# MERGERS AND NETWORK EFFECTS: UNDERSTANDING THE RECENT INCREASE IN PERCENTAGE OF NON-WEATHER-CAUSED FLIGHT DELAYS IN THE UNITED STATES

By

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## ABSTRACT

The proportion of flights delayed by non-weather causes has steadily increased over the past decade amidst fluctuating levels of passenger volume and overall delay. With large increases in individual air carrier levels of non-weather delay having been found to coincide with merger events, two such mergers are studied in detail. Domestic flight data from the Bureau of Transportation Statistics is utilized to identify characteristics of routes that increased in non-weather delays following the Delta-Northwest and United-Continental mergers. Common characteristics of such "problematic" routes are identified through network analysis in Gephi software, and are tested for statistical significance with multivariate regression analysis. Route characteristics that are significantly positively correlated with increases in non-weather related delay for both mergers include: operation by the acquiring carrier (Delta or United), originating from a medium or large hub, and originating from an airport with high delay.

INDEX WORDS: Aviation, Flight delays, Network analysis, Transportation, Geography

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# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

## 1.1 The Problem

The airline industry has grown substantially over the past half century with the expansion of commercial aviation, leading to heightened globalization and economic opportunity. However, with growing air travel has come growing flight delays, with 23.75% of all flights in the United States delayed by more than fifteen minutes in 2014 (BTS 2014). Flight delays are not just a minor nuisance, as delays cost billions of dollars and hundreds of thousands of travelers' hours each year in the United States alone (NEXTOR 2010; BTS 2014). While the causes of some delays, such as weather, are out of human control and therefore unavoidable to a certain extent, a significant portion of delays are caused by congestion in the system (BTS 2014) or other factors that should theoretically be deemed as avoidable.

A large part of the flight delay problem is a growing demand for flights in a capacity-constrained infrastructure system, with congestion-caused delays on the rise and predicted to increase in the future (FACT 2, 2007). Even with the implementation of NextGen, a series of technological improvements designed to increase air traffic control efficiency, delays are projected to rise in the future as passenger demand increases more quickly than infrastructure capacity (Fleming 2010). The broader root of the problem was stated succinctly in a recent Washington Post article, in the quote: "Post-WWII America is wearing out." (Halsey III, 2013). The Federal Aviation Administration (FAA) conducts ongoing research, published in the Future Airport Capacity Task (FACT) to suggest long-term infrastructure planning decisions for airports; but with findings that delays will still be significant problems especially at already-busy airports despite future infrastructure improvements. Other than Denver International Airport and Dallas Fort-Worth, no new large commercial airports have been built in the United States in the past 45 years (FACT 2, 2007). Given the extreme cost of building a new airport, the majority of changes have and will likely continue to be in the form of optimizing existing infrastructure, such as adding new runways or gates, or through policy change (FACT 2, 2007). With any future solutions, though, having a thorough understanding of all factors leading to the problem is absolutely necessary.

An additional factor that fuels the flight delay problem is the fragile nature of air carriers as businesses. With high operating costs, including those of fuel, labor, and capital, as well as the volatile nature of the market and sensitivity to the economy (Pilarski 2007), it is a well-known fact that air carriers are prone to financial trouble. Given the need for profit, air carriers may choose to schedule as many flights as possible during peak travel times, but often at the expense of incurred congestion and delays, resulting in a "tragedy of the commons" scenario, especially when multiple air carriers are involved (Mayer and Sinai 2003).

Another way that air carriers have sought solutions to financial trouble is through acquisition and consolidation deals, or mergers with other air carriers. Through a merger, the sharing of operating costs of two air carriers is achieved, as well as the mutual expansion and shifting of combined market components (Pilarski 2007). Changes in flight frequencies within the route network are also known and studied effects of mergers (Bilotkach 2013; Richard 2003). Such changes in route network structure are likely to influence delay, but these effects are largely overshadowed in the literature by the focus on effects of mergers on direct monetary costs.

Rather than an economic approach, this research adopts a network perspective to examine the relationship between route characteristics and delay surrounding two airline merger events.

