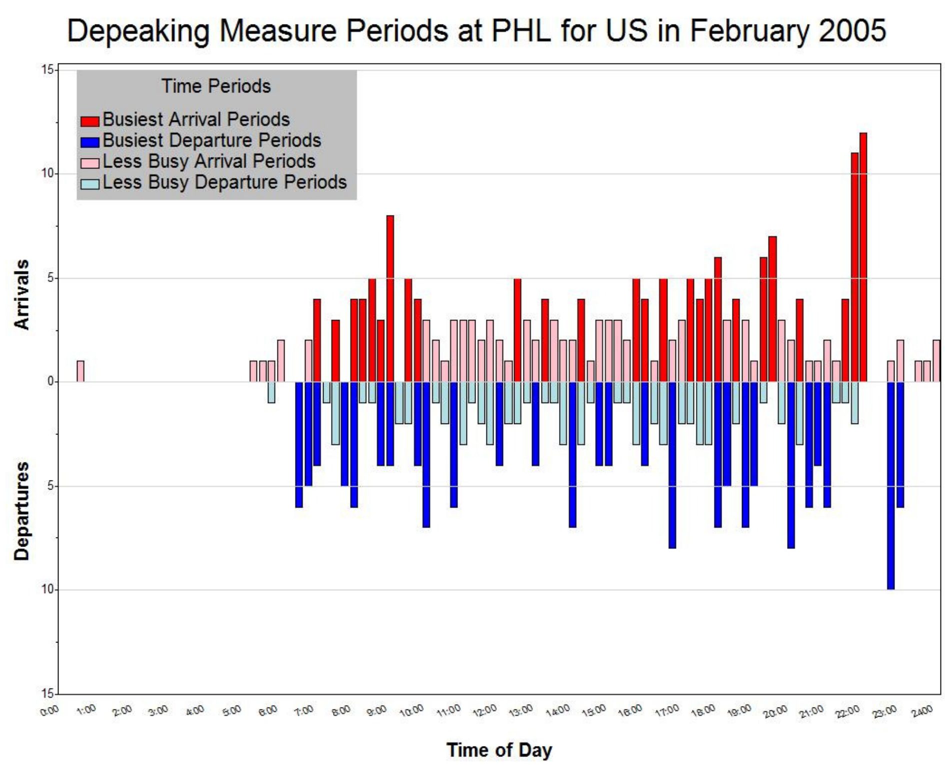

Figure 4.45 Busiest *n* 15-minute periods in the depeaked US Airways schedule at PHL.

4.5.2.4 Connections

The number of connections decreased greatly from the peaked to the depeaked schedule. The peak schedule has 3,373 potential connections from each arriving flight to departing flights within the MCT and MxCT for the given arriving flight. This value decreases to 2,408 in the depeaked schedule. The average number of connections per arriving flight also decreases substantially. The number of connections per arriving flights operated is 15.0 in the peaked schedule, but drops to 10.9 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections increased slightly from 9 to 11 from the peaked to the depeaked schedule. In the peaked schedule, 9 connections existed from Raleigh (RDU) to Boston (BOS) and from Orlando (MCO) to BOS, while the latter market had 11 connections in the depeaked schedule.

4.5.2.5 Validation of Supply-Demand Time Decision

The schedule on the peaked date (or depeaked date) supply data was verified as being similar to the schedule used in the peaked quarter (or depeaked quarter) for the analysis. Table 4.33 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.34 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.33 Supply Measures Over Time for US Airways' Peaked Schedule at PHL

Measure	10/5/04	10/19/04	11/2/04	11/16/04	11/30/04	12/14/04	1/11/05	1/25/05	2/1/05
Max. # of flight arrs. or deps. in 15-min. interval	15	15	15	12	12	13	13	14	14
Max. # of flight operations in 15-min. interval	16	15	16	14	14	14	13	14	14
Number of flights flown into or out of hub	447	404	444	466	465	451	430	429	448
Total avail. seat mi. flown into or out of hub (000s)	47128	45208	46788	50533	50240	46722	46461	44235	46531
Number of destinations served from hub	50	50	50	50	51	51	51	51	51
Coefficient of variation in # of arr./dep. flights	134.2/154.9	136.4/158.3	134.4/154.6	127.8/135.1	128.6/136.4	129.7/137.5	132.9/140.8	134.9/145.0	131.6/142.8
Percentage of flights served by affiliate airline(s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Percentage of flights served in peak period	72.3%	72.8%	73.9%	79.6%	80.7%	77.4%	82.1%	81.6%	79.5%
Number of potential connections	3246	2651	3205	3512	3504	3349	3091	3155	3373
Average connections per arriving flight	14.6	13.1	14.6	15.2	15.3	15.0	14.6	14.7	15.0
Maximum potential connections serving a market	12	9	12	11	10	9	10	9	9

Table 4.34 Supply Measures Over Time for US Airways' Depeaked Schedule at PHL

Measure	2/15/05	3/1/05	3/22/05	4/12/05	4/26/05	5/10/05	5/24/05	6/7/05	6/21/05
Max. # of flight arrs. or deps. in 15-min. interval	12	12	13	10	11	10	10	12	12
Max. # of flight operations in 15-min. interval	13	12	13	11	12	14	14	13	13
Number of flights flown into or out of hub	439	386	443	443	446	409	415	384	410
Total avail. seat mi. flown into or out of hub (000s)	49646	45104	50701	49578	49529	45174	46431	45177	45805
Number of destinations served from hub	47	47	47	47	47	47	47	48	48
Coefficient of variation in # of arr./dep. flights	102.3/105.8	109.9/109.6	99.1/100.8	93.1/99.7	95.3/98.1	106.9/116.0	106.7/114.5	109.5/117.1	105.6/115.9
Percentage of flights served by affiliate airline(s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Percentage of flights served in peak period	64.9%	66.3%	62.8%	61.4%	61.7%	67.7%	67.7%	67.7%	67.3%
Number of potential connections	2408	1920	2419	2447	2453	2137	2199	1886	2158
Average connections per arriving flight	10.9	10.1	11.0	11.1	11.0	10.5	10.6	9.9	10.5
Maximum potential connections serving a market	11	8	11	12	11	9	10	9	11

4.5.3 Demand Results

The changes in demand and related parameters before and after the depeaking of PHL are shown in Table 4.35. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Just over 22 thousand average daily passengers traveled on US Airways through PHL in the peaked schedule during the peaked quarter, and this increased slightly to around 22.5 thousand during the depeaked quarter. Overall revenue increased from the fourth quarter of 2004 to the second quarter of 2005, from $3.4 million to $3.5 million. Along with the revenue, ASMs also increased, to the extent that RASM decreased from 7.24 cents per mile to 7.08 cents per mile.

Table 4.35 Summary of Demand and Revenue Changes for US Airways at PHL

Measure	Peaked	Depeaked
Total passengers	22,252	22,631
Revenue ($)	3,366,650	3,513,174
Revenue per available seat mile (RASM) (cents per mile)	7.24	7.08
Percent connecting passengers	31.8%	31.2%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was 36, while 15 markets saw a decrease. RASM increased in 31 markets, and decreased in 20.

Across the spokes of PHL there was an average decrease in connecting traffic from the spoke airports. 31.8% of passengers at PHL on US Airways were connecting passengers under the peaked schedule, and 31.2% were connecting passengers under the depeaked schedule. At the spoke level, 29 spoke routes had an increase in the percentage of passengers on flights between PHL and the spoke that made connections. 22 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and PHL. Connecting traffic appears to taken a small hit overall, but in most markets the connecting passenger traffic increased.

The change in revenue is compared to the rest of US Airways' network and the industry as a whole to determine if the decrease in RASM at PHL was perhaps due to depeaking, or rather on trend with the changes at the time elsewhere. The 0.16 cents per mile decrease from the peaked to the depeaked period is thus considered in terms of these other measures. Over this same time period, the entire US Airways network saw a 1.14 cents per mile increase in RASM, including US Airways' other hubs in Phoenix and Charlotte. The industry as a whole saw a 1.32 cents per mile increase between these two quarters. US Airways' revenue growth at PHL lagged way behind the rest of US Airways and the industry as a whole; 1.5 cents per mile in the case of the latter. It is thus possible that the depeaking of PHL could have influenced slower revenue growth.

4.5.4 On-Time Results

The operational effects of depeaking are shown in Table 4.36 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was a slight improvement in delay for arrivals, and a slight decline for departures. Although the average delay for delayed departures went down slightly, there was an increase in delayed aircraft and the total delay. Arrivals had decreases in the percentage of delayed aircraft and the amount of delay. Taxi-in and taxi-out times decreased between the two time periods.

Table 4.36 Summary of Operational Changes for US Airways at PHL

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	25.1	25.8
Average departure delay for delayed aircraft (minutes)	53.8	53.4
Percentage of delayed departing aircraft	42.6%	44.3%
Total delay for delayed departing aircraft (minutes)	146,057	151,409
Average taxi-out time (minutes)	23.5	20.3
Average arrival delay for all aircraft (minutes)*	23.4	19.7
Average arrival delay for delayed aircraft (minutes)	58.5	57.6
Percentage of delayed arriving aircraft	37.3%	31.8%
Total delay for delayed arriving aircraft (minutes)	138,586	116,919
Average taxi-in time (minutes)	8.4	6.9

***Early arriving and early departing aircraft were assigned zero delay**

The US Airways operations at PHL need to be considered in terms of the concurrent changes across US Airways' network and the industry overall.

Departure delay for delayed aircraft at PHL slightly improved from the peaked to depeaked quarter, but the percentage of delayed aircraft increased by about 2 percentage points. These figures, however, when compared to the rest of US Airways and the industry, show a decline in operations. US Airways' operations at PHL lagged behind the rest of its network, which had a greater decrease in departure delay over the same time period, and the industry, which also decreased a greater amount. The industry also had a drop in the percentage of delayed departures, while PHL operations for US Airways increased in percentage of the delayed aircraft. The only area where the PHL operations performed better for departures was that the US Airways network increased in the percentage of delayed departures, by 20%, while only by 4% at PHL.

US Airways' PHL arrival operations lagged slightly behind as compared to the rest of US Airways' network and the industry as a whole. The average delay time for arriving delayed aircraft decreased 1.5% for PHL, while the change was a 4.6% decrease for all US Airways arrivals, and a 2.5% decrease for the industry. The percentage of delayed aircraft at PHL saw a decrease of 15% which was approximately equal to the industry's improvement of about 14%. The airline as a whole though saw more aircraft be delayed, so the PHL operations improved in this sense.

The operations at PHL generally worsened in relation to the rest of US Airways and the industry as a whole. The fact that this change occurred could have played a part in the airline's decision to repeak its operations at PHL.

4.5.5 Predicting Changes in Supply

Analysis was performed using a regression model on the PHL case study to assess the decision-making process of US Airways as the airline determined how to depeak their schedule. The analysis at the spoke level makes use of data that is summarized for all spoke airports destination that were served by US Airways during the depeaking period.

The dependent variable, defined as the change in the number of flights on the route between PHL and a spoke, was found to be well predicted by the variables listed in Table 4.37. The variables include the number of direct passengers, the number of flights to the spoke in the peaked schedule, whether the spoke city is a Southwest focus city, the ratio of US Airways' average fare to the competitors' average fare, and the market share of US Airways. Four of these variables are significant at the 95% confidence level, and the fare ratio variable is significant at the 90% confidence level. The adjusted R^2 for the model is 0.370.

Table 4.37 Regression Model Results for Change in Flights at PHL

Variable	Coefficient	t-stat	p > |t|
Intercept	-3.2617	-0.89	0.380
Direct Passengers	0.0032	2.33	0.025
# of Flights in Peaked Schedule	-0.1513	-2.16	0.037
Spoke is a Southwest focus city*	-1.5588	-2.25	0.031
Fare ratio: US Airways to competitors	5.9284	1.82	0.077
Market Share for US Airways by # of flights	-2.8671	-2.40	0.022

***Indicator variable (1 = yes)**

This model passed all three tests for the normality, linearity, and homoscedasticity assumptions. The normal probability plot in Figure 4.46 shows a straight line of residuals falling close to the diagonal line in the plot, indicating that the distribution is normal. The regression was still checked against a count model and the direction of the variables were the same as those in the regression model, providing assurance that the fit was appropriate.

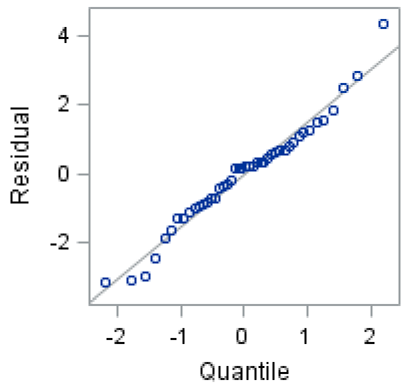

Figure 4.46 Normal probability plot for PHL case.

US Airways' strategy for depeaking PHL, as determined by the results of the regression model, showed a focus on maintaining valuable hub O&D traffic, especially where the airline held a fare premium. US Airways also deemphasized Southwest focus cities where they were the dominant carrier, and emphasized Southwest focus cities where US Airways was splitting the route. In addition, US Airways went after cities where it had a competitor, and decreased frequency to cities where it was the dominant or only carrier.

Cities which US Airways boosted frequency because it held a fare premium and there was considerable direct passenger traffic include Atlanta (ATL), Tampa (TPA), Fort Lauderdale (FLL), Orlando (MCO), Miami (MIA), and New Orleans (MSY). It decreased traffic to cities where US Airways had low demand for direct flights and where it was underselling the competitor such as Milwaukee (MKE) and St. Louis (STL).

The Southwest focus city effect was seen as US Airways dropped down flights to Nashville (BNA) and St. Louis (STL), yet boosted flights to Orland (MCO). These three all are Southwest focus cities, but the former two are cities in which US Airways dominated the route, while in the latter they competed with Southwest.

Overall, US Airways reduced flights in markets it had a monopoly in, and increased in markets in which it fought for market share. Markets in which it reduced and in which it was the monopoly carrier included Portland, Maine (PWM), Richmond (RIC), Charlotte (CLT), Norfolk (ORF), and Kansas City (MCI). It increased flights to the cities mentioned previously (ATL, TPA, FLL, MCO, MIA, and MSY) where it had to compete, but this also included DFW, IAH, and SFO, big competitor hubs.

In summary, US Airway's strategy at PHL can be described as trying to capture market share in markets it was competing in already. This ramp-up included many large hubs of other airlines and cities where US Airways was holding a fare premium. Routes which already had a large number of flights were more likely to see reductions. In addition, there was a Southwest effect in which US Airways decreased frequency to Southwest focus cities, even when Southwest did not fly the route from PHL. Southwest focus cities with a Southwest flight saw an increase. In addition, although not represented by the model, routes Southwest flew were the ones that saw frequency increases. Thus, it could be deduced that the US Airways depeaking strategy was focused on winning routes from competition, particularly Southwest.

4.5.6 Assessing Depeaking and Effects

The supply and demand results that occurred during the depeaking period show changes that likely could have been due to depeaking. Year-over-year measures were calculated in order to better understand whether the changes that occurred were potentially due to depeaking as opposed to being a typical change for that time of the year. The percentage change between the peaked and depeaked dates is calculated, as well as for the year before and year after on similar dates.

For the PHL case, it is evident that many of the supply changes were due to depeaking. Table 4.38 shows schedule measures and reports a percentage change associated with each year. In the case of US Airways, depeaking occurred in 2005. February 1, 2005, was used as the representative Tuesday peaked schedule and February 15, 2005, was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2005 shows the change in schedule measures between these two dates. The process is repeated for two dates each in the years 2004 and 2006, using representative Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2004 and 2006 changes are both between two peaked schedules, because US Airways repeaked their schedule in late 2005. Thus only the 2005 change is for changes that occurred between different schedule types.

Table 4.38 Supply Year-Over-Year Changes for US Airways at PHL

Measure	2004				2005				2006			
	2/3	**2/24**	**Δ**	**%**	**2/1**	**2/15**	**Δ**	**%**	**1/31**	**2/14**	**Δ**	**%**
Max. number of flight arrs. or deps. in a 15-minute interval	15	17	2	13%	14	12	**-2**	**-14%**	10	11	1	10%
Max. number of flight operations in a 15-minute interval	16	18	2	13%	14	13	**-1**	**-7%**	11	11	0	0%
Number of flights flown into or out of hub	340	342	2	1%	448	439	**-9**	**-2%**	305	323	18	6%
Total available seat miles flown into or out of hub (000s)	40128	41255	1126	3%	46531	49646	3115	7%	36812	41547	4735	13%
Number of destinations served from hub	45	45	0	0%	51	47	**-4**	**-8%**	42	44	2	5%
Coefficient of variation in number of arrivals	158.6	150.5	-8.1	-5%	131.6	102.3	**-29.3**	**-22%**	146.5	139	-7.5	-5%
Coefficient of variation in number of departures	190.6	192.6	2	1%	142.8	105.8	**-37**	**-26%**	145.8	158	12.2	8%
Percentage of flights served by affiliate airline(s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Percentage of flights served in peak period	79.1%	76.3%	-2.8%	-4%	79.5%	64.9%	**-14.6%**	**-18%**	77.4%	78.0%	0.6%	1%
Number of potential Connections	2304	2208	-96	-4%	3373	2408	**-965**	**-29%**	1525	1736	211	14%
Average connections per arriving flight	13.6	12.9	-0.7	-5%	15	10.9	**-4.1**	**-27%**	10.0	10.7	0.7	7%
Maximum potential connections serving a market	7	7	0	0%	9	11	**2**	**22%**	8	8	0	0%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages represent the most notable changes upon US Airways' depeaking. From the year-over-year data, it is evident that depeaking involved a reduction in the number of flights flown in a given period, the number of flights flown overall, the number of destinations served, and the creation of a more even distribution of flights (as evidenced by the reduction in the coefficients of variation and reduction in peak percentage). These changes contributed to a drop in the number of potential connections, both gross and per arriving flight.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus, RASM is still used in comparison with the RASM of the airline network and for the industry.

One useful measurement in terms of measuring demand using it year-over-year is the percentage of connecting passengers. The percentage of connecting passengers in 2005 did not deviate from the change seen across the same time periods in 2004, but was very different from the change seen in 2006. Thus, there is no evidence that depeaking caused a unique change in connecting traffic.

The change in RASM for US Airways' PHL schedule lagged behind the rest of US Airways and the industry across all three years. As seen in Table 4.39, however, the lag in 2004/5 was more substantial in the depeaking year than the year before. In addition, in 2005/6, the proportional gain compared to the network and industry gains was not as great as what occurred in the depeaking year. Thus it appears that US Airways' depeaking in PHL perhaps caused a revenue loss.

Table 4.39 RASM Year-Over-Year Changes for US Airways at PHL

Measure	2003/4				2004/5				2005/6			
	Q4	Q2	Δ	%	Q4	Q2	Δ	%	Q4	Q2	Δ	%
RASM for Depeaked Airport	8.02	7.61	-0.41	-5%	7.24	7.08	-0.16	-2%	8.15	9.93	1.78	22%
RASM for Airline Network	12.37	12.64	0.27	2%	11.24	12.38	1.14	10%	7.84	11.82	3.98	51%
RASM for Industry	9.64	10.45	0.81	8%	10.09	11.41	1.32	13%	10.31	13.4	3.09	30%

US Airways in the depeaking year at PHL saw a worsening in the average arrival and departure delay compared to the rest of the US Airways network and the industry. At the same time, it experienced an improvement in terms of the percentage of delayed arriving aircraft. When comparing these changes year-over-year, these changes do not appear to be notable, as seen in Table 4.40. For departure delay, as an example, the relative increase in the depeaking year in departure delay in relation to the comparative measures is seen similarly in the year before and in the year after.

Table 4.40 Operations Year-Over-Year Changes for US Airways at PHL

Measure	2004				2005				2006			
	Jan	**Mar**	**Δ**	**%**	**Jan**	**Mar**	**Δ**	**%**	**Jan**	**Mar**	**Δ**	**%**
Dep. Delay Depeaked Airport	44.2	47.2	3	7%	53.8	53.4	-0.4	-1%	50.3	47.2	-3.1	-6%
Dep. Delay Airline Network	44.7	47.1	2.4	5%	51.8	49.5	-2.3	-4%	46.9	43.5	-3.4	-7%
Dep. Delay Industry	52.6	50.2	-2.4	-5%	53.7	52.7	-1	-2%	53.1	51.9	-1.2	-2%
% Delayed Dep. Depeaked Airport	27.4	24.5	-2.9	-11%	42.6	44.3	1.7	4%	24.5	20.9	-3.6	-15%
% Delayed Dep. Airline Network	14.1	11.9	-2.2	-16%	22.9	27.6	4.7	21%	14.3	13.6	-0.7	-5%
% Delayed Dep. Industry	17.8	14.2	-3.6	-20%	21.4	18.8	-2.6	-12%	17.6	20.4	2.8	16%
Arr. Delay Depeaked Airport	47.8	45.3	-2.5	-5%	58.5	57.6	-0.9	-2%	56.3	43.9	-12.4	-22%
Arr. Delay Airline Network	44.3	43.7	-0.6	-1%	52	49.6	-2.4	-5%	44.7	40.4	-4.3	-10%
Arr. Delay Industry	50.6	47.7	-2.9	-6%	52.9	51.6	-1.3	-2%	51.9	51.3	-0.6	-1%
% Delayed Arr. Depeaked Airport	20.4	20.3	-0.1	0%	37.3	31.8	-5.5	-15%	26.6	18.5	-8.1	-30%
% Delayed Arr. Airline Network	18.5	15.1	-3.4	-18%	27.7	29.7	2	7%	17.4	16.9	-0.5	-3%
% Delayed Arr. Industry	22.8	17.5	-5.3	-23%	25.2	21.6	-3.6	-14%	19.7	22.8	3.1	16%

US Airways' schedule changes show evidence of a considerable cut in cost by spreading out the banks in the schedule. When compared to the years before and after, there is evidence that the changes in the supply measures were unique to depeaking. The changes appeared to affect revenue negatively, although there was no effect on connecting traffic. It appears that the shifts in supply could have likely caused shifts in revenue. Operationally, the evidence suggests that there was not a shift in operations that could be attributed to depeaking.

4.5.7 Repeaking

Of the six cases, only PHL was repeaked soon after depeaking of the hub's operations occurred. It is reasonable to assume that repeaking indicated a dislike for the depeaked operations, as it occurred only seven months after depeaking. The date of repeaking was Friday September 16, 2005. Figure 4.47 shows the PHL's repeaked schedule, which has seven arrival and departure peaks, the same number US Airways was operating in February of 2005 before depeaking.