## 1.2 Literature Review

Research in aviation traverses many fields, including operations research, geography, statistics, engineering, economics, and business. Specifically with regard to flight delays and system performance, many modeling tools have been developed to optimize: aircraft routing (Bennell et al. 2013; Eun et al. 2010; Lan et al. 2006), taxiing strategies (Maharjan and Matis 2012; Bolat 2000), re-routing during delay (Petersen et al. 2012; Bard et al. 2001), prediction of delay (Abdelghany 2004; Wieland 1997), understanding of delay propagation (Fleurquin et al. 2012; Schaefer and Millner 2002) and even the ordering of passengers boarding a plane (Bazargan 2007).

While many of these modeling strategies fall under the subject of operations research, geographers and transportation scientists have sought to characterize and quantify flight delays as well, including broad characterization of delay (Zhang et al. 2010; Wu 2005; Wu and Caves 2003), propagation of delay through the system (Fleurquin et al. 2012; Diana 2009; Andersson and Varbrand 2004), the interplay of market forces and delay (Prince and Simon 2009; Suzuki 2000), policy implications and delay (Rupp 2009; Morrison and Winston 2008; Todd and Sinai 2003) including slot-controlled airports (Swaroop et al. 2012; Venkatakrishnan et al. 1993), as well as the potential for delay mitigation through other transport options (Janic 2010).

Some research has dealt with the more specific nature of individual air carriers as opposed to the entire network, including broadly analyzing individual airline networks (Lee et al. 1994), addressing passenger choice (Tierney and Kuby 2008; Suzuki 2004), and the effect of certain airports being dominated by a single carrier (Mayer and Sinai 2003). However, research delineating the specific profiles of delay exhibited by individual air carriers is not readily available, and is a point that is examined through this study.

The examination of the aviation system through the lens of network analysis is also apparent in the literature. Guimera et al. (2005) studied global airline network topology in order to construct "communities" within the airline network, and to subsequently analyze the differing roles that airports play within these communities. The scope of Guimera et al.'s (2005) study did not traverse the subject of flight delays, which is a focus of this study in relation to components of air carrier route network structures.

Another trend noted in the literature is how the busy airports have been getting busier while low-to-moderate-traffic airports have experienced the opposite, as only six of the core 30 airports in 2013 were above their activity levels for the year 2005 (FAA Aerospace Forecast 2013-2014). Keeping in mind that flight volumes were generally higher in 2005 than in 2014, this fact is not a good sign for congestion, as much congestion already occurs at these already-busy airports. Through the analysis of individual airport and route characteristics following merger events, the role of traffic-volume patterns is considered in this study, with special attention paid to the effects on large hub vs. non-hub airports.

A large portion of existing aviation research is within the economic/business realm and its relation to policy. Bilotkach et al. (2013), who cite the relatively sparse existing literature on airline consolidation, produced a theoretical framework for consolidation effects on air traffic, and empirically analyzed the merger between Delta and Northwest Airlines. While the empirical findings were that dominant carrier hub traffic at Atlanta Hartsfield-Jackson increased following the merger while Northwest's secondary hub traffic decreased, a model-generated framework suggested that other scenarios could play out given different dynamics of individual air carrier networks. The integration of two separate networks following a merger is a phenomenon that lends itself well to network analysis, which is an important task that is performed through this study. In particular, this study examines the effects that such changes to the network have on congestion-related delays and their prevalence at specific airports and along specific routes, or airport pairs.

While Bilotkach et al. (2013) provides one of the few studies that does incorporate an analysis of mergers and delays, no distinctions are made between *types* of delays, which is a key aspect of this study. In fact, in the aviation literature as a whole, delays are most often calculated as the difference in actual vs. scheduled arrival time (Baumgarten et al. 2014; Rupp 2009; Mayer and Sinai 2003), which indicates overall delay rather than more specific delay causes.

In summary, this research provides several unique contributions to the existing body of literature. A focus on specific causes of delay is achieved, in particular non-weather delay, which provides an additional perspective to many studies that only address delay as one general metric. Additionally, given that much of the existing literature on mergers stems from an economic perspective focusing on the profitability of air carriers, this study contributes research from a network perspective, focusing on the relationship between route network component attributes and non-weather-related flight delays.

### 1.3 Motivation and Objectives

With the known presence of flight delays in the aviation system, a further understanding of the problem can be achieved by examining specific *types* of delays. While some delays are caused by inclement weather, a growing portion is caused by other factors that are theoretically within human control. With acceptance of the fact that humans cannot control weather conditions, it is logical to focus on delays that are more within human control, namely those *not* caused by weather. Heavy traffic volume, late-arriving aircraft, mechanical issues, security, and air carrier inefficiencies all constitute "non-weather" delays, which accounted for 69% of total delays in 2014, according to the Bureau of Transportation Statistics (BTS 2014). The remaining 31% of delays experienced in 2014 were caused by weather, both of the extreme and non-extreme varieties. In examining approximately one decade of data for weather vs. non-weather delay, the gap between the two types has steadily widened from 2004 to 2014, with only 54% of delays caused by non-weather in 2004 compared to 69% in 2014 (BTS 2014). This concerning trend forms the basis and motivation for this study, in understanding why the percentage of non-weather-caused delays has increased.

The first step in understanding the increasing trend in non-weather delay is to examine flight volumes and overall levels of delay in recent years. Given the subjectively non-essential nature of air travel, air passenger traffic volume correlates strongly with economic health (Fleming 2010). Before the economic recession in the United States, passenger demand was high, with the years 2004-2007 exhibiting the highest levels of flight operations during the years 2004 - 2014. During the economic recession, a lessened demand for flights meant that number of operations decreased, with 7,455,458 domestic operations in 2007 compared to 6,085,281 in 2011. An improving economy brought an increase in operations in 2012 and 2013, with this increase largely projected to continue in the future (NEXTOR 2010).

As may be expected, percentage of overall delay (reported as flights arriving greater than fifteen minutes past the scheduled arrival time) exhibits a similar pattern to total number of operations. As the number of operations increases, the number of delayed flights *and percentage* of flights delayed tends to increase. With more operations, there is a larger chance for delays, especially with heavy traffic volume and the compounded effect of weather delays. Interestingly, despite the decreasing percentage of overall delay during the recession years, the percentage of non-weather delay increased during this time. Such a phenomenon suggests that it is not an addition of flights to the system that necessarily causes non-weather delay's proportion to increase (as is the case with overall delay), but rather a *shifting* of components within the system. A significant occurrence in the aviation system known to involve a shifting of routes and route frequencies is mergers-- two of which provide the focus of analysis for this study.

An examination of yearly weather vs. non-weather delay experienced individually by major air carriers reveals a strong temporal relationship between mergers and increases in non-weather delay. For the years 2004 - 2014, the two largest one-year increases in non-weather delay percentage for an air carrier occurred the year after a merger became effective. The largest increase was Delta Airlines' increase by 14.0 percentage points from 2009 to 2010, which is when merger with Northwest Airlines became effective. The second largest yearly increase in non-weather delay was United Airlines' increase by 12.9 percentage points from 2011 to 2012, corresponding to its merger with Continental Airlines. Such observed air carrier-specific increases in non-weather delay inevitably contributed to the overall increase experienced by the entire system during this time.

The objective of this study is thus to delve further into the route-level changes in non-weather-caused delay that occurred following the Delta-Northwest and United-Continental mergers, to gain a better understanding of the nature of these shifting system components that have contributed to the system-wide trend. To satisfy this objective, tabular and network data analyses are utilized to define and calculate route characteristics, and their prevalence among "problematic routes"; with multivariate regression models constructed to quantify relationships between route characteristics and change in non-weather-caused delay following both mergers.

Having a better understanding of the delay-causing factors that are not completely out of human control can provide a clearer direction for targeting changes that can actually be attained in the aviation industry. While it will take billions of dollars and/or a vast overhaul of the system to completely eradicate flight delays, smart and thorough planning is imperative in order to make the most efficient possible steps in the right direction. Understanding all aspects of the problem, including the effect that mergers play, is an essential step in this planning.

# CHAPTER 2

# MERGERS AND NETWORK EFFECTS: UNDERSTANDING THE RECENT INCREASE IN PERCENTAGE OF NON-WEATHER-CAUSED FLIGHT DELAYS IN THE UNITED STATES [1]

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[1] Anderson, L.E. and X.A. Yao. To be submitted to *Journal of Air Transport Management.*

## 2.1 Introduction

Commercial aviation flight volumes in the United States have risen and fallen over the last decade with fluctuating economic health. Before the economic recession, passenger demand was high, with the years 2004-2007 exhibiting the highest levels of flight operations during the past decade. During the economic recession, a lessened demand for flights meant that number of operations decreased, with 7,455,458 domestic operations in 2007 compared to 6,085,281 in 2011 (Figure 1a). An improving economy brought an increase in operations in 2012 and 2013, with this increase projected to continue in future years (NEXTOR 2010).