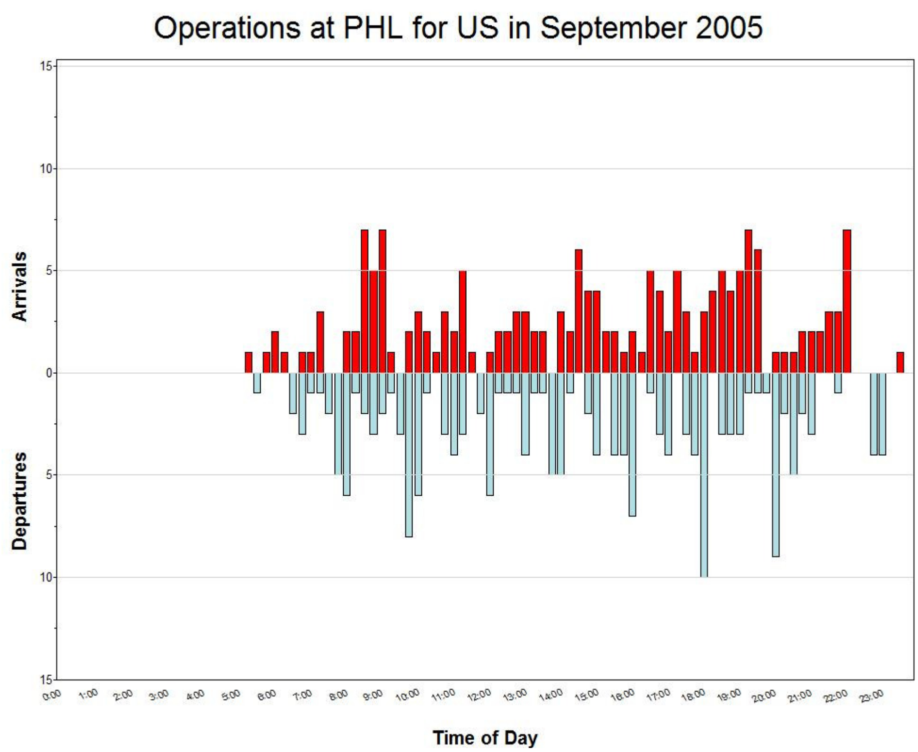

Figure 4.47 Repeaked schedule for US Airways at PHL.

US Airways' repeaked schedule, despite having the same number of banks throughout the day, is different from what they operated initially before depeaking. Table 4.41 lists the performance measures from the peaked schedule, from the peaked date of Tuesday

February 1, 2005, and the repeaked schedule, from the repeaked date of Tuesday September 20, 2005. Only performance measures which are not heavily affected by seasonality are reported for comparison.

Table 4.41 Peaked and Repeaked US Airways Supply Measures at PHL

Measure	Peaked	Repeaked
Coefficient of variation in number of arr. flights	131.6	109.8
Coefficient of variation in number of dep. flights	142.8	123.8
Percentage of flights served in peak period	79.5%	61.6%
Average connections per arriving flight	15.0	9.8

Although US Airways did not retain its depeaked schedule, it did not peak as extremely when it repeaked. The coefficients of variation for arrivals and departures in the repeaked schedule are less than they were in the peaked schedule. The peak percentage dropped as well, so much so that it is lower than the comparable percentage for the depeaked schedule. The result was fewer connections per arriving flight in the repeaked schedule than in the peaked schedule.

4.5.8 Summary

US Airways did not find depeaking to be a successful endeavor, and repeaked the schedule soon after. US Airways' depeaking strategy focused on winning routes from competition, and aggressively going after those markets. US Airways particularly seemed to want to win back market share from Southwest and traffic to other major airline hubs. These changes occurred where US Airways held a fare premium. Meanwhile, high frequency routes saw reductions. Simultaneously, the airline needed to cut cost, and the result was a reduction in flight frequency overall and in operations in a given 15-minute period. These cuts resulted in a major loss of connectivity in the schedule.

The supply changes US Airways underwent hurt them both in operations and revenue. Operationally, PHL lagged behind the rest of the airline's network and the industry in terms of delay and the percentage of delayed aircraft, but this change was similar to that seen in the years before and after. In terms of revenue, there was a negative effect, with the RASM for PHL flights lagging behind comparative measures for the same year and other years. Perhaps due to this poor performance, the schedule was repeaked to recapture revenue and improve operations.

Part of the reason that the PHL schedule repeaked was the merger of US Airways and America West in the summer of 2005. The poor performance of the experiment likely would lead new ownership to prefer the standard quo of the industry for hubs. In addition, with a new major hub in the network in Phoenix, there may have been issues of coordinating schedules which the new management preferred to have solved with a consistent schedule type across its hubs.

4.6 United Airlines at Los Angeles (LAX)

United declared bankruptcy in 2002, but it was not until 2004 that United would try depeaking at its hub airports. United depeaked ORD in February 2004, although this case had to be excluded from this study, with reasons described in 3.5.1.2.7. Over a year later, in June 2005, United depeaked Los Angeles, removing seven arrival and departures peaks from their schedule at the coastal hub.

United Airlines filed for bankruptcy protection in December 2002, due to the downturn in passenger travel in the post-9/11 industry. Its staff cuts, cancelled routes, and fleet reductions all contributed to allowing United to restructure itself. United also dehubbed its MIA hub operations, and terminated and restructured contracts with its contractors, employees, and affiliate airlines. Later in 2005, United officially exited bankruptcy. The following winter, United depeaked SFO, with those changes happening slowly through January and February 2006. The slow pull-down of operations that SFO experienced is different than United's strategy at LAX.

4.6.1 Data Periods Used and Input Parameters

United Airlines depeaked LAX on Tuesday June 7, 2005. The date used to represent the peak schedule is Tuesday, May 24, 2005. The date used to represent the depeaked schedule is Tuesday, June 14, 2005.

United depeaked LAX in the middle of the second quarter of 2005, so the representative peaked quarter is the first quarter of 2005. The representative depeaked quarter is the third quarter of 2005. The peaked month used for operational measures is May 2005; the depeaked month is July 2005.

For creating year-over-year measures, May 25, 2004, and June 15, 2004, were used as the supply comparison dates the year prior. May 23, 2006, and June 13, 2006, were used as the supply comparison dates for the year after depeaking. The first and third quarters of 2004 are used as the year prior demand comparison quarters, and the first and third quarters of 2006 are used for the year after. May 2004 and July 2004 are used for the year prior operational comparison months, and May 2006 and July 2006 are used for the year after.

The distribution of actual connection times at LAX for passengers flying on United itineraries is shown in Figure 4.48. This distribution is from itineraries flown in June 2010. At that time, LAX was still operating under a depeaked schedule. The 5th and 75th percentiles, indicating the MCT and MxCT, are denoted in the figure. For this case, the MCT is 35 minutes and MxCT is 119 minutes.

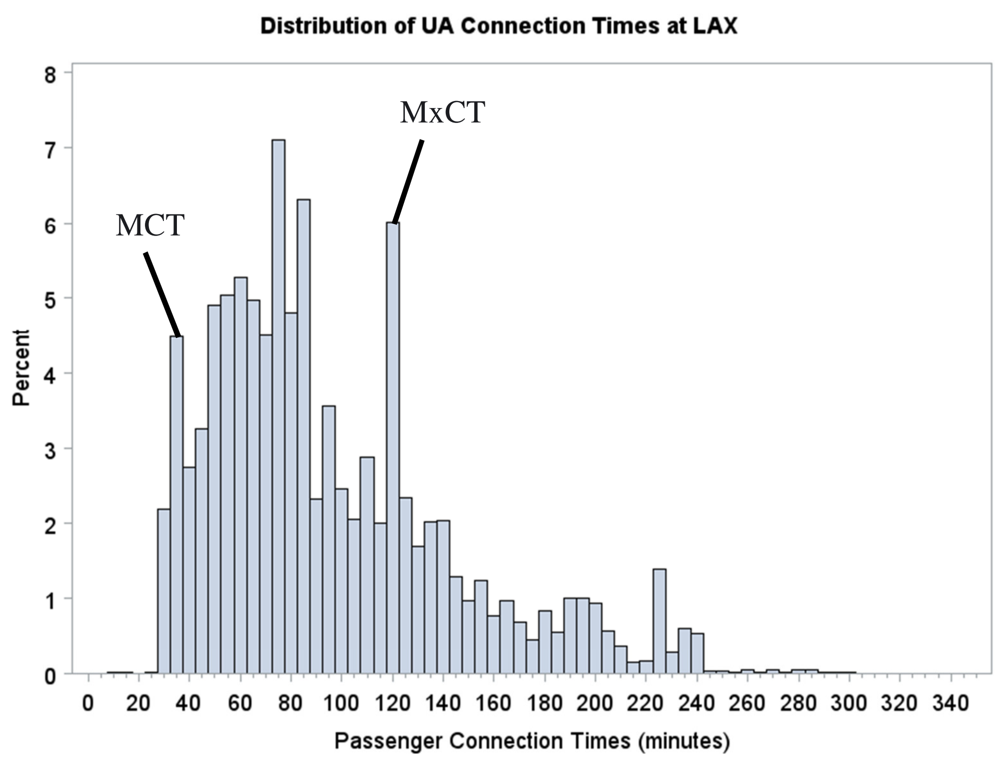

Figure 4.48 Connection time distribution for UA at LAX. MCT and MxCT are denoted.

4.6.2 Supply Results

The following section describes the supply-side results for United's depeaking of LAX, which include data derived from the On-Time database. Table 4.42 summarizes the supply measures representing peaked and depeaked schedules discussed in this section.

Table 4.42 Summary of Supply Changes for United at LAX

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	15	8
Max. number of flight operations in a 15-minute interval	19	13
Number of flights flown into or out of hub	453	462
Total available seat miles flown into or out of hub	46,842,489	49,309,052
Number of destinations served from hub	42	42
Coefficient of variation in number of arr./dep. flights	119.8/144.0	76.8/82.3
Percentage of flights served by affiliate airline(s)	59.2%	59.3%
Percentage of flights served in peak period	62.0%	44.6%
Number of potential connections	4,774	4,152
Average connections per arriving flight	21.1	18.0
Maximum potential connections serving a market	21	23

4.6.2.1 General Supply

United Airlines' reproduced peaked schedule at LAX is shown in Figure 4.49 and the reproduced depeaked schedule in Figure 4.50.

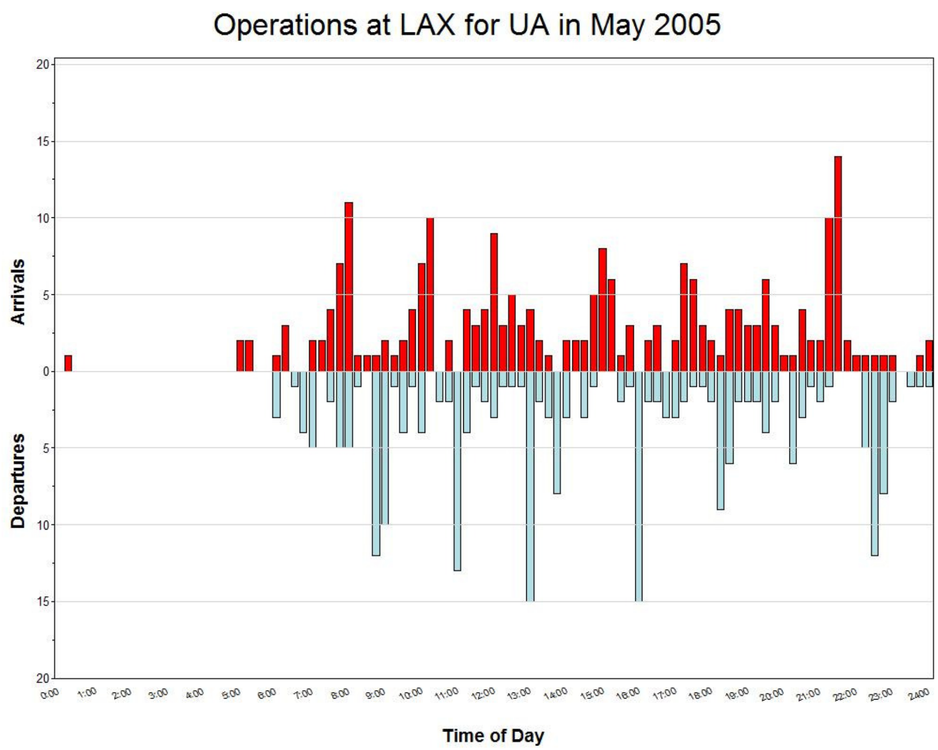

Figure 4.49 Peaked schedule for United at LAX.

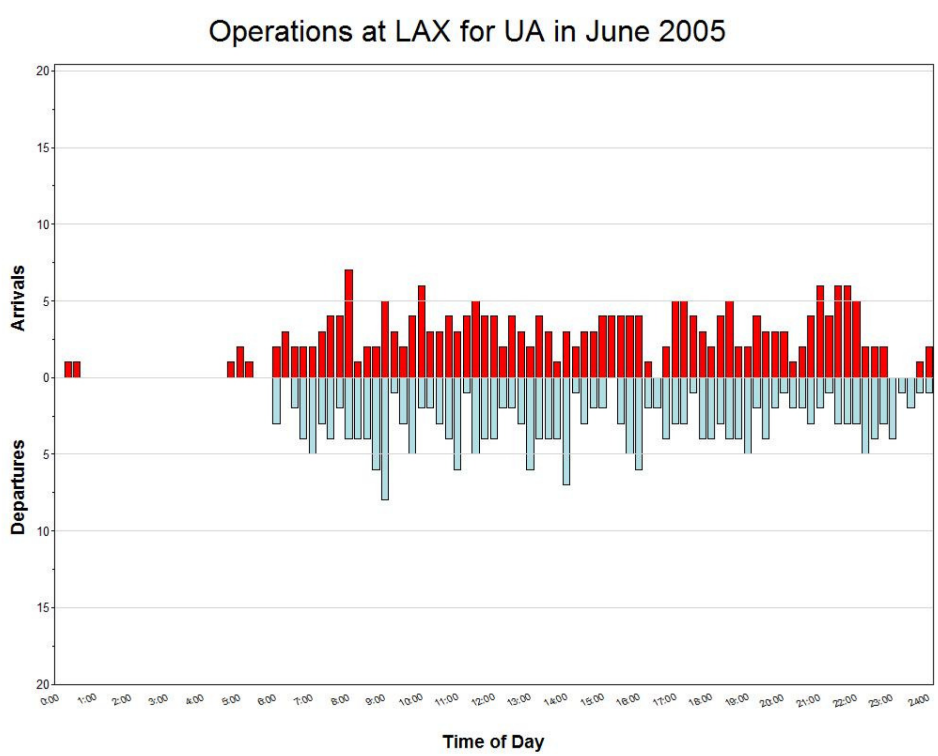

Figure 4.50 Depeaked schedule for United at LAX.

The maximum number of operations in a 15-minute period drops greatly from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 15, while in the depeaked schedule it is 8. The combined number of arrivals and departures in a 15-minute period in the peaked schedule is 19, while it drops to 13 in the depeaked schedule.

The distribution of United's operations at LAX is more spread out throughout the day, as seen in the density function plot shown in Figure 4.51. In this plot, the 15-minute periods are ranked in order of frequency. The depeaked schedule is flatter as compared to the peaked schedule, which has a steep slope. United operated the depeaked schedule across more 15-minute periods than the peaked schedule, showing a greater use of airport facilities across the length of the day. With the depeaked schedule, there was a greater likelihood of passengers being in the terminal across more hours of the day, which is beneficial for airport revenue.

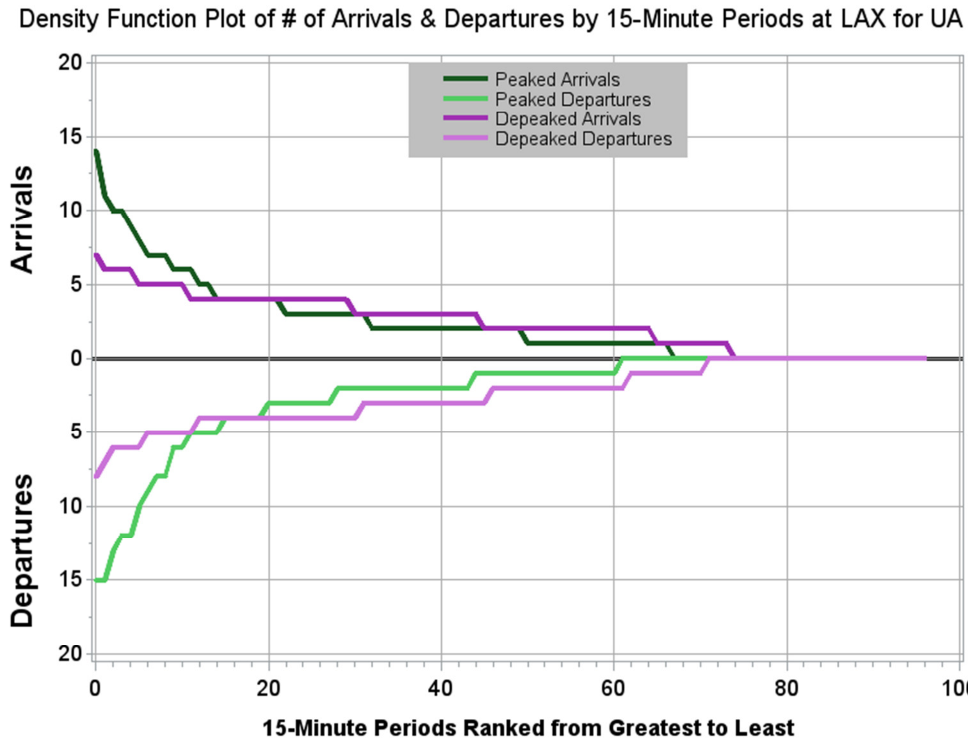

Figure 4.51 Density function plot of United operations at LAX.

Although the activity is more spread out in the depeaked schedule, the total number of flights increased slightly from the peaked schedule. In the peaked daily schedule, in late May 2005, United operated 453 flights out of LAX. This increased to 462 flights by mid-June. The airline retained the same number of destinations during this period. Due to the increased number of flights, daily ASMs increased as well, from just fewer than 47 million to just over 49 million.

4.6.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines stays near constant from the peaked to the depeaked schedule. This percentage is 59.2% for the affiliate airlines in the peaked schedule and 59.3% in the depeaked schedule. This value is for affiliates that reported on-time statistics to the On-Time database, which in 2005 primarily included Skywest Airlines. As seen in Figure 4.52, the affiliate airlines primarily operate in the banks of the schedule, although the affiliate has a large number of flights outside the banks. In the depeaked schedule shown in Figure 4.53, the affiliate airlines operate at a consistent level throughout the day.

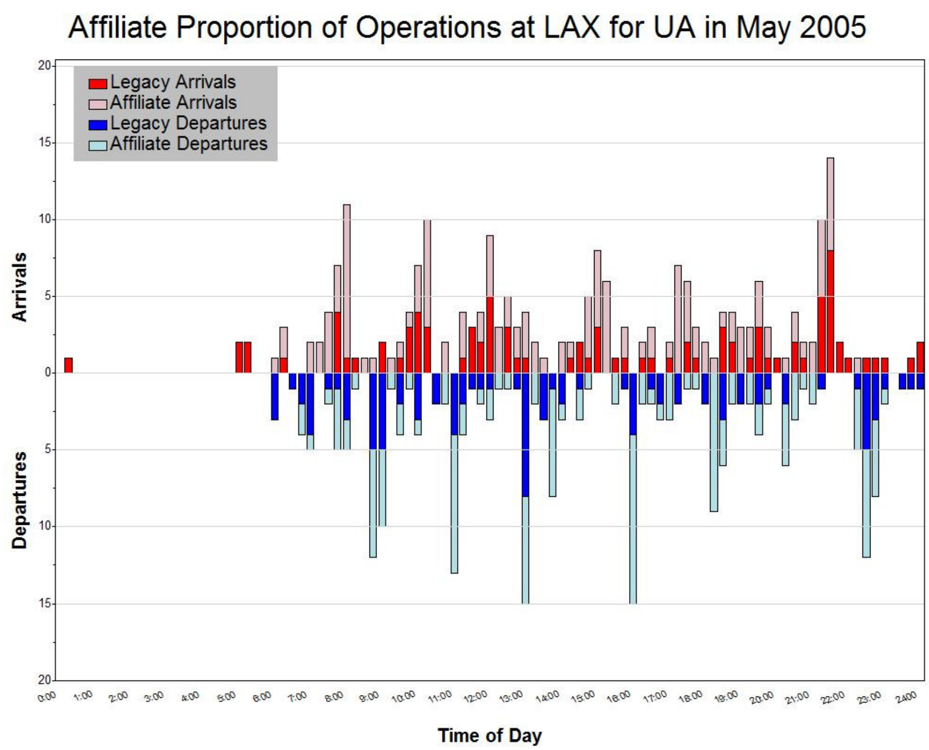

Figure 4.52 Affiliate airlines in the peaked schedule of United at LAX.

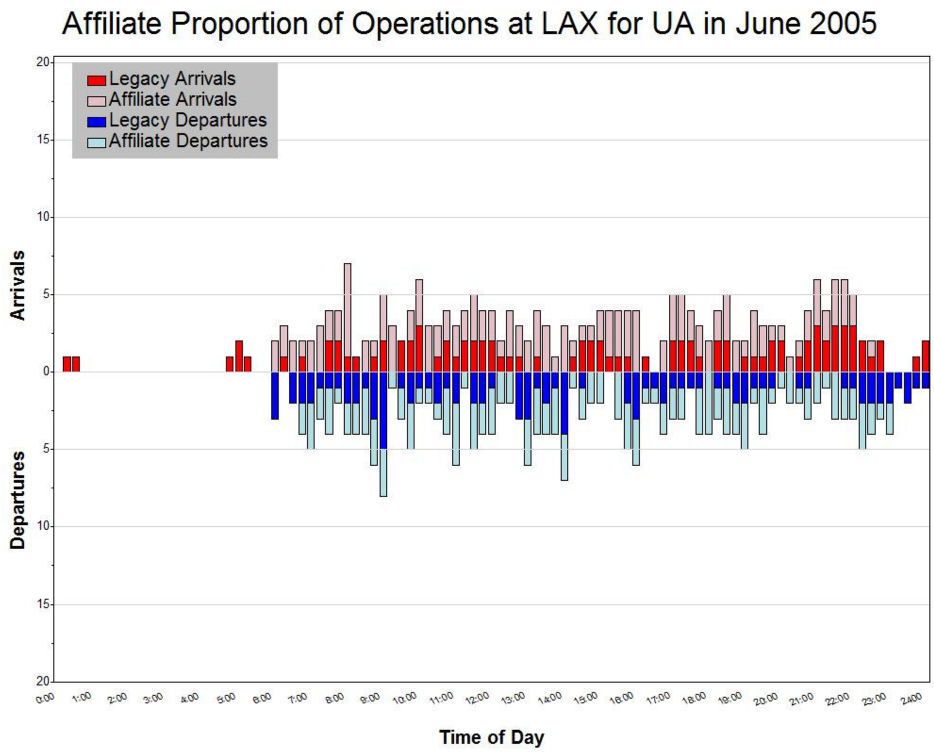

Figure 4.53 Affiliate airlines in the depeaked schedule of United at LAX.