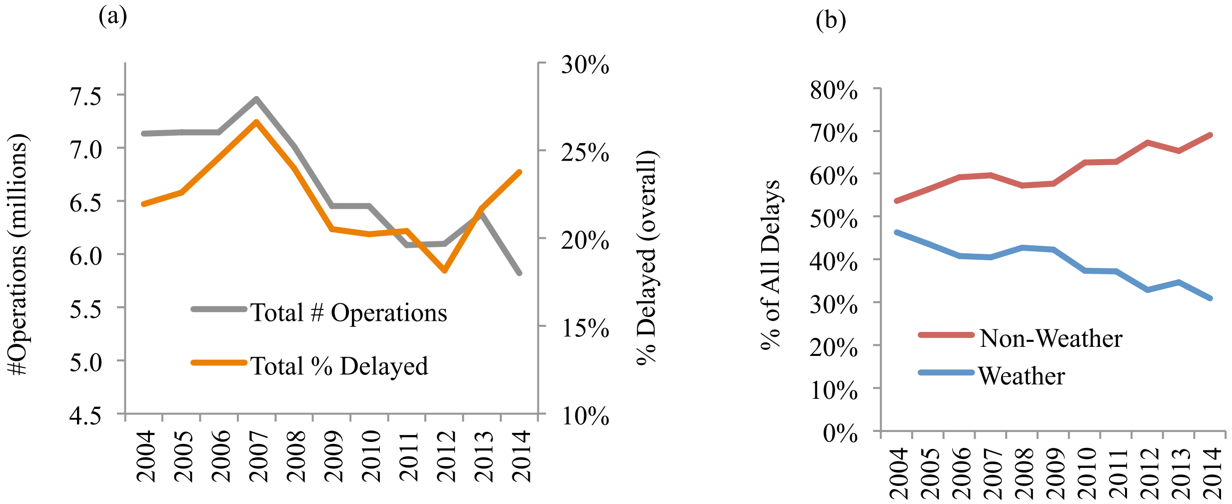


Figure 1. (a) Total number of operations and total percent of flights delayed 2004-2014 and (b) Weather vs. non-weather delay 2004-2014.

Overall on-time performance and flight volumes have followed similar patterns over the past decade, with a larger proportion of flights tending to be delayed (defined as an arrival fifteen or more minutes past scheduled arrival time) when flight volumes are high. With more operations, there is a larger chance for delays, especially with heavy traffic volume and the compounded effect of weather delays. While the pattern of overall operations and performance levels are not particularly surprising, interesting trends arise when examining the percentages of specific *types* of delays. Despite the decreasing percentage of overall delay during the recession years (Figure 1a), the percentage of non-weather delay increased during this time (Figure 1b). The overall decreasing trend in number of flights during this time suggests that it is not an addition of flights to the system that necessarily causes non-weather delay proportion to increase (as is the case with overall delay), but rather a *shifting* of components within the system. With air carrier mergers known to cause a shifting of routes and flight frequencies, two mergers provide the focus of analysis for this study.

An examination of yearly weather vs. non-weather delay experienced individually by major air carriers (airlines) reveals a strong temporal relationship between mergers and increases in non-weather delay (Table 1). Over 2004 to 2014, the two largest one-year increases in non-weather delay percentage for an air carrier occurred the year after a merger became effective. The largest increase was Delta Airlines' increase by 14.0 percentage points from 2009 to 2010, which is when its merger with Northwest Airlines became effective. The second largest yearly increase in non-weather delay was United Airlines' increase by 12.9 percentage points from 2011 to 2012, corresponding to its merger with Continental Airlines. Each of the *combined* air carrier networks (Delta-Northwest and United-Continental) also experienced net increases in non-weather delay of greater than 10.0 percentage points during these times. Given these air carrier-specific increases, which inevitably were part of the overall increase in non-weather delay experienced by the entire system, this study delves further into the route and airport-level changes that occurred following the Delta-Northwest and United-Continental mergers to gain a better understanding of the nature of these shifting system components.