4.6.2.3 Peak/Depeak Measures

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 119.8, which drops to 76.8 in the depeaked schedule. The change for the departures goes from 144.0 to 82.3.

The peak and depeak percentage measures show a drop in the peaked nature of the schedule. In the peaked schedule, 62% of flights occur within the banks, highlighted in Figure 4.54. In the depeaked schedule, 45% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.55. This drop, combined with the changes in the coefficient of variation, indicates a quantitative reduction in the peak level of the schedule.

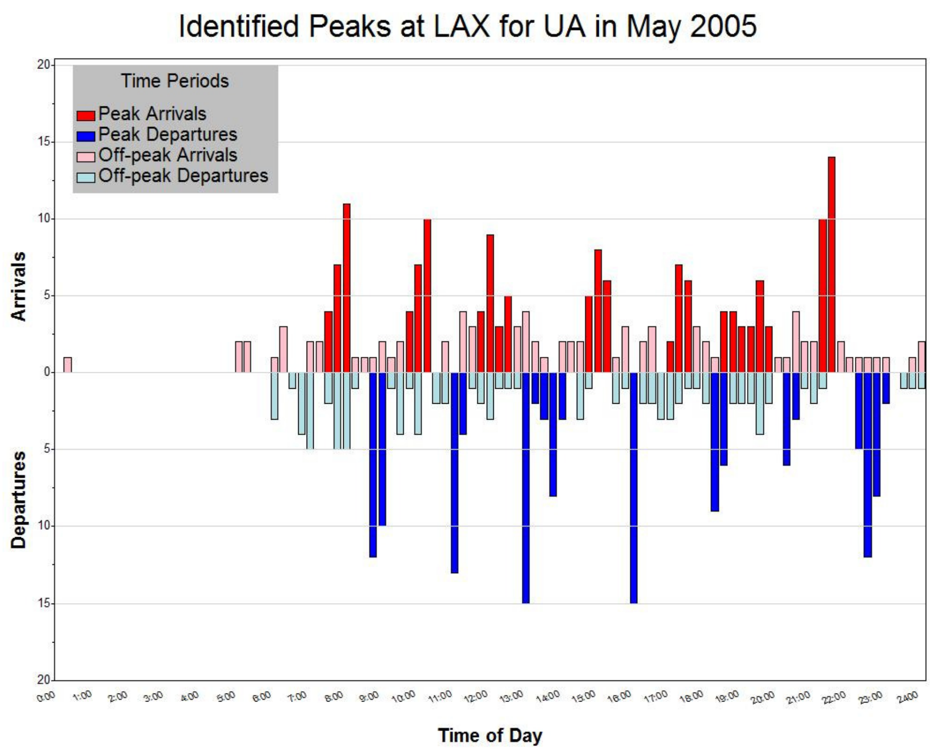

Figure 4.54 Identified banks in the peaked United schedule at LAX.

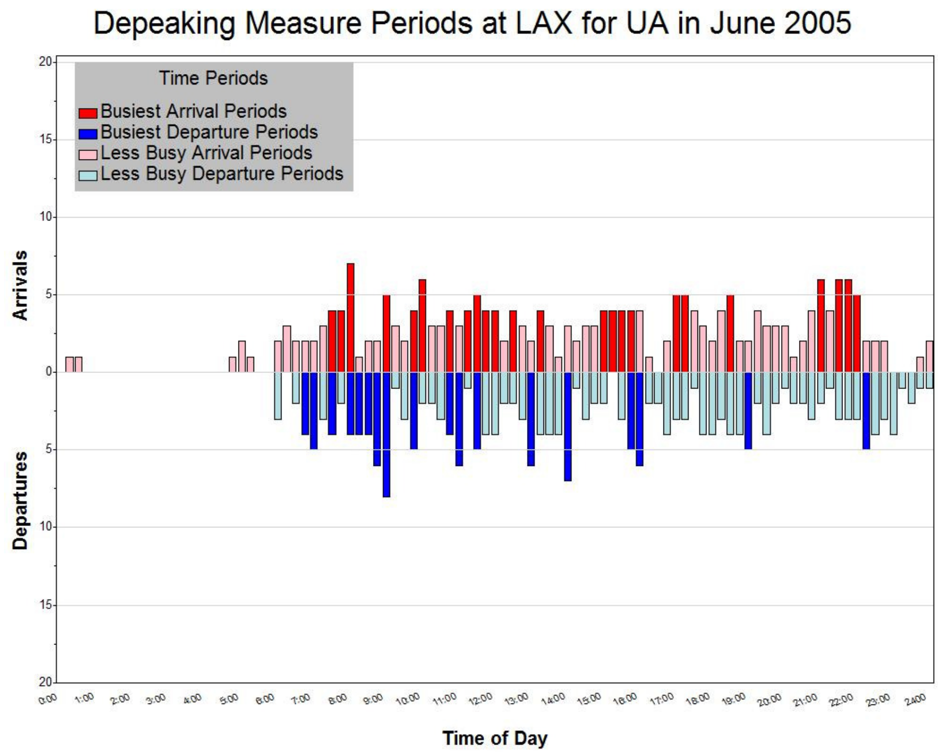

Figure 4.55 Busiest *n* 15-minute periods in the depeaked United schedule at LAX.

4.6.2.4 Connections

The number of connections decreased from the peaked to the depeaked schedule. The peak schedule has 4,774 potential connections from each arriving flight to departing flights within the MCT and MxCT for the given arriving flight. This value decreases to 4,152 in the depeaked schedule. This drop occurs even as the number of flights increases overall. Because of the increasing number of flights and the drop in connections, the average number of connections per arriving flight operated is 21.1 in the peaked schedule, and drops to 18.0 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections increased from 21 to 23 connections from the peaked to the depeaked schedule. In the peaked schedule, 21 connections existed from San Francisco to San Diego (SAN). This same market in the depeaked schedule had 23 daily potential connections. These values are high because, during this period, there were around 20 flights per day from LAX to SAN.

4.6.2.5 Validation of Supply-Demand Time Decision

The peaked date (or depeaked date) supply data was verified as being similar to the schedule used in the peaked quarter (or depeaked quarter) for the analysis. Table 4.43 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.44 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.43 Supply Measures Over Time for United's Peaked Schedule at LAX

Measure	1/11/05	1/25/05	2/8/05	3/1/05	3/22/05	4/5/05	4/19/05	5/10/05	5/24/05
Max. # of flight arrs. or deps. in 15-min. interval	14	16	15	16	15	14	14	15	15
Max. # of flight operations in 15-min. interval	17	19	18	19	18	16	16	19	19
Number of flights flown into or out of hub	426	444	443	460	453	456	455	454	453
Total avail. seat mi. flown into or out of hub (000s)	43736	44118	44117	46818	46968	46088	45255	46146	46842
Number of destinations served from hub	41	41	41	42	42	43	43	42	42
Coefficient of variation in # of arr./dep. flights	124.5/142.7	123.6/143.5	122.5/144.9	124.0/141.8	124.7/143.3	118.3/137.7	118.6/136.5	119.3/144.5	119.8/144.0
Percentage of flights served by affiliate airline(s)	58.9%	59.9%	60.3%	59.8%	59.2%	59.2%	60.0%	59.5%	59.2%
Percentage of flights served in peak period	62.4%	61.0%	59.4%	56.5%	63.1%	58.3%	56.5%	60.8%	62.0%
Number of potential connections	4217	4555	4568	4853	4712	4758	4745	4782	4774
Average connections per arriving flight	20.2	20.7	20.9	21.4	20.9	21.0	21.1	21.3	21.1
Maximum potential connections serving a market	19	21	21	27	25	26	26	24	21

Table 4.44 Supply Measures Over Time for United's Depeaked Schedule at LAX

Measure	6/14/05	6/21/05	6/28/05	7/12/05	7/26/05	8/9/05	8/23/05	9/13/05	9/27/05
Max. # of flight arrs. or deps. in 15-min. interval	8	7	8	8	8	8	8	10	9
Max. # of flight operations in 15-min. interval	13	12	13	13	13	13	13	13	12
Number of flights flown into or out of hub	462	457	465	462	460	463	456	458	460
Total avail. seat mi. flown into or out of hub (000s)	49309	49449	49658	49577	48297	48577	47136	46627	46269
Number of destinations served from hub	42	42	42	41	41	41	41	40	40
Coefficient of variation in # of arr./dep. flights	76.8/82.3	78.4/82.3	76.6/81.8	77.0/83.0	77.0/82.5	78.0/85.5	78.7/85.6	77.5/87.4	77.0/85.9
Percentage of flights served by affiliate airline(s)	59.3%	58.0%	58.7%	58.9%	58.7%	58.8%	59.2%	59.0%	58.7%
Percentage of flights served in peak period	44.6%	45.1%	44.3%	45.2%	45.0%	45.8%	45.8%	47.4%	47.2%
Number of potential connections	4152	4043	4195	4161	4140	4201	4048	4225	4253
Average connections per arriving flight	18.0	17.9	18.2	18.2	18.1	18.3	17.9	18.4	18.5
Maximum potential connections serving a market	23	26	26	23	26	24	24	28	29

4.6.3 Demand Results

The changes in demand and related parameters before and after the depeaking of LAX are shown in Table 4.45. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Around 12.5 thousand average daily passengers traveled on United through LAX in the peaked schedule during the peaked quarter, and this increased to nearly 14 thousand during the depeaked quarter. Overall, the revenue increased from the first to the third quarter of 2005, from $2.6 million to $3.1 million. More importantly, even though ASMs also increased along with revenue, the RASM increased from 5.51 cents per mile to 6.27 cents per mile.

Table 4.45 Summary of Demand and Revenue Changes for United at LAX

Measure	Peaked	Depeaked
Total passengers	12,569	13,788
Revenue ($)	2,581,075	3,093,691
Revenue per available seat mile (RASM) (cents per mile)	5.51	6.27
Percent connecting passengers	32.3%	27.7%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was 30, while 12 markets saw a decrease. RASM increased in 31 markets and decreased in 11.

Across the spokes of LAX, there was an average decrease in connecting traffic from the spoke airports. 32.3% of passengers at LAX on United were connecting passengers under the peaked schedule, and 27.7% were connecting passengers under the depeaked schedule. At the spoke level, 20 spoke routes had an increase in the percentage of passengers on flights between LAX and the spoke. 22 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and LAX. Connecting traffic was likely reduced due to depeaking.

Comparing the change in RASM at LAX to the rest of the airline and the industry helps to see if depeaking was at the root of the increase in RASM. The 0.76 cents per mile increase from the peaked to the depeaked period is a slower increase than both the industry and the rest of United as a whole. Over this same time period, the entire United network saw a 1.17 cents per mile increase in RASM, including United's other hubs in Chicago and San Francisco. The industry as a whole saw a 1.34 cents per mile increase between these two quarters. United's revenue growth at LAX lagged behind the rest of United and the industry as a whole. It is thus possible that the depeaking of LAX could have influenced slower revenue growth.

4.6.4 On-Time Results

The operational effects of depeaking are shown in Table 4.46 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was a reduction in operational performance. There was an overall increase in average delay per aircraft for arrivals, and only a slight decrease for departures. There were, however, more delayed aircraft overall as a percentage of all aircraft. Total delay time increased for both departures and arrivals over this period, and taxi-out and taxi-in times saw increases.

Table 4.46 Summary of Operational Changes for United at LAX

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	4.8	7.0
Average departure delay for delayed aircraft (minutes)	50	48.6
Percentage of delayed departing aircraft	8.1%	12.5%
Total delay for delayed departing aircraft (minutes)	27,950	42,328
Average taxi-out time (minutes)	13.7	14.7
Average arrival delay for all aircraft (minutes)*	6.6	8.3
Average arrival delay for delayed aircraft (minutes)	44.4	52.6
Percentage of delayed arriving aircraft	11.9%	13.3%
Total delay for delayed arriving aircraft (minutes)	36,426	48,678
Average taxi-in time (minutes)	6.0	6.8

***Early arriving and early departing aircraft were assigned zero delay**

Although the operations for United at LAX did not seen an improvement in on-time operations from the peaked to the depeaked period, the decline must be viewed in context with the rest of United's network and the industry over the same period.

Departure delay for delayed aircraft at LAX slightly improved from the peaked to depeaked quarter, but the percentage of delayed aircraft increased by about 4.5 percentage points. These changes, though, look good when compared to the rest of United's network, which increased in departure delay by over 3.5 minutes for delayed aircraft, and there was a 6.5 percentage point increase in delayed aircraft, nearly doubling over the time period. The industry saw an even greater increase in delayed aircraft time, with 10 minutes longer on average for delayed departures and an 11 percentage point increase in delayed departures. In this context, LAX's United operations performed well.

The change in arrival delay showed a decline in performance for United at LAX, but put into perspective with comparative measures, is not as troubling. In terms of arrival delay per delayed aircraft, there was a greater decline at LAX compared to the rest of the airline, but an improvement compared to the industry overall during the same time period. The delay for arriving aircraft increased by 18% for the airline's operations at LAX, while the airline overall had an increase in arrival delay by 12%. The industry, however, saw a 26% percent increase in arrival delay. In terms of number of aircraft affected, the percentage of delayed arriving aircraft increased 12% for United at LAX, but network-wide there was a 39% increase in this performance measure. The industry overall saw a 77% increase.

Although it initially appears that depeaking might have had a negative effect on operations at LAX for United, there was an improvement compared to the rest of the airline and the industry overall,. The decline in on-time operations were not as severe for the airline at the depeaked airport, indicating that depeaking might have prevented further declines in operations by spreading out the banks.

4.6.5 Predicting Changes in Supply

Employing the use of a regression model, analysis was performed on the LAX case study to assess the decision-making process American used in determining how to depeak their schedule. Analysis is done at the spoke level, such that all data is summarized for a spoke airport destination that was served by United during the depeaking period.

The dependent variable, defined as the change in the number of flights on the route between LAX and a spoke, was found to be well-predicted by the variables listed in Table 4.47. The variables include the number of potential connections for flights arriving from the spoke at the hub, the ASM of United's competitors, the log of the average

United fare, and the number of direct passengers flying on the route. All of these variables are significant at the 95% confidence level. The adjusted R^2 for the model is 0.460.

Table 4.47 Regression Model Results for Change in Flights at LAX

Variable	Coefficient	t-stat	p > |t|
Intercept	5.2378	4.89	< 0.001
Potential Connections from spoke at hub	-0.0146	-4.39	< 0.001
ASM of competitors	1.5414 E -7	3.54	0.001
Log (average fare)	-1.0170	-4.69	< 0.001
Direct Passengers	0.0024	3.10	0.004

Note: The SAN observation is removed for being an outlier.

During the first run of this model, and before producing the results seen in Table 4.47, it the model did not pass the homoscedasticity assumption. Particularly, a large outlier in the dependent variable was skewing the data such that its standard error was minimized. This outlier was San Diego (SAN), which United served through high frequency shuttle service through its LAX hub. Frequency from LAX to SAN was already higher than any other route for United, and the addition of eight flights for this popular route made it much larger than any other change. The outlier effect misrepresented the cause of the changes to other spokes, so the SAN observation was removed.

After the SAN observation was removed, the model passed all three tests for the normality, linearity, and homoscedasticity assumptions. The normal probability plot in Figure 4.56 shows a straight line of residuals falling close to the diagonal line in the plot, indicating that the distribution is normal. The regression was still checked against a count model and the direction of the variables were the same as those in the regression model, providing assurance that the fit was appropriate.

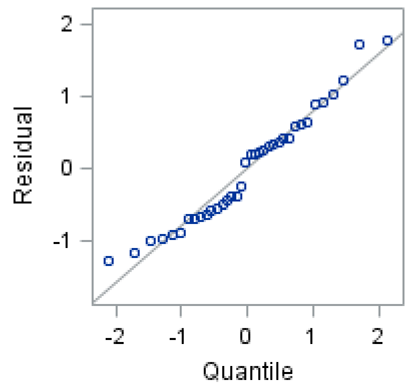

Figure 4.56 Normal probability plot for LAX case. The plot is shown without the SAN observation.

United Airlines' strategy for depeaking LAX, as determined by the results of the regression model, showed a focus on routes with higher levels of direct passenger traffic, and less attention paid to building connections at the hub. There also was a focus on increasing flights on routes which had a larger number of competitor ASMs. Spoke airports which saw increases in frequency, with high levels of direct traffic and without an emphasis on potential connections, included Honolulu (HNL), Kahului, HI (OGG), New York JFK, and Portland (PDX). Spoke airports that saw decreases in frequencies were associated with lower numbers of direct passengers include Phoenix (PHX), Tucson (TUS), and Denver (DEN). HNL, JFK, and OGG all also have high levels of competitor ASMs, compared to PHX, TUS, and DEN. Based on the airports which saw increase and the factors involved in the decision, it appears United was looking to beat out the competition on longer flights with higher direct traffic. In addition, low fare flights also received a boost from United, particularly spokes geographically close to LAX. These included Ontario, CA (ONT), Orange County, CA (SNA), and San Luis Obispo, CA (SBP).

United's strategy at LAX can be described as focusing on long-haul routes that provided high levels of direct traffic. Part of this motivation likely came from trying to beat the competition on these routes. The concern did not lie with maximizing connections. Nearby airports in Southern California also received boosts, including the outlier of San Diego.

4.6.6 Assessing Depeaking and Effects

The changes in the supply and demand results that occurred during the depeaking period could have likely been due to depeaking. Year-over-year measures were calculated in order to better understand whether the changes that occurred were potentially due to depeaking as opposed to being a typical change for that time of the year. The percentage change between the peaked and depeaked dates is calculated, as well as for the year before and year after on similar dates.

For the LAX case, it is evident that many of the supply changes were due to depeaking. Table 4.48 shows schedule measures and reports a percentage change associated with each year. In the case of United, depeaking occurred in 2005. May 24, 2005 was used as the representative Tuesday peaked schedule and June 14, 2005 was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2005 shows the change in schedule measures between these two dates. The process is repeated for two dates each in the years 2004 and 2006, using representative

Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2004 change is between two peaked schedules and the 2006 change is between two depeaked schedules. Thus only the 2005 change is for changes that occurred between different schedule types.

Table 4.48 Supply Year-Over-Year Changes for United at LAX

Measure	2004				2005				2006			
	5/25	6/15	Δ	%	5/24	6/14	Δ	%	5/23	6/13	Δ	%
Max. number of flight arrs. or deps. in a 15-minute interval	17	18	1	6%	15	8	**-7**	**-47%**	9	10	1	11%
Max. number of flight operations in a 15-minute interval	17	21	4	24%	19	13	**-6**	**-32%**	12	13	1	8%
Number of flights flown into or out of hub	459	449	-10	-2%	453	462	9	2%	465	475	10	2%
Total available seat miles flown into or out of hub (000s)	53130	54438	1308	2%	46843	49309	2467	5%	52018	54342	2325	4%
Number of destinations served from hub	41	43	2	5%	42	42	0	0%	44	45	1	2%
Coefficient of variation in number of arrivals	139.7	116.1	-23.6	-17%	119.8	76.8	**-43**	**-36%**	81.5	78.3	-3.2	-4%
Coefficient of variation in number of departures	149.4	144.7	-4.7	-3%	144	82.3	**-61.7**	**-43%**	94	87.8	-6.2	-7%
Percentage of flights served by affiliate airline(s)	54.5%	51.7%	-2.8%	-5%	59.2%	59.3%	0.1%	0%	58.1%	57.5%	-0.6%	-1%
Percentage of flights served in peak period	68.2%	63.0%	-5.2%	-8%	62.0%	44.6%	**-17.4%**	**-28%**	48.8%	45.0%	-3.8%	-8%
Number of potential connections	5114	4602	-512	-10%	4774	4152	-622	-13%	4320	4326	6	0%
Average connections per arriving flight	22.2	20.6	-1.6	-7%	21.1	18	**-3.1**	**-15%**	18.6	18.2	-0.4	-2%
Maximum potential connections serving a market	24	26	2	8%	21	23	2	10%	24	27	3	13%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages represent changes most evident by United's depeaking. From the year-over-year data, it is evident that depeaking involved a reduction in the number of flights flown in a given period and the creation of a more even distribution of flights (as evidenced by the reduction in the coefficients of variation and reduction in peak percentage). These changes contributed to a drop in the number of potential connections per arriving flight, indicating that the spreading out of the operations led to lower likelihood for a passenger to have a useful connection.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases, because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus RASM is used in comparison still with the RASM of the airline network and for the industry.

One measurement which is useful in terms of demand in measuring it year-over-year is the percentage of connecting passengers. The percent of connecting passengers in 2005, however, did not deviate from the change seen across the same time periods in 2004 and 2006. In each year, between the two quarters sampled, connecting traffic dropped between 12% and 14%. Thus this change seems more tied to seasonality.

The change in RASM for United's LAX schedule is on par in terms of percentage change for all three years examined. In the depeaking year, although the actual change in RASM lags behind the rest of United and the industry, in terms of percentage change it is the same. 2006 was very similar to 2005 in that the actual RASM growth value, of 0.55, was less than United overall, 1.12, and the industry, 0.83. But as seen in Table 4.49, the percent change in RASM was on par or exceeded the industry and network growth in each of the three years. This indicates that the RASM underperformance for United at LAX was not more poor in the depeaking year than in other years.

Table 4.49 RASM Year-Over-Year Changes for United at LAX

Measure	2004				2005				2006			
	Q1	Q3	Δ	%	Q1	Q3	Δ	%	Q1	Q3	Δ	%
RASM for Depeaked Airport	4.99	5.77	0.78	16%	5.51	6.27	0.76	14%	6.00	6.55	0.55	9%
RASM for Airline Network	7.39	8.35	0.96	13%	8.6	9.77	1.17	14%	9.72	10.84	1.12	12%
RASM for Industry	8.64	9.07	0.43	5%	8.7	10.04	1.34	15%	9.87	10.7	0.83	8%

Operationally, United's operations at LAX saw notable changes year-over-year in the departure delay and the percentage of delayed departing aircraft, as shown in Table 4.50. Departure delay improved in the depeaking year for the depeaked airport, while it increased elsewhere. When compared year-over-year, the year before and year saw this measure be on par with or worsen when compared to the rest of United's network and the industry. A similar situation exists with the percentage of delayed departing aircraft. In the depeaking year, this percentage increased less than United's entire network and the industry, but in the year before and year after, it increased more than the comparative measures. This suggests that in the depeaking year there was a notable shift in the percentage of delayed departing aircraft. For arriving aircraft, there was no notable change in the depeaking year when compared to the year before and year after.

Table 4.50 Operations Year-Over-Year Changes for United at LAX

Measure	2004				2005				2006			
	May	Jul	Δ	%	May	Jul	Δ	%	May	Jul	Δ	%
Dep. Delay Depeaked Airport	54.4	51.1	-3.3	-6%	50.0	48.6	-1.4	-3%	47.1	55.0	7.9	17%
Dep. Delay Airline Network	67.4	62.1	-5.3	-8%	58.3	61.9	3.6	6%	60.9	65.9	5.0	8%
Dep. Delay Industry	57.7	55.4	-2.3	-4%	49.9	60.1	10.2	20%	51.8	58.0	6.2	12%
% Delayed Dep. Depeaked Airport	8.8	9.6	0.8	9%	8.1	12.5	4.4	54%	15.6	19.3	3.7	24%
% Delayed Dep. Airline Network	14.4	14.6	0.2	1%	13.7	20.2	6.5	47%	19.2	21.9	2.7	14%
% Delayed Dep. Industry	16.8	19.5	2.7	16%	13.3	24.4	11.1	83%	18.5	22.7	4.2	23%
Arr. Delay Depeaked Airport	49.9	49.5	-0.4	-1%	44.4	52.6	8.2	18%	46.5	56.1	9.6	21%
Arr. Delay Airline Network	64.6	59.6	-5	-8%	55.7	62.4	6.7	12%	59.0	64.4	5.4	9%
Arr. Delay Industry	57.4	55.4	-2	-3%	48.6	61.3	12.7	26%	51.9	58.7	6.8	13%
% Delayed Arr. Depeaked Airport	13.9	12.7	-1.2	-9%	11.9	13.3	1.4	12%	19.6	21.0	1.4	7%
% Delayed Arr. Airline Network	19.4	18	-1.4	-7%	16.1	22.3	6.2	39%	22.7	24.2	1.5	7%
% Delayed Arr. Industry	20.8	22.6	1.8	9%	15.4	27.3	11.9	77%	20.6	24.8	4.2	20%

In summary, the supply changes for United at LAX showed an observable difference from the surrounding years. Thus it appears depeaking had an effect on the number of potential connections in the schedule, and certainly altered the schedule itself in how it was structured. The changes in demand however were not different from what occurred over a longer period of time. Instead it appears the changes were more typical to what occurred during that point in history for United. For operations, the departing aircraft appear to have had a notable improvement in delay in the depeaking year, while arriving aircraft did not see a corresponding improvement.

4.6.7 Summary

The changes to the schedule made at LAX by United during depeaking were considerable. There was a reduction in the number of flights flown as the airline created a more even distribution of flights across its schedule. The focus during this period was to increase frequency for long-haul routes that had high levels of direct traffic, in an attempt to beat out competition on these routes. Nearby airports in the larger region also saw increased frequency, reflecting United's focus on providing strong west coast shuttle service. United did not focus on maximizing connections, and thus saw a drop in connections per arriving flights in the schedule.

The effects of depeaking showed a benefit for operations and no decline in revenue. Even though operations saw a decrease during this period, it was in fact an improvement over the rest of United and the industry. It is likely that depeaking prevented a further increase in delay. In terms of revenue, despite the drop in connections, RASM was on par with other changes occurring across United and the industry. Even looking year-over-year, it appears that RASM for United at LAX did not suffer.

4.7 United Airlines at San Francisco (SFO)

The final depeaking case in this study chronologically is United's depeaking of San Francisco in the winter of 2006. SFO was the third airport United depeaked, with ORD and LAX previously getting depeaked in the previous two years. SFO's depeaking, however, is unique among the cases in that it happened slowly; United transitioned away the peaks gradually over two months. This slow pull-down, with changes occurring on a rolling basis is very different from the immediate transformation the airports in the other cases experienced.

United had left bankruptcy in June 2005, and began transitioning SFO to a depeaked schedule in January of 2006. Just prior to depeaking SFO, Delta and Northwest each declared bankruptcy, indicating the instability still existing in the industry. United was still running depeaked schedules at both ORD and LAX during this period. United removed SFO's seven arrival and departure peaks, but not drastic changes like the other cases were depeaked. By late January, remnants of peaks still were present in the schedule, and it was not until the end of February that the SFO schedule was finished getting depeaked.

4.7.1 Data Periods Used and Input Parameters

United Airlines depeaked SFO initially on Monday January 9, 2006. As mentioned previously, this was not a drastic change, and the schedule retained some characteristics of banks. It was not until the end of February that the schedule was fully depeaked. Thus the peak and depeak schedule dates are over two months apart. The date used to represent the peak schedule is Tuesday December 20, 2005. The date used to represent the depeaked schedule is Tuesday February 28, 2006.

Because United depeaked SFO only nine days into the first quarter of 2006, it was decided that the first quarter could serve as the depeaked quarter for demand data. About one week of demand data being under the peaked schedule, with a slow transition to fully depeaked, was seen as less of an issue than looking ahead nearly three months to get demand data. In addition, it could be possible to describe how a slow transition to depeaking potentially differed from a drastic change. The fourth quarter of 2005 is used as the peaked quarter for demand data. The peaked month used for operational measures is December 2005; the depeaked month is February 2012.

For creating year-over-year measures, December 14, 2004 and February 15, 2005 were used as the supply comparison dates the year prior. December 19, 2006 and February 27, 2007 were used as the supply comparison dates for the year after depeaking. The fourth quarter of 2004 and the first quarter of 2005 are used as the year prior demand comparison quarters, and the fourth quarter of 2006 and the first quarter of 2007 are used for the year after. December 2004 and February 2005 are used for the year prior operational comparison months, and December 2006 and February 2007 are used for the year after.

The distribution of actual connection times made at SFO for passengers flying on United itineraries is shown in Figure 4.57. This distribution is from itineraries flown in June 2010. At that time, SFO was still operating under a depeaked schedule. The 5th and 75th percentiles, indicating the MCT and MxCT are denoted in the figure. For this case, the MCT is 35 minutes and MxCT is 109 minutes.

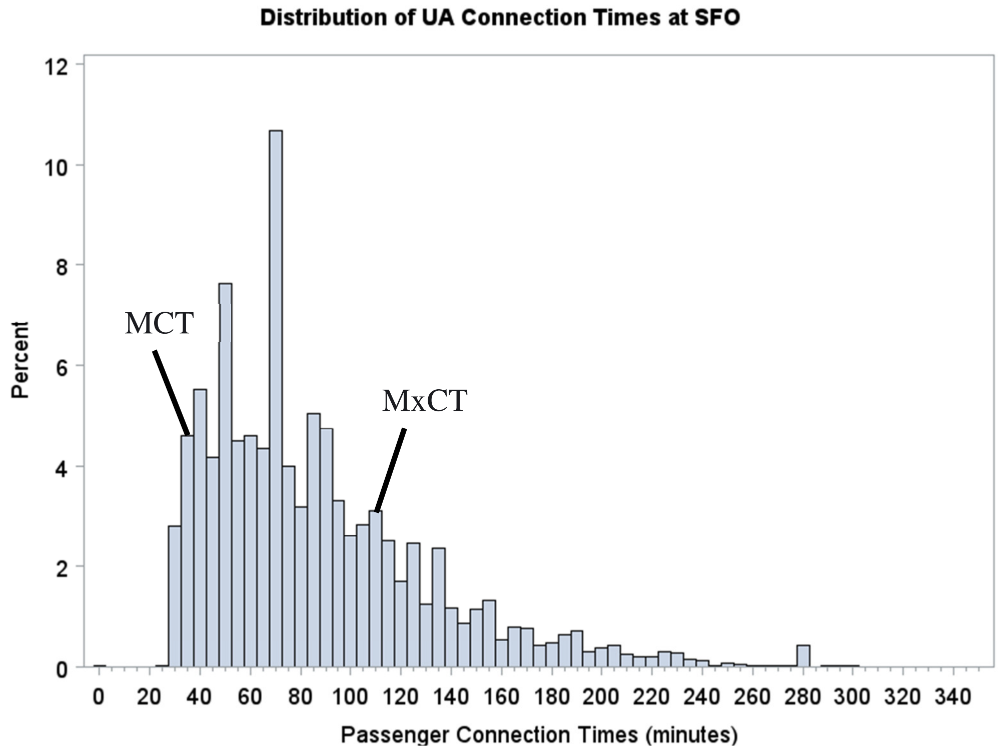

Figure 4.57 Connection time distribution for UA at SFO. MCT and MxCT are denoted.

4.7.2 Supply Results

The following section describes the supply-side results for United's depeaking of SFO, which includes data which is calculable using the On-Time database. Table 4.51 summarizes the supply measures representing peaked and depeaked schedules that are discussed in this section.

Table 4.51 Summary of Supply Changes for United at SFO

Measure	Peaked	Depeaked
Max. number of flight arrs. or deps. in a 15-minute interval	14	11
Max. number of flight operations in a 15-minute interval	17	16
Number of flights flown into or out of hub	445	440
Total available seat miles flown into or out of hub	57,228,077	55,062,705
Number of destinations served from hub	46	48
Coefficient of variation in number of arr./dep. flights	101.7/128.2	87/101.9
Percentage of flights served by affiliate airline(s)	42.7%	45.5%
Percentage of flights served in peak period	68.5%	65.7%
Number of potential connections	4,066	3,621
Average connections per arriving flight	18.3	16.8
Maximum potential connections serving a market	16	13

4.7.2.1 General Supply

United Airlines' reproduced peaked schedule at SFO is shown in Figure 4.58 and the reproduced depeaked schedule in Figure 4.59.

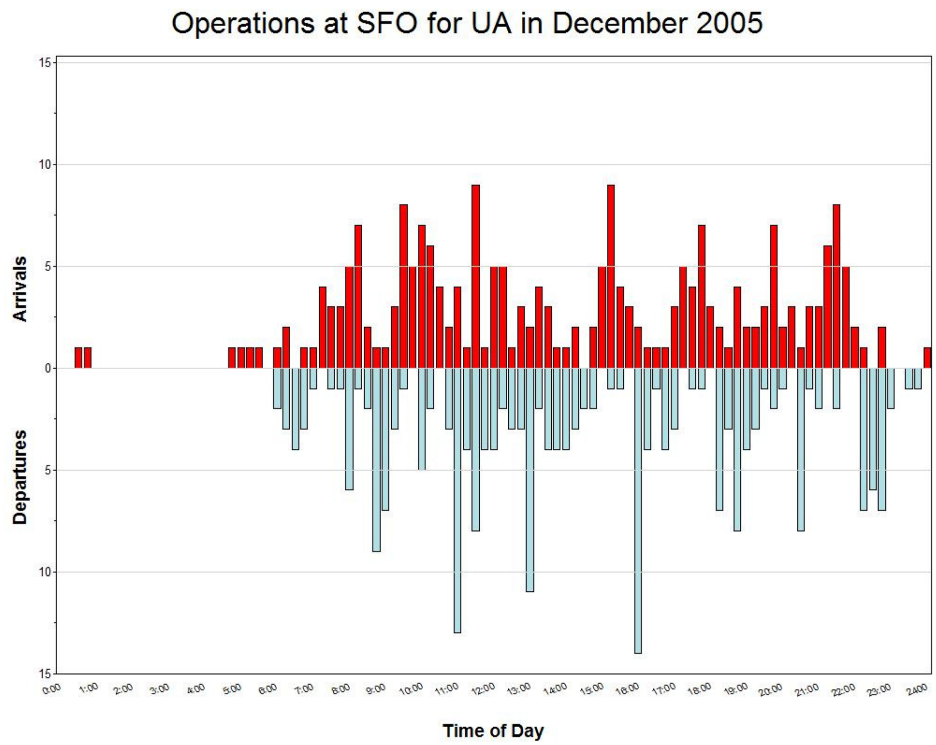

Figure 4.58 Peaked schedule for United at SFO.

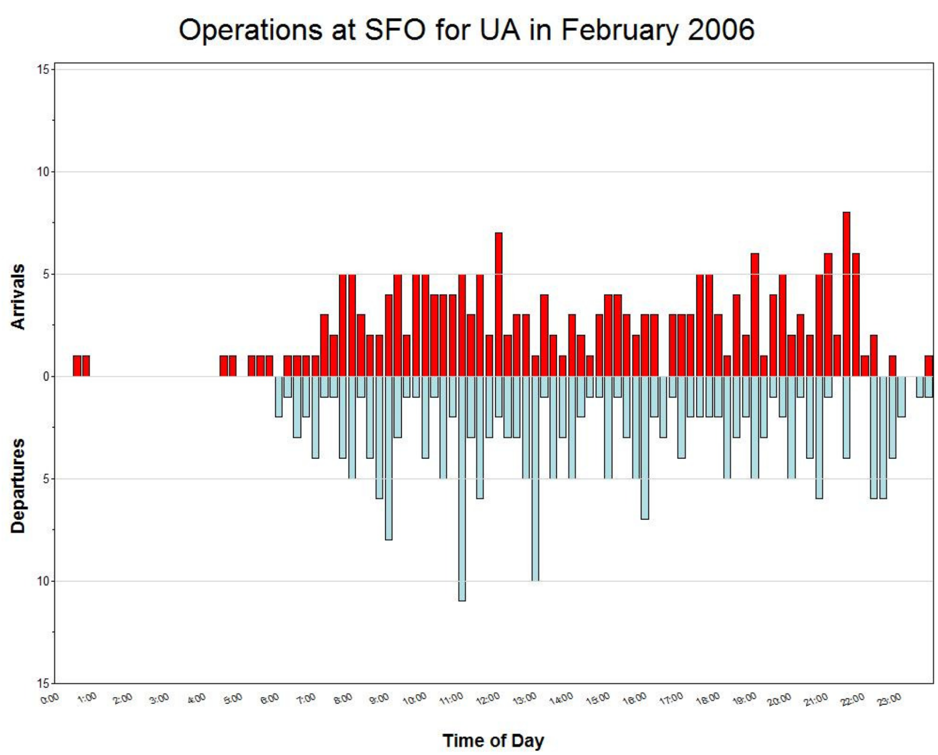

Figure 4.59 Depeaked schedule for United at SFO.

The maximum number of operations in a 15-minute period drops from the peaked to the depeaked schedule. In the peaked schedule, the maximum number of either arrivals or departures is 14, while in the depeaked schedule it is 11. The combined number of arrivals and departures in a 15-minute period in the peaked schedule is 17, while it drops to 16 in the depeaked schedule. United's SFO schedule retains some busier periods of activity, even without the banks.

The distribution of United's operations at SFO between the peaked and depeaked periods is similar throughout the day, as seen in the density function plot shown in Figure 4.60. In this plot, the 15-minute periods are ranked in order of frequency. Although the maximum number of operations in arrivals and departures is decreased moving to the depeaked schedule, the rest of the curves are similar. The depeaked departures get slightly more spread out compared to the peaked schedule than the depeaked arrivals as compared to the peaked arrivals.

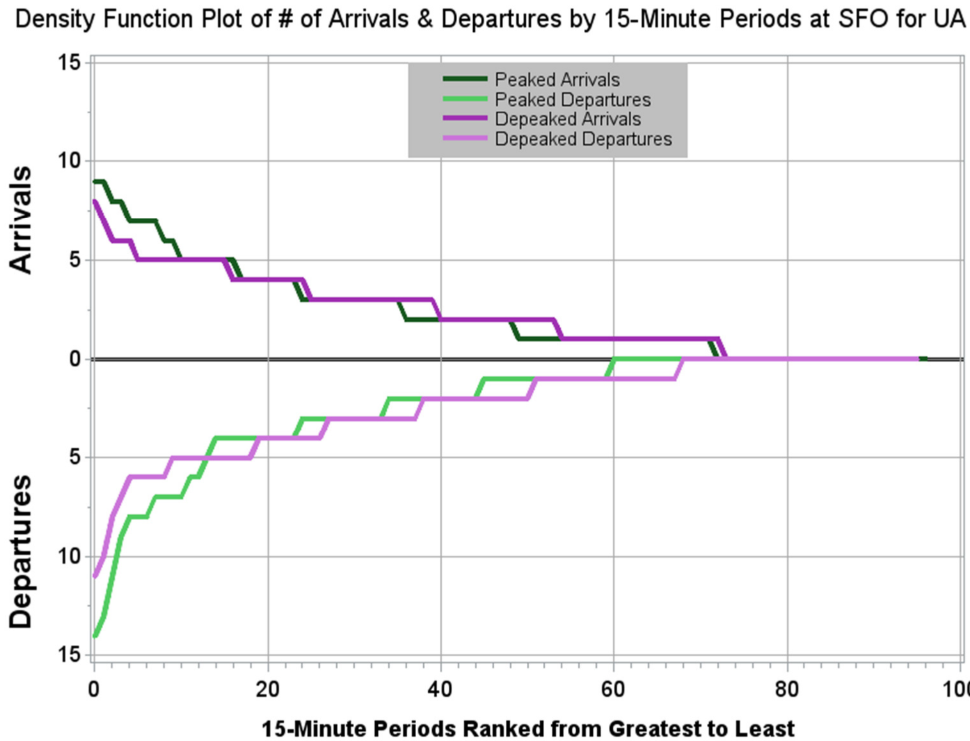

Figure 4.60 Density function plot of United operations at SFO.

Although the activity is slightly more spread out in the depeaked schedule, the total number of flights stays almost the same from the peaked schedule. In the peaked daily schedule in late December of 2005 United operated 445 flights out of San Francisco, and this decreased to 440 flights by late February. United added two destinations to their network under the depeaked schedule: Boise and Palm Springs, CA. Partially due to the decreased number of flights, daily ASMs decreased as well, from just over 57 million to just above 55 million.

4.7.2.2 Affiliate Airlines

The percentage of flights operated by affiliate airlines rises slightly from the peaked to the depeaked schedule. This percentage is 42.7% for the affiliate airlines in the peaked schedule and 45.5% in the depeaked schedule. This value is for affiliates that reported on-time statistics to the On-Time database, which in late 2005 and early 2006 primarily included Skywest Airlines. As seen in Figure 4.61, the affiliate airlines mostly operate in the banks of the schedule, although the affiliate certainly has a large number of flights outside the banks. In the depeaked schedule shown in Figure 4.62, the affiliate airlines operate at a consistent level throughout the day, with more in the busiest periods.

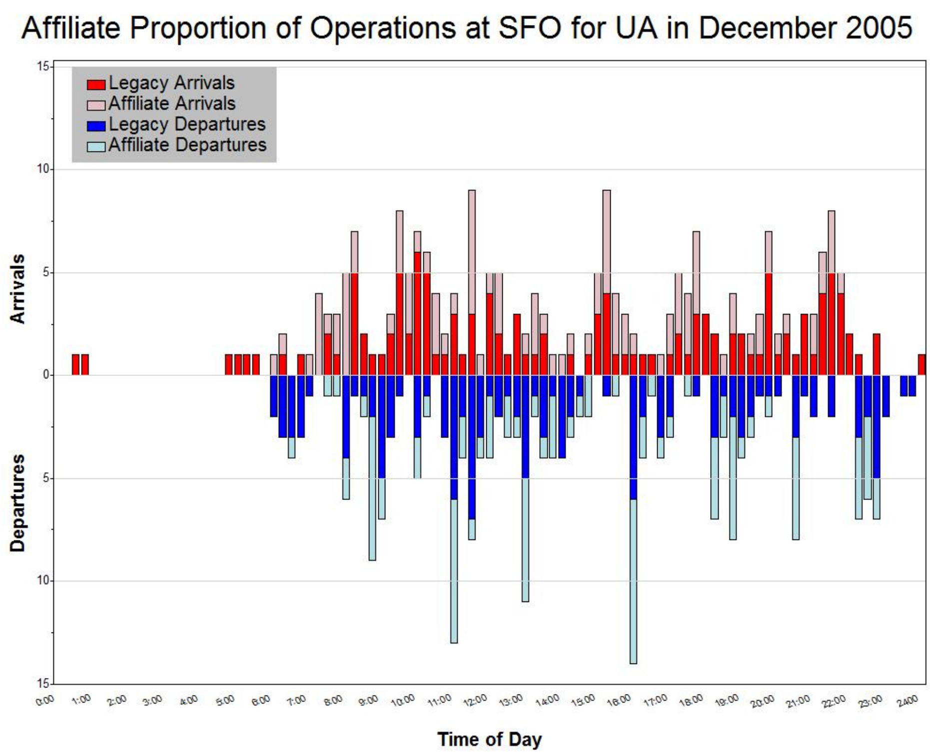

Figure 4.61 Affiliate airlines in the peaked schedule of United at SFO.

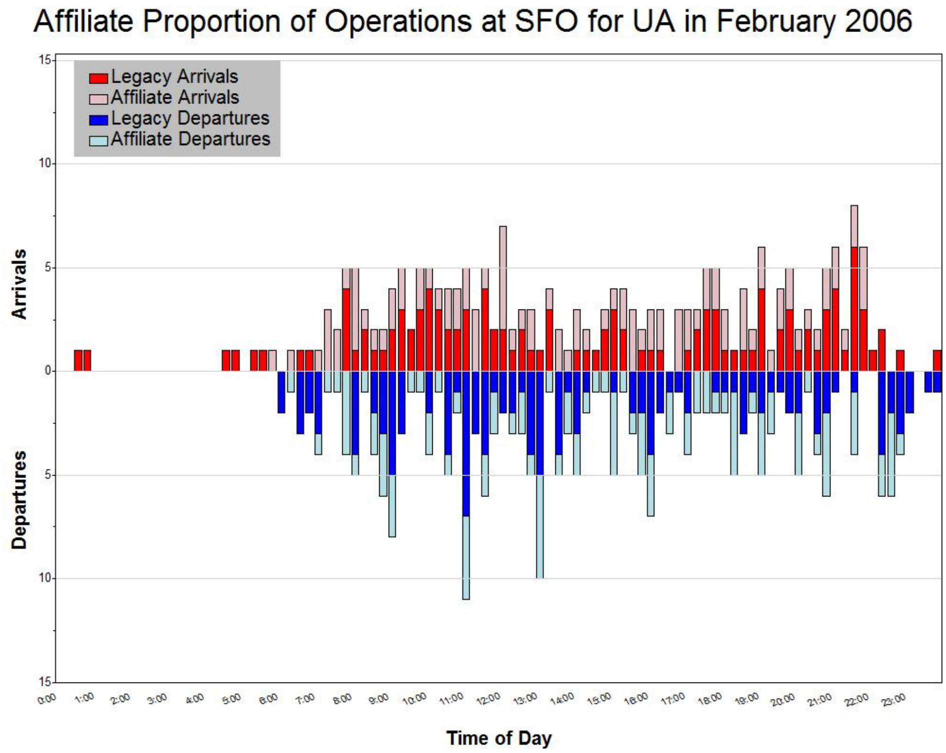

Figure 4.62 Affiliate airlines in the depeaked schedule of United at SFO.

4.7.2.3 Peak/Depeak Measures

The coefficient of variation decreases from the peaked to the depeaked schedule, as the level of activity becomes more consistent across 15-minute periods. The arrivals in the peaked schedule have a coefficient of variation of 101.68, which drops to 87.0 in the depeaked schedule. The change for the departures goes from 128.2 to 101.9.