Table 1. Year to year percentage point change in non-weather delay, highlighting largest increases experienced directly following Delta-Northwest and United-Continental mergers.

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **American Airlines** | - | 3% | 1% | 0% | 5% | 2% | 1% | 2% | 7% | -4% | 2% |
| **Delta Airlines** | - | -3% | 11% | 1% | -1% | -5% | 14% | -1% | 4% | -2% | 1% |
| **JetBlue** | - | 0% | -4% | -6% | 3% | 3% | 11% | -6% | 8% | -3% | 1% |
| **Southwest Airlines** | - | 2% | 1% | -3% | 0% | 4% | 4% | -2% | 4% | 0% | 5% |
| **US Airways** | - | -1% | 7% | 6% | -8% | -2% | 5% | 3% | 0% | -1% | 8% |
| **United Airlines** | - | 10% | -2% | 0% | 0% | 1% | -5% | 3% | 13% | -4% | 5% |
| **Continental Airlines** | - | 3% | 0% | -5% | 7% | -1% | 5% | 2% | | | |
| **Northwest Airlines** | - | 1% | 1% | -3% | -8% | 9% | | | | | |
| **Average** | | 2% | 2% | -1% | 0% | 1% | 5% | 0% | 6% | -2% | 4% |

Note: For example, “3%” for American Airlines in 2005 means that the percentage of flights delayed by non-weather increased by 3 percentage points from 2004 to 2005.

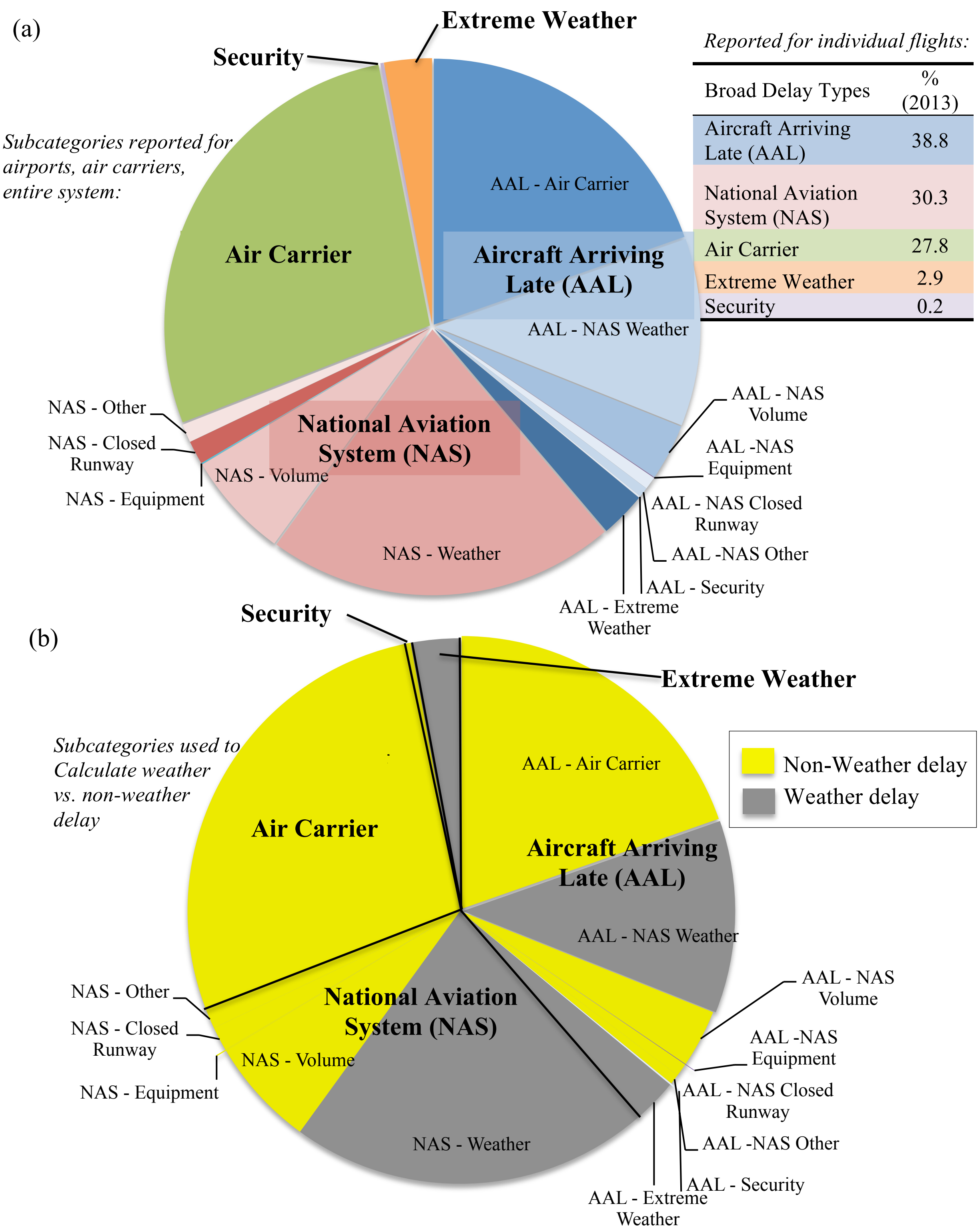
While mergers are commonly addressed in transportation literature, relatively few studies focus on the relationship between mergers and delays. Much of the literature on mergers stems from an economic perspective, focusing on mergers’ effects on ticket fares (Heuschelrath and Mueller 2014; Luo 2014; Park 2014), competition (Bougette et al. 2014; Kwoka and Shumilkina 2010; Bilotkach 2011; Bruekner and Spiller 1991; Borenstein 1990), and stock prices (Manuella and Rhoades 2014; Singal 1996). Bilotkach et al. (2013) relates the economic aspect of mergers to delays, where findings indicate that a the presence of congestion at an airline’s main hub may lead to more traffic being routed through secondary hubs following the route restructuring involved with a merger event. No distinctions are made between *types* of delays though, which is a key aspect of this study. In fact, in the aviation literature as a whole, delays are most often calculated as the difference in actual vs. scheduled arrival time (Baumgarten et al. 2014; Rupp 2009; Mayer and Sinai 2003), which indicates overall delay rather than more specific delay causes. In this study, particular attention is paid to the reported types of delays (explained in