The peak and depeak percentage measures show a slight drop in the peaked nature of the schedule. In the peaked schedule, 69% of flights occur within the banks, highlighted in Figure 4.63. In the depeaked schedule, 66% of flights occur in the corresponding busiest periods of the depeaked schedule, as shown in Figure 4.64. This drop, combined with the changes in the coefficient of variation, both indicate that SFO was depeaked less than the other cases. The change overall, even after the transition period, was not very large. The banks certainly disappear, but periods of activity in the depeaked schedule, particularly in the departures, show that it was not as much of a depeaking as previous instances.

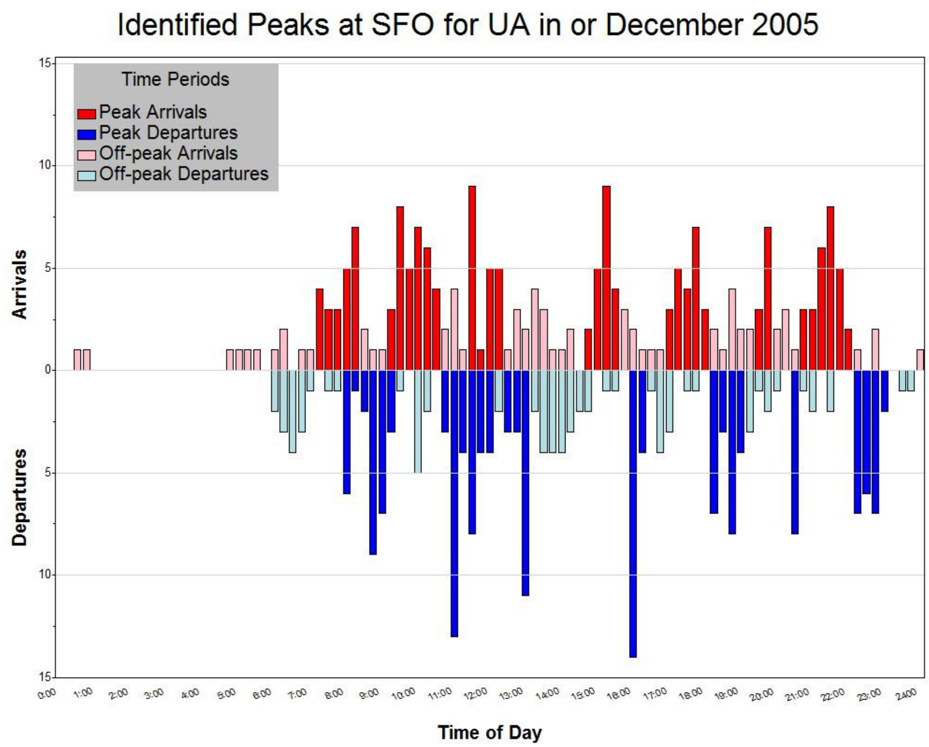

Figure 4.63 Identified banks in the peaked United schedule at SFO.

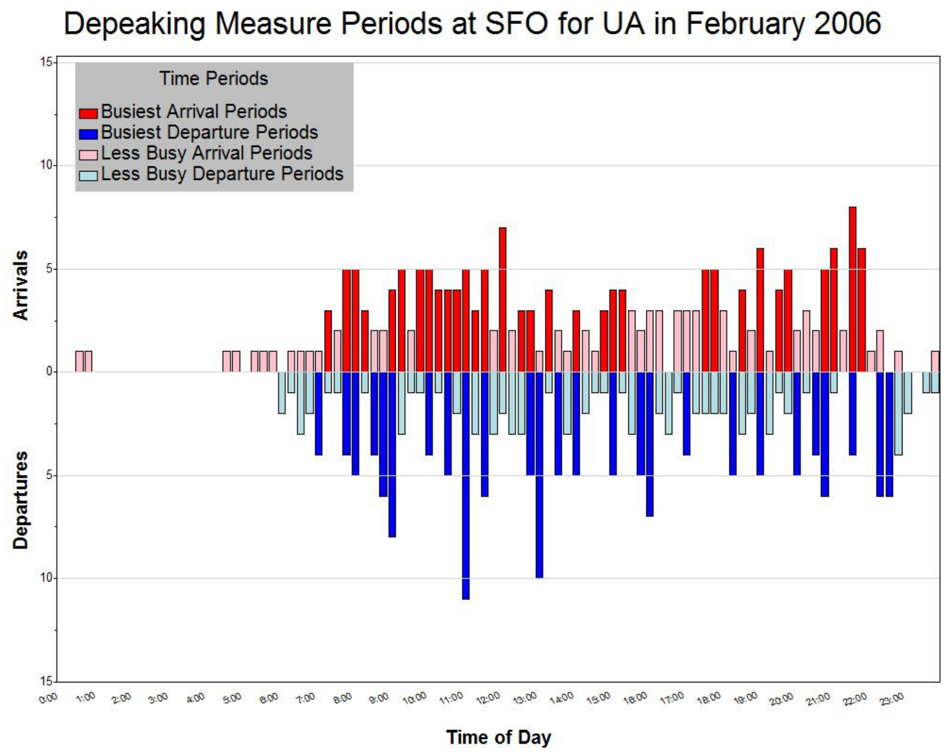

Figure 4.64 Busiest *n* 15-minute periods in the depeaked United schedule at SFO.

4.7.2.4 Connections

The number of connections decreased from the peaked to the depeaked schedule. The peak schedule has 4,066 potential connections from each arriving flight to departing flights within the MCT and MxCT for the given arriving flight. This value decreases to 3,621 in the depeaked schedule. This reduction, even with the drop in number of flights, decreases the average number of connections per arriving flight operated from 18.3 in the peaked schedule to 16.8 per arriving flight in the depeaked schedule.

The market which had the maximum number of potential connections decreased from 16 to 13 connections from the peaked to the depeaked schedule. In the peaked schedule, 16 connections existed from Sacramento (SMF) to LAX. In the depeaked schedule, 13 connections existed daily from LAX to Seattle (SEA).

4.7.2.5 Validation of Supply-Demand Time Decision

The schedule on the peaked date (or depeaked date) supply data was verified as being similar to the schedule used in the peaked quarter (or depeaked quarter) for the analysis. Table 4.52 shows the changes in supply over time for the quarter before the peaked date up until the peaked date. Table 4.53 shows the changes in supply for the quarter after the depeaked date from the depeaked date and after.

Table 4.52 Supply Measures Over Time for United's Peaked Schedule at SFO

Measure	10/4/05	10/18/05	11/1/05	11/15/05	11/29/05	12/6/05	12/13/05	12/20/05
Max. # of flight arrs. or deps. in 15-min. interval	15	15	14	14	13	14	14	14
Max. # of flight operations in 15-min. interval	17	17	18	18	16	17	18	17
Number of flights flown into or out of hub	449	447	446	439	427	439	443	445
Total avail. seat mi. flown into or out of hub (000s)	54469	54101	53779	52962	53410	53347	54163	57228
Number of destinations served from hub	46	46	47	47	47	47	47	46
Coefficient of variation in # of arr./dep. flights	113.8/142.9	113.7/143.1	112.1/135.9	111.0/137.7	110.0/135.3	110.5/139.5	111.6/136.7	101.7/128.2
Percentage of flights served by affiliate airline(s)	43.2%	43.9%	44.8%	45.1%	41.5%	44.0%	43.6%	42.7%
Percentage of flights served in peak period	75.3%	74.1%	71.8%	70.8%	72.4%	69.9%	71.8%	68.5%
Number of potential connections	4279	4243	4342	4225	3914	4164	4277	4066
Average connections per arriving flight	19.1	19.0	19.6	19.2	18.3	19.0	19.3	18.3
Maximum potential connections serving a market	12	12	16	16	16	15	16	16

Table 4.53 Supply Measures Over Time for United's Depeaked Schedule at SFO

Measure	2/28/06	3/7/06	3/21/06	4/11/06	4/25/06	5/9/06	5/23/06	6/6/06	6/20/06
Max. # of flight arrs. or deps. in 15-min. interval	11	12	12	12	13	13	13	14	11
Max. # of flight operations in 15-min. interval	16	17	18	18	19	16	16	17	14
Number of flights flown into or out of hub	440	452	458	425	468	452	441	457	457
Total avail. seat mi. flown into or out of hub (000s)	55063	53886	56448	56671	56131	54509	54864	54175	59632
Number of destinations served from hub	48	48	48	48	48	48	48	48	49
Coefficient of variation in # of arr./dep. flights	87/101.9	83.4/102.0	84.4/100.8	93.2/102.4	87.0/97.4	87.6/98.6	87.4/99.1	88.4/99.8	88.0/94.3
Percentage of flights served by affiliate airline(s)	45.5%	47.6%	46.9%	40.9%	46.2%	45.8%	44.4%	46.2%	43.8%
Percentage of flights served in peak period	65.7%	63.7%	63.8%	65.7%	63.0%	64.4%	64.2%	63.7%	61.9%
Number of potential connections	4191	3846	3947	3521	4082	3749	3593	3864	3789
Average connections per arriving flight	19.4	17.0	17.2	16.5	17.4	16.6	16.4	16.9	16.5
Maximum potential connections serving a market	14	13	12	15	14	12	11	12	14

4.7.3 Demand Results

The changes in demand and related parameters before and after the depeaking of SFO are shown in Table 4.54. The data comes from the peaked and depeaked quarters. The values are the average daily values from across the quarter. Just over 18 thousand average daily passengers traveled on United through SFO in the peaked schedule during the peaked quarter, and this decreased to around 16 thousand during the depeaked quarter. Overall revenue decreased from the fourth quarter of 2005 to the first quarter of 2006, from $3.8 million to $3.6 million. Along with the revenue, ASMs also decreased, but the revenue drop was considerable enough that RASM decreased from 6.68 cents per mile to 6.62 cents per mile.

Table 4.54 Summary of Demand and Revenue Changes for United at SFO

Measure	Peaked	Depeaked
Total passengers	18,300	16,105
Revenue ($)	3,821,204	3,647,050
Revenue per available seat mile (RASM) (cents per mile)	6.68	6.62
Percent connecting passengers	30.1%	30.5%

On a per market basis, the number of markets in which gross revenue increased between the two quarters was 14, while 34 markets saw a decrease. RASM increased in 23 markets, and decreased in 25.

Across the spokes of SFO there was an average increase in connecting traffic from the spoke airports. 30.1% of passengers at SFO on United were connecting passengers under the peaked schedule, and 30.5% were connecting passengers under the depeaked schedule. At the spoke level, 25 spoke routes had an increase in the percentage of passengers on flights between SFO and the spoke that made connections. 23 spoke routes saw an increase in the percentage of passengers whose trips were only non-stop flights between the spoke and SFO. Connecting traffic appears to have risen slightly overall.

The change in revenue is compared to the rest of United's network and the industry as a whole to determine if the slight decrease in RASM at SFO was perhaps due to depeaking, or rather on trend with the changes at the time elsewhere. The 0.06 cents per mile decrease from the peaked to the depeaked period is thus considered in terms of these other measures. Over this same time the entire United network saw a 1.04 cents per mile increase in RASM, including United's other hubs in Los Angeles and Chicago. The industry as a whole saw a 0.81 cents per mile increase between these two quarters. United's revenue decreased at SFO occurred while the rest of United and the industry as a whole increased. It is thus possible that the depeaking of SFO could have influenced slower revenue growth.

4.7.4 On-Time Results

The operational effects of depeaking are shown in Table 4.55 using on-time statistics from before and after depeaking. Using these aggregated measures, it is seen that between the peaked and depeaked months there was a large improvement in operations. There was an overall decrease in average delay per aircraft, both for departing and arriving aircraft, and there was less delayed aircraft overall as a percentage of all aircraft.

Total delay decreased for both departures and arrivals over this period, although taxi-out and taxi-in times did not deviate greatly.

Table 4.55 Summary of Operational Changes for United at SFO

Measure	Peaked	Depeaked
Average departure delay for all aircraft (minutes)*	24.6	16.8
Average departure delay for delayed aircraft (minutes)	72	53.7
Percentage of delayed departing aircraft	32.4%	28.6%
Total delay for delayed departing aircraft (minutes)	154,822	94,159
Average taxi-out time (minutes)	16	15.2
Average arrival delay for all aircraft (minutes)*	31.8	18.1
Average arrival delay for delayed aircraft (minutes)	78.1	54.9
Percentage of delayed arriving aircraft	39.1%	30.3%
Total delay for delayed arriving aircraft (minutes)	201,415	101,612
Average taxi-in time (minutes)	6	6.1

***Early arriving and early departing aircraft were assigned zero delay**

The improvements in operations at SFO for United are taken in context with what was occurring for the rest of United during this time, and what occurred industry-wide.

The departure delay throughout United decreased along with the SFO operations, while the industry slightly increased in delay. The SFO operational improvement, however, was much larger in terms of departure delay for delayed aircraft. This parameter was reduced by 25%, as compared to 8% for the rest of United. The industry had a 0.3% increase in departure delay. In terms of percentage of delayed departing aircraft, though, United's SFO operations lagged behind the rest of United and the industry. The decrease at SFO was 12%, while United decreased 26% overall and the industry 19%.

Arrival delay saw a more consistent change for SFO. Both the arrival delay for delayed aircraft and the percentage of delayed aircraft decreased, and these decreases outperformed the rest of United and the industry. Arrival delay for United at SFO decreased 24 minutes, a 30% overall decrease. United as a whole decreased about 7 minutes in average arrival delay, while the industry just 1 minute. The reduction in delayed aircraft was about a 9 percentage point decrease for United at SFO, which was a 22.5% reduction. The rest of United reduced this value similarly, a 6.5 percentage point reduction which was a 21% drop. Meanwhile the industry reduced the delayed aircraft percentage by less than 5 percentage points, a 17% drop.

United's operations at SFO improved from the peaked to the depeaked month, and in most measures, this improvement outpaced the improvements across United's network and the industry. These larger improvements relative to the normalizing measures indicate that depeaking could have had some beneficial effect on delay.

4.7.5 Predicting Changes in Supply

Although many regression models were attempted for the SFO case study, none showed significant results that provided intuitive results. The main likely reason for this insignificance is the lesser degree to which SFO was depeaked and its more continuous method of depeaking. As noted earlier, the changes in the depeaking measures (coefficients of variation and the peak percentage) were smaller than the other cases. The schedule was depeaked over two months, which also likely had an effect on the factors involved in the depeaking decision-making process.

4.7.6 Assessing Depeaking and Effects

The supply and demand results over the depeaking period show changes that likely could have been due to depeaking. To get a better understanding as to whether the changes that occurred were likely due to depeaking as opposed to being a typical change for that time of the year, year-over-year measures were calculated. The percentage change between the peaked and depeaked dates is calculated, and also for the year before and year after on similar dates.

For the SFO case, there is little evidence for the supply changes to show that the changes were due to depeaking. Table 4.56 shows schedule measures and reports a percentage change associated with each year. In the case of United, depeaking occurred in early January 2006. December 20, 2005 was used as the representative Tuesday peaked schedule and February 28, 2006 was used as the representative Tuesday depeaked schedule. The percentage associated with the year 2005/6 shows the change in schedule measures between these two dates. The table shows the results listed for 2004/5, 2005/6, and 2006/7, because the time period is split over two years due to SFO's depeaking occurring close to the turn of the calendar year. The process is repeated for two dates each in the years 2004/5 and 2006/7, using representative Tuesday dates closest to the year-over-year depeaking date. Note that the year before and year after changes are respectively for the same types of schedules: the 2004/5 change is between two peaked schedules and the 2006/7 change is between two depeaked schedules. Thus only the 2005/6 change is for changes that occurred between different schedule types.

Table 4.56 Supply Year-Over-Year Changes for United at SFO

Measure	2004/5				2005/6				2006/7			
	12/14	2/15	Δ	%	12/20	2/28	Δ	%	12/19	2/27	Δ	%
Max. number of flight arrs. or deps. in a 15-minute interval	14	12	-2	-14%	14	11	-3	-21%	13	13	0	0%
Max. number of flight operations in a 15-minute interval	19	14	-5	-26%	17	16	-1	-6%	18	17	-1	-6%
Number of flights flown into or out of hub	398	409	11	3%	445	440	-5	-1%	454	433	-21	-5%
Total available seat miles flown into or out of hub (000s)	51350	52590	1241	2%	57228	55063	-2165	-4%	58077	56735	-1342	-2%
Number of destinations served from hub	42	44	2	5%	46	48	2	4%	48	48	0	0%
Coefficient of variation in number of arrivals	131.4	121.3	-10.1	-8%	101.7	87	**-14.7**	**-14%**	88.1	90.2	2.1	2%
Coefficient of variation in number of departures	129.9	141.5	11.6	9%	128.2	101.9	**-26.3**	**-21%**	112.8	112.3	-0.5	0%
Percentage of flights served by affiliate airline(s)	40.5%	44.0%	3.5%	9%	42.7%	45.5%	2.8%	7%	45.2%	41.1%	-4.1%	-9%
Percentage of flights served in peak period	75.4%	71.6%	-3.8%	-5%	68.5%	65.7%	-2.8%	-4%	64.8%	65.8%	1.0%	2%
Number of potential Connections	3508	3742	234	7%	4066	3621	-445	-11%	3802	3493	-309	-8%
Average connections per arriving flight	17.5	18.4	0.9	5%	18.3	16.8	**-1.5**	**-8%**	16.7	16.2	-0.6	-3%
Maximum potential connections serving a market	14	11	-3	-21%	16	13	-3	-19%	14	17	3	21%

***Bold percentages are for measures identified to be likely due to depeaking**

Bolded percentages represent changes most evident by United's depeaking. Compared to other cases, the SFO case has less evidence to show that depeaking occurred. The most important change was the reduction in the coefficients of variation. Although there was a reduction in the number of flights and ASMs for the depeaking year, the years before and after also showed changes that were similar. Even the peak percentage which dropped 4% overall, did not have as substantial a drop as the year prior, a drop of 5%. It appears United was continually adjusting SFO's schedule, and thus the depeaking which occurred is hard to pick out in the supply measures. The coefficients of variation's drop, however, do provide good evidence that a shift occurred. The depeaking potentially led to drop in potential connections per arriving flight.

The year-over-year measurements are also useful in comparing the demand and revenue changes. The time frame is longer in these cases, because the demand data is gathered for an entire quarter, but the results are still useful. The year-over-year changes for revenue and total passengers are not included because these values heavily depend on what is going on in the market, more so than the schedule. Thus RASM is used in comparison still with the RASM of the airline network and for the industry.

One measurement which is useful in terms of demand in measuring it year-over-year is the percentage of connecting passengers. The percent of connecting passengers in 2005/6, had a lower increase than what occurred in 2004/5 and 2006/7. There was a change of 1% in the depeaking year, while the years before and after had changes of 7% and 8%, respectively. It is possible that connecting traffic was inhibited by the depeaking schedule change which reduced potential connections.

The change in RASM for United's SFO schedule slightly exceeded the RASM changes across the rest of United and the industry in the depeaking year as compared to the years before and after, as shown in Table 4.57. The one percent decrease in RASM over the depeaking period was behind the growth of the network and the industry by a smaller margin than the losses that occurred in the surrounding years. The gross change differences are nearly the same across the three years, ranging from 0.87 to 1.59. So although the depeaking year saw a slight improvement compared to other years, it seems more on par and not enough to say depeaking improved the revenue situation for United.

Table 4.57 RASM Year-Over-Year Changes for United at SFO

Measure	2004/5				2005/6				2006/7			
	Q4	**Q1**	**Δ**	**%**	**Q4**	**Q1**	**Δ**	**%**	**Q4**	**Q1**	**Δ**	**%**
RASM for Depeaked Airport	6.49	5.84	-0.65	-10%	6.68	6.62	-0.06	-1%	6.98	6.44	-0.54	-8%
RASM for Airline Network	8.76	9.7	0.94	11%	10.02	11.06	1.04	10%	10.6	11.1	0.50	5%
RASM for Industry	9.04	9.72	0.68	8%	10.5	11.31	0.81	8%	10.4	11.1	0.70	7%

Operations at SFO were seen in the depeaking year to generally improve relative to the rest of United's network and the industry. Only the percentage of departing delayed aircraft worsened when using a difference-in-difference method of comparison. When looking year-over-year, however, not all of these changes still were unique to the depeaking year, as shown in Table 4.58. Departure delay still stood out as an improvement unique to the depeaking year as the year before and year after had a departure delay changed at SFO on par with the comparative measures. Arrival delay was similar, with the depeaking year change showing a notable reduction in delay in relation to the comparative measures and the change in the year before and year after being on par with their respective comparative measures. The percentage of delayed departing aircraft at SFO did not improve as much as United's network and the industry in the depeaking year, but it had been on par in the year before and year, and thus this change was still notably poor for United. The percentage of delayed arriving aircraft, however, which saw a slight improvement over the comparative measures in the depeaking year, did not stand out when compared year-over-year. In both the year before and year after this measure changed similarly in relation to the United network and the industry as it did in the depeaking year.

Table 4.58 Operations Year-Over-Year Changes for United at SFO

Measure	2004/5				2005/6				2006/7			
	Dec	Feb	Δ	%	Dec	Feb	Δ	%	Dec	Feb	Δ	%
Dep. Delay Depeaked Airport	53	50.1	-2.9	-5%	72	53.7	-18.3	-25%	54.7	58.4	3.7	7%
Dep. Delay Airline Network	55.5	55.8	0.3	1%	62.8	57.7	-5.1	-8%	57.3	60.3	3	5%
Dep. Delay Industry	54.2	50.4	-3.8	-7%	50.8	51	0.2	0%	56	56.8	0.8	1%
% Delayed Dep. Depeaked Airport	24.9	17.9	-7	-28%	32.4	28.6	-3.8	-12%	29.4	28.7	-0.7	-2%
% Delayed Dep. Airline Network	22.6	16.3	-6.3	-28%	28.3	21	-7.3	-26%	25	26.7	1.7	7%
% Delayed Dep. Industry	23.3	17.4	-5.9	-25%	24.3	19.8	-4.5	-19%	24.4	25.5	1.1	5%
Arr. Delay Depeaked Airport	57.2	53.5	-3.7	-6%	78.1	54.9	-23.2	-30%	59.4	61.2	1.8	3%
Arr. Delay Airline Network	53.6	52.1	-1.5	-3%	62.1	55.2	-6.9	-11%	55.9	58	2.1	4%
Arr. Delay Industry	53.3	48.7	-4.6	-9%	50.6	49.7	-0.9	-2%	55.1	55.7	0.6	1%
% Delayed Arr. Depeaked Airport	30.3	22.8	-7.5	-25%	39.1	30.3	-8.8	-23%	30.6	36.1	5.5	18%
% Delayed Arr. Airline Network	24.7	19.1	-5.6	-23%	30.9	24.4	-6.5	-21%	26.8	31.9	5.1	19%
% Delayed Arr. Industry	26.1	20.9	-5.2	-20%	27.5	22.9	-4.6	-17%	27.9	29.4	1.5	5%

In summary, the supply changes for United at SFO did not change drastically as compared to other cases. The year-over-year measurements do not show consistency, however, but rather a range of changes occurring over time. United seemed to be experimenting with the schedule, and depeaking was one such experiment. RASM did not drop from depeaking, and saw a slight improvement, but since the schedule measures were not drastic, it is hard to say if depeaking helped boost RASM. The changes in operations experienced by United for the most part were notable even when compared year-over-year, except for the percentage of delayed arrivals which stayed similar to the surrounding years.

4.7.7 Summary

The SFO case is unique because of the longer time period over which United depeaked the hub's operations. In addition, the hub was the least depeaked of all the cases, and most of the supply measures did not have noteworthy changes when compared year-over-year. The most telling statistic was the coefficients of variation which showed that United did create a more even schedule. The small change resulted in a drop in potential connections for United per arriving flight, which likely led to the connecting passenger percentage which lagged behind other years.

Operationally, United saw an improvement in operations at SFO after depeaking. In addition, RASM saw a slight improvement. It is difficult to say whether these changes were due to depeaking, however, because of the minimal change in the supply measures.

4.8 Passenger Dwell Time and Revenue

Depeaking has been shown in previous studies to be associated with extended transfer times in the terminal for connecting traffic (Bogusch, 2003; Jiang, 2006; Luethi et al., 2009; Mecham, 2004). Because the tight banks no longer exist, passenger connection times become longer. Thus passengers are in the terminal space for a longer period of time and have a greater opportunity to purchase food and beverages as well as shop for retail items.

As was seen earlier, depeaked schedules operate across more 15-minute periods than peaked schedules. As a result, passengers arrive at the terminal at a more constant rate across the day. This is beneficial for concessionaries because it means that they have extended periods of business and do not need to staff for peak customer arrival times. Extended connection times and a steadier customer arrival rate may also induce more shopping as there are lower congestion levels in shops. These factors all play a role in increasing revenue for the airport.

The following results make use of the PANYNJ air traffic report from 2004 to 2011, as described in the Methodology chapter.

4.8.1 Significant Factors Affecting Purchasing

Simple linear regression models are used to quantify relationships between transfer time in a terminal and airport revenue. Table 4.59 shows the results of nine simple regression models that examine the relationship between dwell time variables and various breakdowns of retail revenue. The table shows the adjusted R^2 model fit statistics (coefficient of determination) for the nine simple regression models, the intercept and parameter coefficient associated with the dwell time measure, and the significance of the dwell time coefficient. Total spending is the summation of food and beverage spending and retail spending.

Table 4.59 Results for Nine Simple Regression Models Predicting Terminal Spending as a Function of Dwell Times

Dwell Time (min)	Terminal Spending		
	Food & Beverage ($/passenger)	**Retail ($/passenger)**	**Total ($/passenger)**
Average	*6.456 + 0.055* (0.267)*	*-4.425 + 0.258* (0.313)**	*2.031 + 0.314* (0.329)**
Local	*6.761 + 0.059* (0.115)	*-4.204 + 0.285* (0.155)*	*2.557 + 0.344* (0.161)*
Connecting	*7.537 + 0.038* (0.379)***	*-1.843 + 0.192* (0.534)***	*5.694 + 0.229* (0.543)***

Table reports *intercept term + dwell time coefficient* (adjusted R^2) and significance levels of the dwell time coefficient:
***0.05 significance level **0.005 significance level ***0.0005 significance level**

The simple regression that fits the data best is that between connecting passengers' average dwell time and the total terminal spending. The coefficient indicates that for every additional minute in connecting passenger traffic's dwell time, total spending on retail, food, and beverages increases about 23 cents. This relationship is displayed along with a best-fit regression line in Figure 4.65.

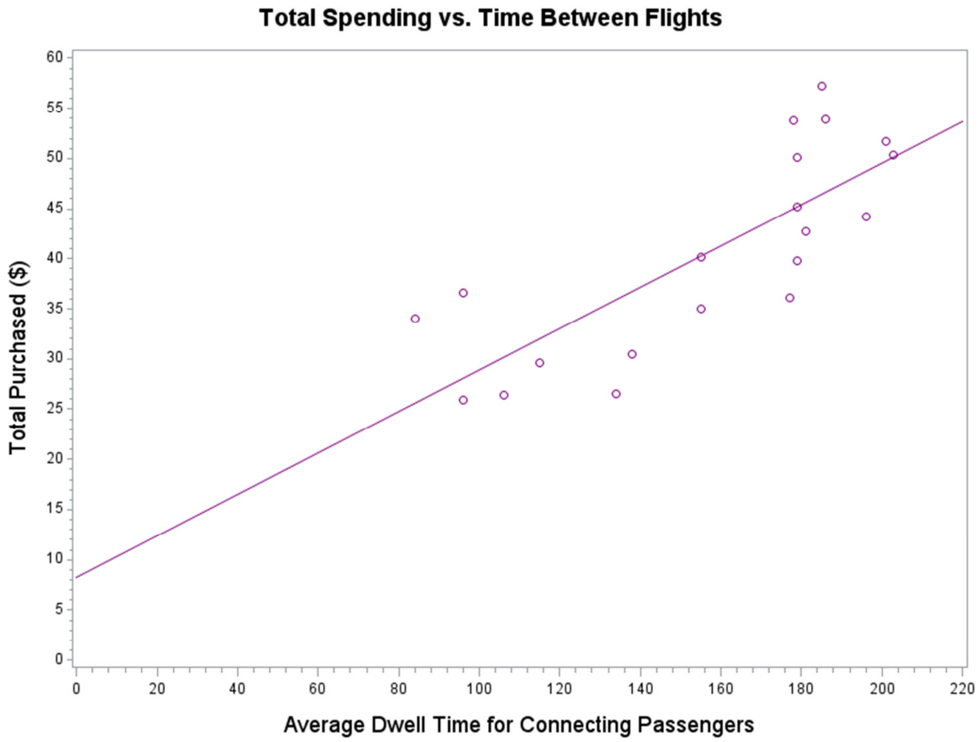

Figure 4.65 Relationship between connecting dwell time and passenger spending.

Three other simple regressions were used to explore the relationship between terminal spending and the percentage of connecting passengers traveling through the airport. The results of these regressions are shown in Table 4.60.

Table 4.60 Results for Three Simple Regression Models Predicting Terminal Spending as a Function of the Percentage of Connecting Passengers

	Terminal Spending		
	Food & Beverage (cents/passenger)	**Retail (cents/passenger)**	**Total (cents/passenger)**
Percent Connecting	*11.228 + 9.301* (0.183)*	*17.964 + 43.377* (0.216)*	*29.192 + 52.678* (0.228)*

Table reports *intercept term + percent connecting coefficient* (adjusted R^2) and significance level of the percent connecting coefficient:
***0.05 significance level **0.005 significance level ***0.0005 significance level**

The model that predicts total terminal spending as a function of the percent of connecting passengers has the highest R^2 value. For every one percent increase in the percentage of connecting passengers, total terminal spending increases about 53 cents. This relationship is shown graphically with a best-fit line in Figure 4.66.

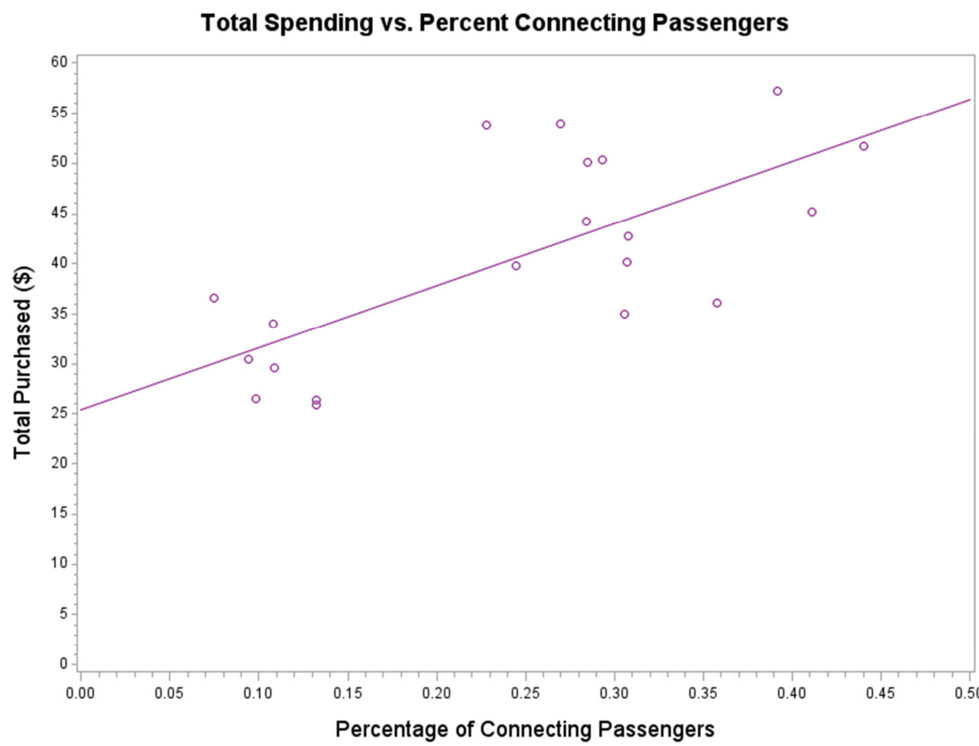

Figure 4.66 Relationship between the connecting passenger percentage and passenger spending.

The difference between the dwell time for local passengers and connecting passengers was also compared to passenger spending. For most years at each airport the difference was positive, reflecting that connecting passengers have longer dwell times at the airport, although one year at LGA had negative difference. The result of the simple regression between this difference and passenger spending is shown in Table 4.61.

Similar to the previous regressions, the most significant relationship with the highest coefficient of determination was between all spending and percent connecting passengers. For every minute difference in the average dwell time between the connecting passengers and the local passengers, total terminal spending increases about 34 cents.

Table 4.61 Results for Three Simple Regression Models Predicting Terminal Spending as a Function of the Average Dwell Time Difference

	Terminal Spending		
	Food & Beverage ($/passenger)	**Retail ($/passenger)**	**Total ($/passenger)**
Average dwell time for connecting passengers – average dwell time for local passengers	*11.115 + 0.054* (0.415)**	*16.222 + 0.281* (0.603)***	*27.336 + 0.335* (0.609)***

Table reports *intercept term + dwell time difference coefficient* (adjusted R^2) and significance level of independent parameter:
***0.05 significance level **0.005 significance level ***0.0005 significance level**

4.8.2 Spending in Terminals and Income

Income was assessed to see its effect on passenger spending in terminals. Income is reported as the average passenger income at each airport for a given year.

It was hypothesized that an increase in the average income of the passenger base would increase spending on food, beverages, and retail. The issue that arose in relating spending to passenger income was the directionality of the relationship. An inverse, but well correlated, relationship was discovered between spending and income, indicating that as passenger income increased passenger spending decreased.

This relationship is the opposite of what one would expect for spending in relation to income. The reason for the relationship may be that higher income passengers are more likely to be frequent flyers, and thus spend time in airline clubs and less time in the terminal. Thus, these higher income passengers do not spend as much in the terminal because of free food and drink in the clubs. In addition, frequent flyers are probably less likely to buy retail items because they are less likely to forget a travel essential or make an impulse buy.

Because it is an average income across all passengers that is being worked with, it is not surprising that it may not provide the expected results. In addition to the reason describe above, average incomes often are difficult to work with because the distribution behind the average could be shifting in ways that better reflect the movement of the response variable.

4.9 Case Comparison

The six case studies evaluated in this study have some similarities, but share a number of differences as well. Broadly, most cases saw the same types of supply changes, but they varied on how operations and revenue were affected. Even with the supply changes, there was a wide range in the degree of depeaking, from a large percentage drop in peak measures, such as at DFW, to a small percentage drop in peak measures, such as at SFO. Table 4.62 summarizes the noteworthy changes for each case, so that they can be easily compared across several categories. The notable changes are reported for their directional change, as the magnitude of the change is not comparable due to the unique situations at

Table 4.62 Notable Measure Changes Across Cases

	Measure	ORD	DFW	ATL	PHL	LAX	SFO
Supply	Max. number of flight arrs. or deps. in a 15-minute interval	–	–	–	–	–	
	Max. number of flight operations in a 15-minute interval		–	–	–	–	
	Number of flights flown into or out of hub	+	–	+	–		
	Total available seat miles flown into or out of hub	+		+			
	Number of destinations served from hub				–		
	Coefficient of variation in number of arrivals	–	–	–	–	–	–
	Coefficient of variation in number of departures	–	–	–	–	–	–
	Percentage of flights served by affiliate airline(s)						
	Percentage of flights served in peak period	–	–	–	–	–	
	Number of potential connections	+	–	–	–		
	Average connections per arriving flight		–	–	–	–	–
	Maximum potential connections serving a market			+	+		
Demand	Proportion of Connecting Passengers	–					–
	RASM for Depeaked Airline at Depeaked Airport	–		–	–		
Operations	Departure Delay	–	–			–	–
	Percent Delayed Departing Aircraft	–	–			–	+
	Arrival Delay	–					–
	Percent Delayed Arriving Aircraft	–					

Note: +/- indicates a change through difference-in-difference in the depeaking year analysis that is notable year-over-year. Green and red indicates a change which is objectively good or bad for the airline, respectively.

each airport at different points in time. Changes which are objective good or bad for the airline are noted in green and red, respectively.

4.9.1 Supply Changes

As seen in the previous table, nearly all the cases saw a decrease in the maximum number of flights in a 15-minute period. This is the biggest cost-cutting measure for an airline as it reduces the high levels of staffing needed to operate all those flights. All of the cases exhibited reductions in the coefficient of variation for arrivals and for departures. This reduction occurs for all cases because there is no longer as big a difference between the busiest and least busiest 15-minute periods. The periods are more consistent with activity, and thus the standard deviation decreases, and thereby decreases the coefficient of variation. Similarly, the peak percentage decreases for all cases except SFO. This shows that typically depeaking is verifiable using the peak and depeak measurements which were created for this study. The measurements are able to identify the spreading out of the busiest periods.

Depeaking does not necessarily require an airline to change its flight frequency. In two cases there is a certain decrease in the number of flights when depeaking occurred, while two cases saw an increase in flights (and in ASMs as well). For two cases there was not enough evidence to show a change occurred compared year-over-year. In addition, depeaking does not seem to be associated with having to reduce or increase the number of destinations served from the hub, and service can be maintained through the network.

The major issue with depeaking is the inevitable reduction in potential connections. Most cases saw a decrease in the gross number of potential connections, and even more telling is that five of the six cases saw a decrease per arriving flight. This shows that banks are important in maximizing potential markets for passengers to fly, and depeaking causes a reduction in this potential. Although the ORD case saw an increase in the gross number of connections, it also had an increase in the number of flights. It did not have a corresponding positive increase in potential connections per arriving flight, so the gross increase is due to the increase in flights, not the depeaking strategy.

4.9.2 Demand Changes

Although all cases exhibited a drop in revenue over the depeaking period in relation to their respective airline networks and the industry, only three cases had changes which were noteworthy year-over-year. In the other three cases, revenue always lagged behind the rest of the airline and the industry year-over-year. It is gathered from these data that depeaking has the risk of being revenue negative, and does not appear to be able to increase revenue compared to a typical year. This is most likely due to the severing of potential connections which was seen to consistently occur in the supply changes.

Despite the drop in potential connections in the schedule, there does not appear to be an overwhelming indication that depeaking hurts connecting traffic. In the two cases where connecting traffic decreases, ORD and SFO, the former was described earlier as having a relatively low connecting traffic rate already for an airport of its type, and the latter had the unique depeaking case where changes happened slowly over time. Across the remainder of the cases, connecting traffic did not appear to change differently when compared year-over-year.

4.9.3 Operations Changes

From the results, depeaking appears to improve operations in most cases. Four of the six cases saw improvements in at least two of the four measures examined against the rest of the airline’s network and the industry. This gives indication that depeaking aids in reducing congestion for the runway and gate area allowing aircraft to have both a lower likelihood of being delayed and a lower amount of delay if it does so.

The two cases in which operations did not improve, ATL and PHL, stand out as different among the rest of the cases. There does not appear to a unique shared change in a supply measure between these two cases that would indicate a shared lack of a positive shift in operational performance. It is possible that these airports have other reasons why operations stayed the same after depeaking. These reasons could be hard to overcome, and thus why US Airways decided to repeak PHL. Overall, though, it seems that depeaking is more than likely to improve operations for the hub airline.

4.10 Current Status of Cases

As of March 2012, four of the six cases were still depeaked. American has maintained depeaking even through its 2011 bankruptcy at both its ORD and DFW hubs. United has also maintained a depeaked schedule at its LAX and SFO hubs. Delta repeaked its schedule and currently operates twelve daily arrival and departure banks out of ATL. US Airways kept a repeaked schedule from 2005 onward and PHL currently has eight arrival and departure banks.

The current status of the cases sheds light on what could be most critical for an airline when deciding to retain a depeaked schedule. The two cases which have since been repeaked were the two cases which saw a negative effect on their operations: US Airways and Delta. It is possible that if a depeaking schedule does not work operationally an airline may have no qualms repeaking their flight schedule.

CHAPTER 5

CONCLUSION

5.1 Introduction

The depeaking that occurred during the first part of the 2000s at U.S. hub airports appeared to have a mix of results. There is evidence that each airline had a unique strategy for changing the flight frequencies to its spoke network. This wide range of decision processes prohibits the creation of a comprehensive answer as to how to effectively depeak, but provides the potential knowledge that any airline considering depeaking should be careful to assess its revenue strengths and connection possibilities before shifting frequency between markets. The notable results of depeaking, though, suggest the basis for conclusions to be drawn regarding if and how schedules should be depeaked.

This chapter describes the key findings of this study, the conclusions which can be drawn from the results, and recommendations for practice. In addition, it provides perspective as to what is contributed to the field by this research. Lastly, it acknowledges the study's limitations and provides suggestions for future research extending from this work.

5.2 Key Findings and Conclusions

The findings of this study and the conclusions which are able to be drawn from them can be broken into two types: those pertaining to airlines and those to airports. The following two subsections discuss what can be gathered from this research project. A summary table is provided in Table 5.1 outlining the key takeaways from this study.

Table 5.1 Key Takeaways from Study

Key Takeaways
Airline-pertinent
• Depeaking is not seen as revenue positive. • Potential connections likely will reduce after depeaking. • Operations tend to improve from depeaking, but at the risk of a decreased ability to recover from bad weather. • Spoke level depeaking decisions are different for each situation, suggestive that depeaking does not happen in a vacuum. • Common components of depeaking include reducing high frequency flights and considering competitive factors. • When a strong competitive threat is present, there is potentially a greater chance that RASM will decrease. • Combination of losses in RASM and increases in operational delay likely leads to repeaking.
Airport-pertinent
• Operational improvements can occur for all airlines at the airport, and could potentially make the airport more attractive for service. • Evidence that airport revenue can increase with depeaking due to longer passenger connection times in the terminal. • Depeaking is particularly helpful for capacity-constrained airports. • Unused gates can be potentially used to attract new entrants and expand competitor offerings.

5.2.1 Airline-pertinent Conclusions

Despite being a cost-cutting tool for airlines, depeaking has many risks that could ultimately make the schedule change a bad decision for airlines. The key concerns for airlines is that the research suggests that depeaking is revenue negative due primarily to the loss of connections in the schedule, and that the improvement in operations comes at a the risk of being less responsive to extreme delay cases (such as bad weather). Despite the variety of strategies that have been implemented in putting together a depeaked schedule, there has not been a consistent method that has prevented an airline from falling behind in revenue.

As predicted in the literature, and found consistent with suggestive evidence in this study, depeaking an airline schedule negatively affects revenue. Across the six case study airports discussed in this research, all lagged behind the rest of the respective airlines and the industry as a whole when compared through a difference-in-difference comparison. More importantly, when examining the cases year-over-year, three of the cases had even larger degrees of lagging in the depeaking year as compared to the years before and after. The drop in RASM seen in these three cases indicates a probable daily revenue loss of between $300 thousand and $600 thousand, depending on the size of the RASM drop and the number of ASMs. There is a potential relationship between the revenue lag and the drop in the number of potential connections in the schedule. As seen in the results, there is evidence that the number of connections per arriving aircraft drops after depeaking. With less potential connections between arriving and departing flights, potential passengers may not be able to fly their desired itinerary on the depeaking airline.

This decrease in revenue leads to the conclusion that depeaking is a risk for airlines because it has the potential to reduce profit, depending on how much cost is actually cut by the airline. The airline would need to balance depeaking and cutting costs with revenue loss incurred from increasing connection times, and should strive to maintain short connection times for its most valuable connections to reduce lost revenue in these most profitable markets.

Depeaking also poses operational benefits as well as operational risks. As seen in the results of this study, there is potential for depeaking to benefit operations by reducing delay and the percentage of delayed aircraft. By operating fewer flights per unit of time, there is less runway and gate area congestion. In addition, without tightly packed banks and short connection times, passengers have a better opportunity to make connections, and aircraft have less of a need to wait on passengers. This benefit, however, must be balanced out with the built in recovery time that banks provided. When bad weather causes aircraft to become delayed, the banked schedule allows for time in the schedule to recover as there are breaks in the day when relatively few aircraft arrived and departed. Depeaking removes these natural recovery periods, and thus delays can cascade through the day as there is less room for error (Jenkins et al., 2012).

Thus during good weather, there is evidence that suggests depeaking can eliminate common delays through decreased congestion and the spreading of activity. During bad weather, the airline has less of a chance to recover its schedule when aircraft start getting delayed. This leads to the conclusion that depeaking would be less successful at airports that are prone to weather delays. An airline must decide if the risk of having extreme delays during bad weather is worth the trade-off of having fewer delays on average. The former could have much more serious consequences, especially in the modern day with the U.S. government becoming stricter about long tarmac delays.

The decision-making process for depeaking is unique to each airline-airport combination. Even when examining the two American cases with which there was a regression model developed, there was not a similar strategy. This is suggestive of each depeaking airline having a unique range of factors it chose to rearrange its schedule. It also suggests that depeaking does not happen in a vacuum but occurs within the competitive context. Among these different depeaking strategies, there is not a consistent method that caused larger revenue losses.

The situation of unique depeaking circumstances meant that a comprehensive model of spoke level decisions for depeaking was not able to be constructed. Within these differences, however, there was some consistency that a future airline considering depeaking could make use of in developing its own strategy. First, each of the cases focused on increasing either nonstop passenger traffic (PHL and LAX) or increasing connecting passenger traffic (ORD, DFW, and ATL). Thus an airline considering depeaking may need to decide which type of passenger they would like to target in increasing or decreasing frequency to spokes. Second, three of the five regression models showed an airline decision to decrease high frequency routes, indicating an airline preference to accomplish depeaking by removing flights where there was high activity. This likely occurred because as flights get spread out from the banks, it is likely that two flights to the same spoke may become closer together and make one of the flights redundant. Third, most of the cases had a competition component in consideration when depeaking. There were a variety of strategies, but most appear to go after competitors' traffic in some way (e.g. increasing flights to other airlines' hubs, taking attention away from routes where they were already "winning", adding flights to where the depeaking airline held a fare premium). In summary, the most important factors to depeaking airlines appeared to be focusing on a single passenger type, decreasing flights on high frequency routes, and having a competitive component to the decision.