Section 2.2), in order to gain a clearer picture of those delays specifically caused by factors other than weather, and how they are influenced by mergers.

## 2.2 Data

All data was obtained from the U.S. Department of Transportation (USDOT)'s Bureau of Transportation Statistics (BTS), which reports flight operations and delay data for all air carriers with at least 1% of the total market share. Domestic data reported at the individual flight level is utilized, with reported delay types including air carrier, aircraft arriving late (AAL), National Aviation System (NAS), security, and extreme weather (Figure 2a). In order to calculate delay caused specifically by weather, the weather subcategories for NAS and AAL delays must be extracted and added to the extreme weather category (Figure 2b). Unfortunately, with the BTS data, subcategories of NAS and AAL delay are not reported at the individual flight level. Rather, weather vs. non-weather delay is reported aggregately at the airport-level or air carrier-level by month (Figure 2a). Given that air carrier delays contain no subcategory for weather, and are defined by BTS as, "Delays due to circumstances within the airline's control (e.g. maintenance or crew problems, aircraft cleaning, baggage loading, fueling, etc.)" (BTS 2014), this category was found to be the most meaningful in terms of providing a proxy for congestion-related or non-weather delay. A strong positive correlation was also found to exist between yearly averages from 2004 to 2014 of non-weather delay percentage and air carrier delay percentage for both merging airlines (Delta: $R^2 = 0.88$; United: $R^2 = 0.79$), which supports the use of carrier delay as a proxy for non-weather delay.

To further confirm the use of air carrier delay as the delay metric of choice to approximate non-weather delay, spatial statistics were performed to test for any significant localized spatial autocorrelation for airports’ levels of air carrier delay, which, if present, could be indicative of regional conditions/weather influences.  While prior work to this study has identified regional and seasonal patterns of localized spatial autocorrelation of certain delay types (particularly of NAS delays and extreme weather), no such local spatial autocorrelation was found for air carrier delay for air carriers in the current study period.   Given the lack of regional influences from weather, air carrier delay is thus further confirmed as a good approximation for non-weather delay.