Although revenue considerations played a role in all depeaking decisions, regression results suggest that airlines approached these revenue considerations differently. Four of the five cases considered ticket fares, but not in a consistent manner. Two of the cases increased frequency on higher fare routes, while one case decreased these same types of routes. The fourth case increased frequency on routes in which it had a fare premium over competitors. It was also notable that one case appeared to consider RASM. Thus, while revenue (in addition to competitor) factors influenced depeaking, the relative influence of revenue components varied by case.

One aspect of an airline's schedule which does not get altered during depeaking is the depeaking airline's relationship with its affiliates. As seen in all of the cases, the percentage of flights operated by affiliate airlines stayed near constant. The likely reason is that the affiliate airlines have capacity purchase agreements with the parent airline and this is still honored through the depeaking process. The most important change for affiliate airlines is that their operations which in the peaked schedule were concentrated in the banks are now more spread out along with the depeaking airline's flights. The affiliate airline thus also experiences lower staff needs, and may have to cut staff in response to the parent airline's depeaking.

A strong competitive threat at a depeaking airport appears linked to the potential to lose RASM during depeaking. The ORD, ATL, and PHL cases are characterized by a competitive threat, with United having a large hub alongside American at ORD, AirTran having a medium size alongside Delta at ATL, and Southwest strongly pursuing traffic out of PHL. All three of these depeaking cases saw a relative decrease in RASM when compared year-over-year. As a comparison, Delta operated a small hub out DFW alongside American, and the DFW case did not see such a RASM decrease.

An airline's decision to repeak seems tied to a worsening of operations and losses in RASM. The two cases examined in this study which have been repeaked are ATL and PHL, the only two cases of the six which experienced worse operations and lower RASM after depeaking. The drop in RASM could have been due to the competition threat, but poorer operations appears to be the breaking point for an airline to forego the cost savings of depeaking.

Meanwhile, the other case to lose RASM, ORD, improved in operations after depeaking. This improvement in operations could have offset the loss of RASM for American. In addition, RASM for American at ORD is likely not as important because of the high percentage of originating passengers and the overlapping networks of American and United. There is a greater need for American to drop fares across the network out of ORD in order to compete with United in garnering the large number of originating passengers, without which RASM would suffer even more.

5.2.2 Airport-pertinent Conclusions

The results of this research suggest that airports are likely to benefit from depeaking. There are potential gains to be made from both an improvement in operations and in the area of non-aeronautical revenue. In addition, as the depeaking airline reduces its gates to cut cost, opportunities for new airlines to enter a congested airport become available.

When an airport is capacity constrained, its operations suffer for all airlines and its tendency for delay increases. This leaves the potential for negative effects for the airport as airlines with flexibility may choose to fly to a secondary airport or not fly to the city at all, if an airline considers the risk to its network operations too high because of the potential of delay at the airport. In addition, for passengers who perceive the airport as a congested airport, there is the potential for passengers to choose another airline hub to fly through, resulting in less passengers facility charges collected by the airport.

The benefit the airport could get from depeaking is overall improved operations. Not only the depeaking airline experiences an improvement in operations when it depeaks. As seen in the American/United at ORD case, American improved its operations with depeaking, but United also saw a large benefit, albeit not as great. Thus with competitors seeing a benefit in operations, the airport experiences less congestion on its runways, apron, and within the terminal. This is beneficial when trying to attract new entrants into the airport, or when competing against other airports in a multi-airport city. Although bad weather delays may cause the depeaking airline to not recover as well in terms of its hub operations, the airport as a whole has freed capacity that allows it to manage all airlines (non-hubbing competitors do not need to recover as substantially as the hub airline) during bad weather.

Another reason for airports to prefer depeaking is the potential for increased non-aeronautical revenue. As discussed in the literature review, often a very large portion of airport revenue is from concession sales, and depeaking only serves to improve this. The longer connection times that occur due to depeaking leave passengers dwelling in the terminal. As was seen in this study, dwell time increases are indicative of the potential for increases in food, beverage, and retail spending. These sales would directly benefit the airport. In addition, passengers not only dwell for longer, but are under less stress in a less congested terminal. This decreased stress aids in inducing spending. Depeaking is thus very beneficial for airport revenue streams. In the unique case where the airline also owns the terminal and shares in the revenue from concessions, depeaking could also bring in some revenue for the airline.

Airports also would serve to gain from depeaking because of the reduced gate needs of the depeaking hub airline. As the airline cuts its banks, it needs fewer gates to perform its operations. If the depeaking airline who had been using the gates relinquishes the lease on them (perhaps not immediately but over time), the airport would have gates it could offer to new entrants. This additional capacity can be used to open up new markets, increase competition on current routes, and allow the airport to market itself better to passengers.

Because the results of this study lend credence to depeaking being beneficial for airports, airports may pursue a depeaking strategy and suggest a hub airline depeak. Particularly for capacity-constrained airports, depeaking may be a very attractive strategy because building additional airport capacity – such as new runways, taxiways, or terminal expansions – is very expensive, and requires substantial investment on the part of the airport authority. Although constructing capacity allows an airport to take in a greater number of flights per hour, it requires long term planning and may not be possible. Depeaking works as a cheaper shorter-term solution, with additional benefits for the airport.

5.2.3 Synthesis of Conclusions

By putting together all that has been gathered from the produced results and the compiled conclusions, an overall statement on depeaking can be constructed. Putting aside the SFO case which had a number of issues, there are five remaining cases. These five cases and the important factors which are indicative of the potential for the success in depeaking are listed in Table 5.2. The regression models that shed light on the manner in which depeaking occurred at these airports indicated that depeaking does not happen in a vacuum. It appears depeaking was done with consideration given to the competitive context of the airport. Those airlines at airports with the largest competitive threats lost RASM.

Table 5.2 Important Factors in Determining Depeaking Success

Airport	Competitive Threat	RASM	Operations	Percent Connecting	Repeak
ORD	Yes	Down	Improved	39%	No
DFW	No	Consistent	Improved	47%	No
ATL	Yes	Down	Consistent	54%	Yes
PHL	Yes	Down	Consistent	32%	Yes
LAX	No	Consistent	Improved	32%	No

A loss in RASM alone does not indicate a depeaking failure. If repeaking is considered to be an airline admitting a dislike of depeaking, two cases (ATL and PHL) would be considered to have had poor depeaking. The factor which these two cases have in common is they both experienced a drop in RASM when compared year-over-year and a worsening of operations. Meanwhile, ORD also lost RASM, but saw an improvement in operations that may have offset the RASM loss for American. In addition, because ORD has a low connecting passenger percentage in relation to the other non-coastal hubs (ATL and DFW), it is very focused on capturing the originating traffic. This is accentuated by United also hubbing out of ORD, making capturing the originating traffic more important and reducing the focus on RASM.

5.3 Recommendations

The following section includes recommendations from the author based on the key findings and conclusions that were discussed in the previous section. The recommendations are based on lessons learned in the literature, the results of the study, and the author's experience with the topic.

This research project is extendable for industry use. The compilation of domestic depeaking occurrences, the resulting changes which occurred in each case, and an analysis on how the airline was affected in terms of revenue and operations are informative to an airline debating changing its schedule. Airlines could use the results of the project to aid in determining the risks of depeaking at a given airport. The study provides one of the first assessments of how depeaking affects revenue and these insights can be used by airlines to compare revenue losses to their savings predictions. It is recommended that an airline assess which case study best fits their profile in terms of supply and competition, and learn from how the previous airline depeaked.

Despite the usefulness of the results derived from this study and the regression models developed, airlines should be hesitant to depeak. A motivation to cut cost is not enough to make depeaking a worthwhile decision because of the risk to revenue and operations. In addition, although depeaking can cut costs for the airline, it sacrifices their strong network of connections on which the hub was built, and only if the airline is capacity constrained should depeaking be an option. A good starting point for the decision is if the airport is close to the FAA operations benchmark capacity, a suggestion from Jenkins et al. (2012). If capacity is available and the ability to add flights to banks exists, this should be done if possible.

If capacity is not available, airlines face an uphill battle getting an airport to build them additional capacity, such as a new runway or a terminal expansion, so that they can increase the number of flights in a bank. Capacity increases also take a long time to develop and build. Because adding to the sides of banks lengthens connection time at no savings in cost, depeaking becomes a viable option: the airline saves cost at the expense of increasing connection time and breaking some connections. Further, depeaking can be done quickly on an airline's own timeline. Thus if an airline is reaching capacity in its banks, depeaking is an immediate solution that allows them to increase the number of flights in the schedule.

It is recommended that depeaking is best performed at large airport hubs with a low percentage of international flights, and airports that do not meet these conditions should not be depeaked. Large airport hubs, such as ORD, DFW, and ATL, have a large number of flights to work with when depeaking. With more flights, there is more flexibility in reducing the peak percentage of the schedule, and the airline has more options to move flights around and retain valuable connections. In addition, when a large hub is depeaked, the depeaked schedule still has a high number of operations per 15-minute period, and thus connections are inevitable. A medium-sized hub is at a greater risk of losing a great number of its connections. With fewer banks in the schedule and a lower number of flights, even a slight reduction in the peak percentage can break a substantial number of connections. Thus a large hub is better suited for depeaking.

A lower percentage of international flights is also recommended. Airline hubs with a large number of long-haul routes have many wide-body jets with high seating capacities that need to be filled. To fill these seats, a flight bank is very useful because many spoke cities can connect to the long-haul flight. These connections are reduced in a depeaked schedule, and make it more difficult for a wide-body jet to fill seats. The more an airport serves international destination, the greater the need for flight banking.

The spoke level regression model is recommended for airports to use in determining what an airline may do if it considers depeaking. If an airport believes that its hub airline is considering depeaking, it can make predictions as to what its available service will be for local passengers in the future. By being able to predict where frequency may be added or decreased, it can begin to prepare to attract other airlines to serve that market.

Depeaking is recommended for airports to suggest to their hub airline as a way of helping an airline avoid bankruptcy. Depeaking is beneficial for an airline, and helps the hub city avoid paying what Hanlon (1996) calls a “hubsidy”, where the city pays to help the airline avoid bankruptcy. Depeaking is a better option for the airport, airline, and city in this case.

Based on these recommendations and the conclusions described earlier, there is the basis for a recipe for success that describes what a good hub for an airline to depeak would look like. This recipe would include an airport which is capacity constrained, has a low international mix, is a large mid-continental hub, and lacks a strong competitive threat. Consistent with the evidence shown in this study, these factors indicate the potential for a revenue risk reduction.

5.4 Contributions

This study makes many contributions to the body of knowledge on the airline industry, and certainly to what is known about depeaking.

Most important of the contributions is that this study lays out a road map for future depeaking studies. Although this study was limited by the use of publicly available data, how to conduct a study of depeaking has been outlined. Future studies can take this research project and learn how to approach examining depeaking if one has full schedule data from OAG, in order to analyze the revenue effects. It also provides indicators on what the factors of success are for depeaking, so they can be tested to further detail in the future.

At a basic level, this study contributes to the literature by identifying those airlines and airports that depeaked from 2000-2010, a list which is not found elsewhere. For those airlines which were carried through case studies, the context under which each airline depeaked is determined. By having several depeaking case studies examined simultaneously, it is possible to compare and contrast strategies and results for the first time.

Methodologically, this study develops data cleaning methodologies for public data, and develops a technique to combine On-Time and DB1B data despite their different time periods. In addition, a new methodology is developed to heuristically identify peaks within a peaked schedule, and schedule measures to capture peaked and depeaked schedules were developed. Airlines, with greater access to industry data, can use the peak percentage and coefficient of variation measures to identify additional depeaking cases and compare peaked and depeaked schedules. Lastly, a methodology is developed for recreating historic schedules flown by parent and their affiliate carriers.

Most importantly, this is the first study to evaluate the revenue impacts of depeaking. In addition, it is the first to contribute to an understanding of the depeaking decision-making process so that in the future airlines can compare their current situation to past cases and assess their best course of action. It also is suggestive that depeaking does not happen in a vacuum, and that the competitive context matters. Finally this study quantifies relationships between passenger connection times and airport revenue.

Summarizing, the three most important contributions that this study provides are: 1) it uses revenue and competitors' system changes to assess the performance of depeaking, which has yet to be done in the literature; 2) it compiles six occurrences of depeaking domestically, allowing a comparison of what the different depeaking strategies are; and 3) it provides insights into factors associated with successful depeaking.

5.5 Study Limitations

This research project has several shortcomings that could not be overcome. At the base of many of these shortcomings is the inability to reproduce a full schedule due to the restrictions of using the data that was used. In addition, the data did not include the ability to calculate passenger connection times.

5.5.1 Not a Full Schedule

This study uses the On-Time Performance Database to recreate historical airline schedules. This database is good for this purpose because it is publicly-available and has a data records for flights that includes departure and arrival times, origin and destination airports, and tail numbers. The On-Time database, however, does not provide for the ability to fully reproduce a schedule due to two main limitations.

First, the On-Time database does not include international flights. This is an issue because the depeaking hubs analyzed in this study are all primary connection points for international travel in their respective airlines' networks, as well as in cities with strong global ties and thus considerable originating international traffic. Thus each case study is missing a proportion of their scheduled operations in the reproduced schedules because the international arrivals and departures are not accounted for. International trips are typically very important for an airline to capture, and the schedule must be arranged carefully around them in order to fill the seats in wide-body jets. Thus, it was not possible to make a formal conclusion in regards to how international flights are handled in depeaking, and how airlines should consider international traffic.

The second limitation to the On-Time database is it does not have all flights flown domestically, as many affiliate airlines are not required to report their on-time statistics. The only airlines that must report are those that have contributed at least one percent to scheduled domestic revenue, and thus many of the smaller affiliate airlines are left out. This effect is greatest in the early 2000s, before affiliate airlines became so prominent in the U.S. industry. Many flights that were scheduled by the parent airline are not reported by the affiliate airline. Without these affiliate airline's flights, a depeaking airline's hub schedule cannot be fully reproduced.

Public data can be used to gain a good picture of the schedule and the changes that occurred, but the dataset has the limitation of missing international and low-revenue affiliate airlines' flights. Some of the airline's depeaking changes could not be determined because this data gap was too large to definitively determine whether depeaking had actually occurred. Thus, many cases which could have been suitable for analysis had to be excluded (but could be examined by airlines who have more complete historic schedule data). In addition, in many situations, the affiliate percentage deviates from what the true value was, because smaller affiliate carriers were not represented.

5.5.2 No Passenger Connection Times

Because the DB1B data does not include passengers' itineraries, only the airports through which they flew, it was not possible to make measurements on the change in connection times at a depeaked airport.

As discussed in much of the literature, a downside of depeaking is the elongating of dwell time for passengers at airports. This, combined with the loss of potential connections, is what drives passengers to fly through another hub in the network and cause a loss of revenue for the depeaking airline. Connection times could not be calculated using publicly-available data, however, so the conclusion of the literature could not be independently verified nor evaluated on a case-by-case basis.

Without the ability to calculate dwell times, one of the key results of this study could not be used to its full potential. The result of the direct relationship between dwell time and passenger spending could not be used to make predictions for each case. Doing so would have tied together these two portions of the study.

5.6 Extensions for Future Work

Based on the findings of this research, and the limitations within it was conducted, there are several recommendations for future research.

Using historic OAG schedule data instead of On-Time Performance data should be a primary goal of any airline or researcher pursuing future work in depeaking. The OAG schedule data would provide a full list of affiliates and international flights which the lack of limited the conclusions of this study. With a full historical schedule, the cases which could not be confirmed for depeaking because of missing affiliates can be verified and analyzed with the same methods used in this report. Having more cases would allow a more full picture of depeaking to be painted, and there would be more data to check the conclusions of this study.

With the inclusion of international flights, the location of where international flights are located in the flight banks of the peaked schedule and how they are shifted and handled in the depeaked schedule can be identified. This inclusion can provide answers as to how international flights are handled in the depeaking decision-making process, and what level of international flights is too much for a schedule to be depeaked.

Another extension for future research would be to quantify the cost of a depeaking airline in both the peaked and depeaked schedule to a point where it could be compared to the revenue. If precise cost figures were available (if an airline was willing to share precise figures) a model could be developed to determine if the saved cost of depeaking would outweigh lost revenue. Once these precise figures of cost are tied to revenue, an airline's profit changes could be assessed.

Developing a full-blown simulation that could simulate a depeaking event and predict its effects is another extension of this work. Simply, using cost data (as described as a need in the last paragraph) and this study's revenue data, a simulation tool could make predictions given depeaking inputs, such as the airline's goals in depeaking, peak percentage desired, and the capacity of the airport. Using this simulation tool, the viability of depeaking in the future could be examined.

As described in the study limitations, calculating connection times would be useful in bolstering the findings of this study. Airlines can use their internal data to determine average connection times at the airport, and use this data to make predictions on airport concession revenue.

Another suggestion for future work would be to look into gate usage before and after depeaking. Determining a source for this data would be the first step. This would also involve looking into how airlines structure their gate leases, and the types of contracts set up with the airports. If this data was available, an assessment into the exact gate needs of an airline before and after depeaking would be an additional evaluation criteria on the degree to which a schedule was depeaked.

The addition of a game-theoretic approach would be useful for examining the cases in which there was either two hubbing airlines at an airport, or a strong competitive threat. With two major players, there could be a capacity constraint on the airport where neither airline has the ability to grow their network. However, there is the potential that an individual decision to depeak could be unilaterally poor for the airline which decides to do so. Meanwhile, through cooperation, both airlines could potentially benefit – similar to putting slot controls on an airport. Through assessing such a situation through game theory, the benefits or risks of singularly depeaking can be determined. For example, the application of anti-trust immunity on scheduling decisions alone could be tested to see how airlines would use this to their advantage, with the potential of reducing delay in the system.

The issue of diversion of passengers from a hub airport to other airline hub routings due to depeaking needs to be further explored. The existing data allows for the exploration of this issue because DB1B provides data on a passenger's routing. By comparing the market share of hub airports for passengers flying between a given OD pair before and after depeaking, the potential exists to see if significant changes occurred in the routings. This analysis needs to be related to the shifts in frequency, potential connections, and ASMs over the same time periods at each of the hub airports being analyzed, to assess what factors controlled for any shifts in the network in an attempt to isolate the effect of the depeaking change.

Lastly, a final extension would be to explore the shifts in RASM in cases where repeaking occurred. The RASM change that occurs from a depeaked to peaked schedule could be explored to see if RASM would have returned to what it would have been had the schedule never been depeaked. Assessing this requires being able to predict what would have changed in revenue streams had depeaking never occurred, and a method to do this needs to be explored.

APPENDIX A

AIRLINE CODES

16	PSA Airlines
17	Piedmont Airlines
AA	American Airlines
AS	Alaska Airlines
AX	Trans States Airlines
B6	JetBlue Airways
CO	Continental Airlines
DH	Atlantic Coast Airlines
DL	Delta Airlines
EV	Atlantic Southeast Airlines
F9	Frontier Airlines
FL	AirTran Airways
HP	America West Airlines
MQ	American Eagle Airlines
NW	Northwest Airlines
OH	Comair
OO	SkyWest Airlines
RP	Chautauqua Airlines
RU	ExpressJet Airlines (until 8/31/2006)
QX	Horizon Air Industries
TZ	America Trans Air Airlines
UA	United Airlines
US	US Airways
WN	Southwest Airlines
YV	Mesa Airlines
YX	Republic Airlines
ZW	Air Wisconsin

APPENDIX B

AIRPORT CODES

ABE	Lehigh Valley International Airport (Allentown, PA)
ABI	Abilene Regional Airport (Abilene, TX)
ABQ	Albuquerque International Sunport
ABY	Southwest Georgia Regional Airport (Albany, GA)
ACT	Waco Regional Airport
ACV	Arcata/Eureka Airport (Arcata, CA)
AEX	Alexandria International Airport (Alexandria, LA)
AGS	Augusta Regional Airport (Augusta, GA)
ALB	Albany Regional Airport
AMA	Rick Husband Amarillo International Airport
APF	Naples Municipal Airport (Naples, FL)
ASE	Aspen-Pitkin County Airport (Aspen, CO)
ATL	Hartsfield-Jackson Atlanta International Airport
ATW	Outagamie County Regional Airport (Outagamie, WI)
AUS	Austin-Bergstrom International Airport
AVL	Asheville Regional Airport (Asheville, NC)
AVP	Wilkes-Barre/Scranton International Airport
AZO	Kalamazoo/Battle Creek International Airport
BDL	Bradley International Airport (Hartford)
BFL	Meadows Field Airport (Oildale, CA)
BGM	Greater Binghamton Airport (Binghamton, NY)
BGR	Bangor International Airport (Bangor, ME)
BHM	Birmingham-Shuttlesworth International Airport
BMI	Central Illinois Regional Airport (Bloomington, IL)
BNA	Nashville International Airport
BOI	Boise Airport
BOS	Logan International Airport (Boston)
BPT	Jack Brooks Regional Airport (Beaumont, TX)
BQK	Brunswick Golden Isles Airport (Brunswick, GA)
BTR	Baton Rouge Metropolitan Airport
BTV	Burlington International Airport (Burlington, VT)
BUF	Buffalo Niagara International Airport
BUR	Bob Hope Airport (Burbank, CA)
BWI	Baltimore/Washington International Thurgood Marshall Airport
CAE	Columbia Metropolitan Airport (Columbia, SC)
CAK	Akron-Canton Airport
CEC	Del Norte County Airport (Crescent City, CA)
CHA	Chattanooga Metropolitan Airport
CHO	Charlottesville-Albemarle Airport (Charlottesville, VA)
CHS	Charleston International Airport (Charleston, SC)
CIC	Chico Municipal Airport (Chico, CA)

CID	The Eastern Iowa Airport (Cedar Rapids, IA)
CLD	McClellan-Palomar Airport (Carlsbad, CA)
CLE	Cleveland Hopkins International Airport
CLL	Easterwood Airport (College Station, TX)
CLT	Charlotte/Douglas International Airport
CMH	Port Columbus International Airport (Columbus, OH)
CMI	University of Illinois Willard Airport (Urbana-Champaign, IL)
COS	Colorado Springs Airport
CRP	Corpus Christi International Airport
CRW	Yeager Airport (Charleston, WV)
CSG	Columbus Airport (Columbus, GA)
CVG	Cincinnati/Northern Kentucky International Airport
DAB	Daytona Beach International Airport
DAY	Dayton International Airport (Dayton, OH)
DBQ	Dubuque Regional Airport (Dubuque, IA)
DCA	Ronald Reagan Washington National Airport
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DHN	Dothan Regional Airport (Dothan, AL)
DLH	Duluth International Airport (Duluth, MN)
DRO	Durango-La Plata County Airport (Durango, CO)
DSM	Des Moines International Airport
DTW	Detroit Metropolitan Wayne County Airport
ELM	Elmira/Corning Regional Airport (Elmira, NY)
ERI	Erie International Airport (Erie, PA)
EUG	Eugene Airport (Eugene, OR)
EVV	Evansville Regional Airport (Evansville, IN)
EWN	Coastal Carolina Regional Airport (New Bern, NC)
EWR	Newark Liberty International Airport
EYW	Key West International Airport
FAT	Fresno Yosemite International Airport
FAY	Fayetteville Regional Airport (Fayetteville, NC)
FLL	Fort Lauderdale-Hollywood International Airport
FLO	Florence Regional Airport (Florence, SC)
FNT	Bishop International Airport (Flint, MI)
FSM	Fort Smith Regional Airport (Fort Smith, AR)
FWA	Fort Wayne International Airport (Fort Wayne, IN)
GGG	East Texas Regional Airport (Longview, TX)
GNV	Gainesville Regional Airport (Gainesville, FL)
GPT	Gulfport-Biloxi International Airport
GRB	Austin Straubel International Airport (Green Bay, WI)
GRR	Gerald R. Ford International Airport (Grand Rapids)
GSO	Piedmont Triad International Airport (Greensboro, NC)
GSP	Greenville-Spartanburg International Airport
GTR	Golden Triangle Regional Airport (Golden Triangle, MS)
HKY	Hickory Regional Airport (Hickory, NC)

HNL	Honolulu International Airport
HOU	William P. Hobby Airport (Houston)
HPN	Westchester Country Airport (White Plains, NY)
HSV	Huntsville International Airport (Huntsville, AL)
HVN	Tweed New Haven Regional Airport (New Haven, CT)
IAD	Washington Dulles International Airport
IAH	George Bush Intercontinental Airport (Houston)
ICT	Wichita Mid-Continent Airport
ILE	Grosse Ile Municipal Airport (Grosse Ile, MI)
ILM	Wilmington International Airport (Wilmington, NC)
IND	Indianapolis International Airport
IPL	Imperial County Airport (Imperial, CA)
IPT	Williamsport Regional Airport (Williamsport, PA)
ISP	Long Island MacArthur Airport (Islip, NY)
ITH	Ithaca Tompkins Regional Airport (Ithaca, NY)
IYK	Inyokern Airport (Inyokern, CA)
JAN	Jackson-Evers International Airport (Jackson, MS)
JAX	Jacksonville International Airport
JFK	John F. Kennedy International Airport (New York City)
LAW	Lawton-Fort Sill Regional Airport (Lawton, OK)
LAX	Los Angeles International Airport
LBB	Lubbock Preston Smith International Airport
LEX	Blue Grass Airport (Lexington, KY)
LFT	Lafayette Regional Airport (Lafayette, LA)
LGA	LaGuardia Airport (New York City)
LIT	Little Rock National Airport
LRD	Laredo International Airport (Laredo, TX)
LSE	La Crosse Municipal Airport (La Crosse, WI)
LWB	Greenbrier Valley Airport (Lewisburg, WV)
LYH	Lynchburg Regional Airport (Lynchburg, VA)
MAF	Midland International Airport (Midland, TX)
MCI	Kansas City International Airport
MCN	Middle Georgia Regional Airport (Macon, GA)
MCO	Orlando International Airport
MDT	Harrisburg International Airport (Harrisburg, PA)
MEI	Meridian Regional Airport (Meridian, MS)
MEM	Memphis International Airport
MFR	Rogue Valley International-Medford Airport (Medford, OR)
MGM	Montgomery Regional Airport (Montgomery, AL)
MHT	Manchester-Boston Regional Airport (Manchester, NH)
MIA	Miami International Airport
MKE	General Mitchell International Airport (Milwaukee)
MLB	Melbourne International Airport (Melbourne, FL)
MLU	Monroe Regional Airport (Monroe, LA)
MOB	Mobile Regional Airport
MOD	Modesto City-County Airport (Modesto, CA)

MQT	Sawyer International Airport (Marquette, MI)
MRY	Monterey Regional Airport (Monterey, CA)
MSN	Dane County Regional Airport (Madison, WI)
MSP	Minneapolis-Saint Paul International Airport
MSY	Louis Armstrong New Orleans International Airport
MTJ	Montrose Regional Airport (Montrose, CO)
MYR	Myrtle Beach International Airport
OAK	Oakland International Airport
OGG	Kahului Airport (Kahului, HI)
OKC	Will Rogers World Airport (Oklahoma City)
OMA	Eppley Airfield (Omaha)
ONT	LA/Ontario International Airport (Ontario, CA)
ORD	Chicago O'Hare International Airport
ORF	Norfolk International Airport
ORH	Worcester Regional Airport (Worcester, MA)
OXR	Oxnard Airport (Oxnard, CA)
PDX	Portland International Airport
PFN	Panama City-Bay County International Airport (Panama City, FL)
PHF	Newport News/Williamsburg International Airport
PHL	Philadelphia International Airport
PHX	Phoenix Sky Harbor International Airport
PIA	General Wayne A. Downing Peoria International Airport
PIT	Pittsburgh International Airport
PNS	Pensacola International Airport
PSP	Palm Springs International Airport (Palm Springs, CA)
PVD	T.F. Green Airport (Providence)
PWM	Portland International Jetport (Portland, ME)
RDD	Redding Municipal Airport (Redding CA)
RDM	Roberts Field (Redmond, OR)
RDU	Raleigh-Durham International Airport
RIC	Richmond International Airport
RNO	Reno-Tahoe International Airport
ROA	Roanoke Regional Airport (Roanoke, VA)
ROC	Greater Rochester International Airport (Rochester, NY)
RSW	Southwest Florida International Airport (Fort Myers, FL)
SAN	San Diego International Airport
SAT	San Antonio International Airport
SAV	Savannah/Hilton Head International Airport (Savannah, GA)
SBA	Santa Barbra Municipal Airport (Santa Barbra, CA)
SBN	South Bend Regional Airport (South Bend, IN)
SBP	San Luis Obispo (San Luis Obispo, CA)
SBY	Salisbury-Ocean City Wicomico Regional Airport (Salisbury, MD)
SCE	University Park Airport (State College, PA)
SDF	Louisville International Airport
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport

SGF	Springfield-Branson National Airport (Springfield, MO)
SGU	St. George Municipal Airport (St. George, UT)
SHV	Shreveport Regional Airport
SJC	San Jose International Airport
SJT	San Angelo Regional Airport (San Angelo, TX)
SJU	Luis Muñoz Marín International Airport (San Juan, Puerto Rico)
SLC	Salt Lake City International Airport
SMF	Sacramento International Airport
SMX	Santa Maria Public Airport (Santa Maria, CA)
SNA	John Wayne Airport (Orange County, CA)
SPS	Wichita Falls Municipal Airport (Wichita Falls, TX)
SRQ	Sarasota-Bradenton International Airport (Sarasota, FL)
STL	Lambert-St. Louis International Airport
SUN	Friedman Memorial Airport (Hailey, ID)
SWF	Stewart International Airport (Poughkeepsie, NY)
SYR	Syracuse Hancock International Airport
TLH	Tallahassee Regional Airport
TOL	Toledo Express Airport
TPA	Tampa International Airport
TRI	Tri-Cities Regional Airport (Tri-Cities, TN)
TUL	Tulsa International Airport
TUP	Tupelo Regional Airport (Tupelo, MS)
TUS	Tucson International Airport
TVC	Cherry Capital Airport (Traverse City, MI)
TXK	Texarkana Regional Airport (Texarkana, AK)
TYR	Tyler Pounds Regional Airport (Tyler, TX)
TYS	McGhee Tyson Airport (Knoxville, TN)
VLD	Valdosta Regional Airport (Valdosta, GA)
VPS	Northwest Florida Regional Airport (Destin, FL)
XNA	Northwest Arkansas Regional Airport (Fayetteville, AR)
YUM	Yuma International Airport (Yuma, AZ)

APPENDIX C

AFFILIATE AIRLINES IN EACH CASE STUDY

The following tables list the affiliate airline exception processing inputs for each case study during the depeaking time period (peaked quarter, depeaking quarter, depeaked quarter). For the combinations that have two ticketing carriers for the same operating carrier for all or some of the spokes (or a specific spoke is if there is only one conflict), the bolded combination for the given bolded spokes is discarded. For that combination, the bolded ticketing carrier listed in these tables is not attributed the flights for the respective operating carrier.

Case: American at ORD

Table C.1 ORD Peaked Quarter (2002q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	AZO, BMI, BTR, CHA, CID, CLE, CLT, CMH, CMI, CVG, DAY, DBQ, DLH, DSM, EVV, FWA, GRB, GRR, GSP, HSV, IND, LSE, MDT, MEM, MKE, MQT, MSN, OMA, ORF, ORH, PIA, PIT, PWM, RIC, SDF, TOL, TVC, TYS, XNA

Table C.2 ORD Depeaked Quarter (2002q2) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	AZO, BMI, BTR, BTV, CHA, CID, CLE, CLT, CMH, CMI, CVG, DAY, DBQ, DLH, DSM, EVV, FWA, GRB, GRR, GSP, HSV, IND, LSE, MDT, MEM, MKE, MQT, MSN, OMA, ORF, ORH, PIA, PIT, PWM, RIC, ROC, SDF, TOL, TVC, TYS, XNA

Case: American at DFW

Table C.3 DFW Peaked Quarter (2002q3) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	ABI, ABQ, ACT, AMA, BOI, BTR, CID, CLL, CMH, CRP, DAY, DRO, FSM, FWA, GGG, GRR, GSP, HOU, ICT, ILE, JAN, LAW, LBB, LIT, LRD, MAF, MEM, MKE, MSN, OKC, SAV, SGF, SHV, SJT, SPS, TUL, TXK, TYR, TYS, XNA
YX	**MQ**	**MKE**

Table C.4 DFW Depeaking Quarter (2002q4) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	ABI, ACT, AMA, BOI, BTR, CID, CLL, CMH, CRP, CVG, DAY, FSM, FWA, GGG, GRR, GSO, GSP, HOU, ICT, ILE, JAN, LAW, LBB, LIT, LRD, MAF, MEM, MKE, MTJ, OKC, SAV, SGF, SHV, SJT, SPS, TUL, TXK, TYR, TYS, XNA
AS	**MQ**	**BOI**
YX	**MQ**	**MKE**

Table C.5 DFW Depeaked Quarter (2003q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	ABI, ACT, AMA, BOI, BTR, CID, CLL, CLT, CMH, CRP, CVG, DAY, FSM, FWA, GGG, GRR, GSO, GSP, HOU, HSV, ICT, ILE, JAN, LAW, LBB, LIT, LRD, MAF, MEM, MKE, MTJ, OKC, SDF, SGF, SHV, SJT, SPS, TUL, TXK, TYR, TYS, XNA
YX	**MQ**	**MKE**

Case: Delta at ATL

Table C.6 ATL Depeaked Quarter (2004q4) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	AX	STL
US	AX	PIT
DL	EV	ABE, ABY, AEX, AGS, APF, ATW, AUS, AVL, AVP, BNA, BQK, BTR, BUF, BWI, CAE, CAK, CHA, CHO, CHS, CLE, CLT, CRP, CRW, CSG, CVG, DAB, DCA, DFW, DHN, DSM, EVV, EYW, FAY, FLO, FNT, FWA, GNV, GPT, GRR, GSO, GSP, GTR, HOU, HPN, HSV, IAD, IAH, ICT, ILM, IND, ISP, JAN, JAX, LEX, LFT, LIT, LWB, LYH, MCN, MDT, MEI, MGM, MHT, MKE, MLB, MLU, MOB, MSY, MYR, OMA, ORF, PFN, PHF, PIA, PIT, PNS, ROA, ROC, SAT, SAV, SBN, SHV, SRQ, TLH, TOL, TRI, TYS, VLD, VPS, XNA
DL	OH	ABE, ATW, AVP, BUF, BWI, CAK, CHS, CLE, CVG, DAB, DAY, DCA, DSM, EVV, FNT, GRR, GSP, HSV, IAH, ICT, JFK, LEX, MDT, MLB, PIT, ROA, ROC, SAV, SDF, SHV, STL, SYR, TLH, TOL, TYS, XNA
CO	RU	CLE, IAH
DL	**RU**	**CLE**
UA	YV	IAD, ORD
US	YV	CLT, PHL

Table C.7 ATL Depeaking Quarter (2005q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	AX	STL
UA	**AX**	**PIT**
US	AX	PIT
DL	EV	ABE, ABY, AEX, AGS, APF, ATW, AUS, AVL, AVP, BNA, BPT, BQK, BTR, BUF, CAE, CAK, CHA, CHO, CHS, CLE, CLT, CRP, CRW, CSG, DAB, DAY, DCA, DFW, DHN, DSM, DTW, EVV, EYW, FAY, FLO, FNT, FWA, GNV, GPT, GRR, GSO, GSP, GTR, HOU, HPN, HSV, IAD, IAH, ICT, ILM, IND, ISP, JAN, JFK, LEX, LFT, LIT, LYH, MCN, MDT, MEI, MEM, MGM, MHT, MKE, MLB, MLU, MOB, MSP, MSY, MYR, OMA, ORF, PFN, PHF, PIA, PIT, PNS, PWM, RIC, ROA, ROC, SAT, SAV, SBN, SHV, SRQ, STL, TLH, TOL, TRI, TUL, TYS, VLD, VPS, XNA
NW	**EV**	**GRR, MSP**
DL	OH	ABE, AVP, BUF, BWI, CAE, CAK, CHA, CLT, CRW, CVG, DAB, DAY, DSM, EVV, GSP, HSV, IAD, JFK, LEX, MKE, OMA, PIT, RDU, ROC, SDF, STL, SYR, TRI, XNA
CO	RU	CLE, IAH
DL	**RU**	**CLE**
UA	YV	IAD, ORD
US	YV	CLT, PHL

Table C.8 ATL Depeaked Quarter (2005q2) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	AX	STL
UA	**AX**	**PIT**
US	AX	PIT
DL	EV	ABE, ABY, AEX, AGS, APF, ATW, AUS, AVL, AVP, BNA, BPT, BQK, BTR, BUF, CAE, CAK, CHA, CHO, CHS, CLE, CLT, CRP, CRW, CSG, DAB, DAY, DCA, DHN, DSM, DTW, EVV, EYW, FAY, FLO, FNT, FWA, GNV, GPT, GRR, GSO, GSP, GTR, HKY, HOU, HPN, HSV, IAD, IAH, ICT, ILM, IND, ISO, ISP, JAN, JFK, LEX, LFT, LIT, LWB, LYH, MCI, MCN, MDT, MEI, MEM, MGM, MHT, MLB, MLU, MOB, MSP, MYR, OKC, OMA, PFN, PHF, PIA, PIT, PNS, PWM, RIC, ROA, ROC, SAT, SBN, SDF, SHV, STL, TLH, TOL, TRI, TUL, TUP, TYS, VLD, VPS, XNA
NW	**EV**	**GRR, MSP**
DL	OH	ABE, BUF, BWI, CAE, CAK, CHA, CRW, CVG, EVV, HSV, IAD, JFK, LEX, MKE, RDU, ROC, STL, TRI, XNA
CO	RU	CLE, IAH
DL	**RU**	**CLE**
UA	YV	DEN, IAD, ORD
US	YV	CLT, PHL

Case: US Airways at PHL

Table C.9 PHL Depeaked Quarter (2004q4) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
UA	**16**	**DAY**
US	16	ABE, ALB, ATL, AVP, BGM, BGR, BHM, BNA, BTV, BWI, CAK, CHO, CLE, CMH, CVG, DAY, DCA, DTW, ERI, GSO, GSP, ITH, LGA, MDT, MHT, ORF, PHF, PWM, RIC, ROC, SCE, SDF, STL, SYR, TYS
UA	**17**	**ISP, LGA, PHF, ROA**
US	17	ABE, AVP, BGM, BUF, BWI, CHO, ELM, HPN, HVN, IPT, ISP, ITH, LGA, MDT, ORF, PHF, RIC, ROA, ROC, SBY, SCE, SWF, SYR
AA	RP	STL
US	**RP**	BGM, BTV, BUF, BWI, CLE, CMH, CVG, GSO, IND, LGA, ORF, RDU, ROC, SAV, SDF, **STL**, SYR
UA	**YV**	**CLE, IAD, STL**
US	YV	ABE, ALB, ATL, AVP, BDL, BGM, BGR, BHM, BNA, BOS, BTV, BWI, CAE, CHS, CLE, CLT, CMH, CRW, CVG, DCA, DTW, ELM, ERI, EWR, GRR, GSP, IAD, ITH, LGA, MCI, MKE, ORF, PHF, PIT, PWM, RIC, ROC, SCE, SDF, STL

Table C.10 PHL Depeaking Quarter (2005q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
UA	**16**	**DAY**
US	16	ALB, ATL, AVP, BTV, BWI, CAK, CHS, CLE, CRW, DAY, DCA, DTW, EWR, GSO, IAD, ILM, IND, ITH, LGA, MSP, PHF, PWM, RIC, ROC, SDF, SYR, TYS
UA	**17**	**ISP, ROA**
US	17	ABE, AVP, BGM, BTV, BUF, BWI, CHO, ELM, HPN, HVN, IPT, ISP, ITH, LGA, MDT, ORF, PHF, ROA, ROC, SBY, SCE, SWF, SYR
AA	RP	STL
US	**RP**	ABE, AVP, BGM, BOS, BUF, BWI, CHS, CLE, CMH, DCA, DTW, ERI, GSO, GSP, IND, LGA, PHF, RDU, ROC, SCE, SDF, **STL**, SYR
UA	**YV**	**BNA, BTV, CLE, IAD**
US	YV	ABE, ALB, ATL, AVP, BGM, BGR, BHM, BNA, BTV, BWI, CAE, CHS, CLE, CLT, CMH, CRW, CVG, DCA, DTW, ELM, ERI, GRR, GSO, GSP, IAD, IND, MCI, MKE, MSP, ORF, PHF, PWM, RIC, ROC, SAV, SCE, SDF, STL, SYR

Table C.11 PHL Depeaked Quarter (2005q2) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
UA	**16**	**DAY**
US	16	ABE, ALB, BNA, BTV, CAK, CHS, CLE, CRW, DAY, DCA, DTW, GSO, HPN, IAD, ILM, IND, ITH, LGA, MSP, MYR, ORF, PHF, PVD, PWM, RDU, RIC, ROC, SDF, TYS
UA	**17**	**ISP, ITH, ROA**
US	17	ABE, AVP, BGM, BTV, BUF, BWI, CHO, ELM, EWN, HPN, HVN, IPT, ISP, ITH, LGA, MDT, ORF, PHF, RIC, ROA, ROC, SBY, SCE, SWF, SYR
AA	RP	STL
UA	**RP**	**BUF**
US	RP	ABE, BUF, CHS, CMH, DCA, DTW, ERI, EWR, GSO, GSP, ILM, IND, LGA, ORF, PHF, RDU, SDF, SYR
UA	**YV**	**BNA, CLE, IAD, STL**
US	YV	ABE, ALB, ATL, AVP, BGM, BGR, BHM, BNA, BTV, BWI, CAE, CLE, CVG, DTW, ELM, ERI, GRR, GSO, GSP, IAD, ILM, IND, MCI, MHT, MKE, MSP, MYR, ORF, PHF, PWM, RIC, ROA, SAV, SCE, STL, SYR

Case: United at LAX

Table C.12 LAX Peaked Quarter (2005q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	FAT, MRY, PSP, SAN, SBA, SBP, SFO, SJC, XNA
AS	**MQ**	**FAT, PSP, SAN, SBP**
CO	**MQ**	**PSP, SAN**
DL	**MQ**	**FAT, MRY, PSP, SAN, SBA, SBP, SJC**
NW	**MQ**	**FAT, PSP, SAN, SBA, SBP**
DL	OO	SLC
UA	**OO**	BFL, CLD, COS, FAT, IPL, IYK, MRY, OAK, ONT, OXR, PHX, PSP, RNO, SAN, SBA, SBP, SGU, SJC, **SLC**, SMF, SMX, SNA, TUS, YUM
AA	**QX**	**BOI, MFR**
AS	QX	BOI, EUG, MFR, RNO, SUN
F9	QX	DEN
UA	ZW	ASE

Table C.13 LAX Depeaking Quarter (2005q2) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	FAT, MRY, SAN, SBA, SBP, SFO, SJC, XNA
AS	**MQ**	**FAT, SAN, SBA, SBP**
CO	**MQ**	**SAN**
DL	**MQ**	**FAT, MRY, SAN, SBA, SBP, SJC**
NW	**MQ**	**FAT, SAN, SBA, SBP**
DL	OO	SLC
UA	**OO**	BFL, CLD, COS, FAT, IPL, IYK, MRY, OAK, ONT, OXR, PDX, PHX, PSP, RNO, SAN, SAT, SBA, SBP, SGU, SJC, **SLC**, SMF, SMX, SNA, TUS, YUM
AA	**QX**	**BOI, MFR**
AS	QX	BOI, EUG, MFR, RNO, SUN
F9	QX	DEN

Table C.14 LAX Depeaked Quarter (2005q3) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
AA	MQ	FAT, MRY, SAN, SBA, SBP, SFO, SJC, XNA
AS	**MQ**	**SAN, SBA, SBP**
CO	**MQ**	**SAN, SBA**
DL	**MQ**	**FAT, MRY, SAN, SBA, SBP, SJC**
NW	**MQ**	**FAT, SAN, SBA, SBP**
DL	OO	SLC
UA	**OO**	BFL, CLD, COS, FAT, IYK, MRY, OAK, ONT, OXR, PDX, PHX, PSP, RNO, SAN, SAT, SBA, SBP, SGU, SJC, **SLC**, SMF, SMX, SNA, TUS, YUM
AA	**QX**	**BOI, MFR, RNO, SUN**
AS	QX	ACV, BOI, EUG, MFR, RDD, RNO, SUN
F9	QX	DEN

Case: United at SFO

Table C.15 SFO Peaked Quarter (2005q4) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
DL	OO	SLC
UA	**OO**	ABQ, ACV, BFL, BOI, BUR, CEC, CIC, COS, EUG, FAT, MFR, MOD, MRY, PDX, RDD, RDM, RNO, SAT, SBA, SBP, **SLC**, SMF, SNA, TUS
AA	**QX**	**PDX**
AS	QX	PDX
NW	**QX**	**PDX**

Table C.16 SFO Depeaked Quarter (2006q1) Exception Processing Input

Ticket Carrier	Operating Carrier	Spoke(s)
DL	OO	SLC
UA	**OO**	ABQ, ACV, BFL, BOI, BUR, CEC, CIC, COS, EUG, FAT, MFR, MOD, MRY, ONT, PDX, PSP, RDD, RDM, RNO, SAT, SBA, SBP, **SLC**, SMF, SNA, TUS
AA	**QX**	**PDX**
AS	QX	PDX
NW	**QX**	**PDX**

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