*Reported for individual flights:*

| Broad Delay Types | % (2013) |
|---|---|
| Aircraft Arriving Late (AAL) | 38.8 |
| National Aviation System (NAS) | 30.3 |
| Air Carrier | 27.8 |
| Extreme Weather | 2.9 |
| Security | 0.2 |

Figure 2. (a) Five broad delay types reported for individual flights, and their subcategories reported aggregately for airports and air carriers, as published by the Bureau of Transportation Statistics. (b) Subcategories that are used to calculate overall weather vs. non-weather delay.

### 2.2.1 Data selection

Fourth quarter data for consecutive years before and after each merger event are obtained and compared. Table 2 shows the timeframes of each merger, from the date they were first publicly announced and financial workings began to take place, to the time when the two merging carriers were completely consolidated and officially began operating as one carrier. As evidenced by the dates given in Table 2, mergers do not simply happen overnight, but rather involve a gradual series of changes to the carriers' financial dealings, booking systems, route network structures, and operations (Luo 2014). The dates chosen to compare for before and after the mergers were deemed most likely to capture route structural changes, as they are the three months directly prior to the effective consolidation date ($t_1$), and the same three months one year later ($t_2$). Consistent months were compared in order to reduce discrepancies in seasonal flight operations and delay patterns that occur throughout different months of the year. Conveniently, the two studied mergers took place over similar month-wise timeframes, but displaced by two years.

Table 2. Timeframes for studied merger events, where $t_1$ and $t_2$ are the points of comparison.

| | **Delta - Northwest** | **United - Continental** |
|---|---|---|
| *Merger announced* | *April 14, 2008* | *May 3, 2010* |
| **Before ($t_1$)** | **Oct-Nov-Dec 2009** | **Oct-Nov-Dec 2011** |
| *Merger effective* | *January 1, 2010* | *January 1, 2012* |
| **After ($t_2$)** | **Oct-Nov-Dec 2010** | **Oct-Nov-Dec 2012** |

### 2.2.2 Data organization

Complete flight datasets are obtained from BTS for the twelve specified months ($t_1$ and $t_2$ for each merger), totaling nearly 6.5 million flight records. Data are then reorganized into individual datasets for routes and airports and designated by air carriers (for example, Delta vs. Northwest vs. all other carriers), for both mergers. The prime variable studied, *ChgCarrDel*, is the amount of change in carrier delay experienced for air carriers involved in each merger, and is calculated as:

$$\text{ChgCarrDel}_{\text{DLNW}} = \frac{\sum \text{DLflightsCarrDel}_{t2}}{\sum \text{DLflights}_{\text{t2}}} - \frac{\sum \text{DLflightsCarrDel}_{\text{t1}}\text{,NWflightsCarrDel}_{t1}}{\sum \text{DLflights}_{t1}\text{,NWflights}_{t1}} \quad (1)$$

$$\text{ChgCarrDel}_{\text{UACO}} = \frac{\sum \text{UAflightsCarrDel}_{t2}}{\sum \text{UAflights}_{\text{t2}}} - \frac{\sum \text{UAflightsCarrDel}_{\text{t1}}\text{,COflightsCarrDel}_{t1}}{\sum \text{UAflights}_{t1}\text{,COflights}_{t1}} \quad (2)$$

where *flightsCarrDel* is the number of flights that experienced any amount of carrier delay, and *flights* is total number of flights, for *DL* (Delta), *NW*( Northwest), *UA* (United), and *CO* (Continental) at $t_1$ (pre-merger) and $t_2$ (post-merger). In this way, the calculated delay changes are those that occurred over the combined route networks involved in the merger. It should be noted that Northwest and Continental did not exist in $t_2$, meaning that Delta and United at $t_2$ include components from the merged Northwest and Continental networks, respectively. *ChgCarrDel* is calculated at the air carrier level, airport level, and route level, with route level change in carrier delay serving as the dependent variable of focus in this study.

### 2.2.3 Data in network form

Gephi, a free and open source network analysis software, is used to analyze the flight data in network form. Gephi allows for the importing of .csv files delineating network nodes (airports) and edges (routes), and also contains a series of filtering tools and network topology calculations. Figure 3 shows the network structure for air carriers involved with both mergers at $t_1$ (pre-merger) and $t_2$ (merged networks).

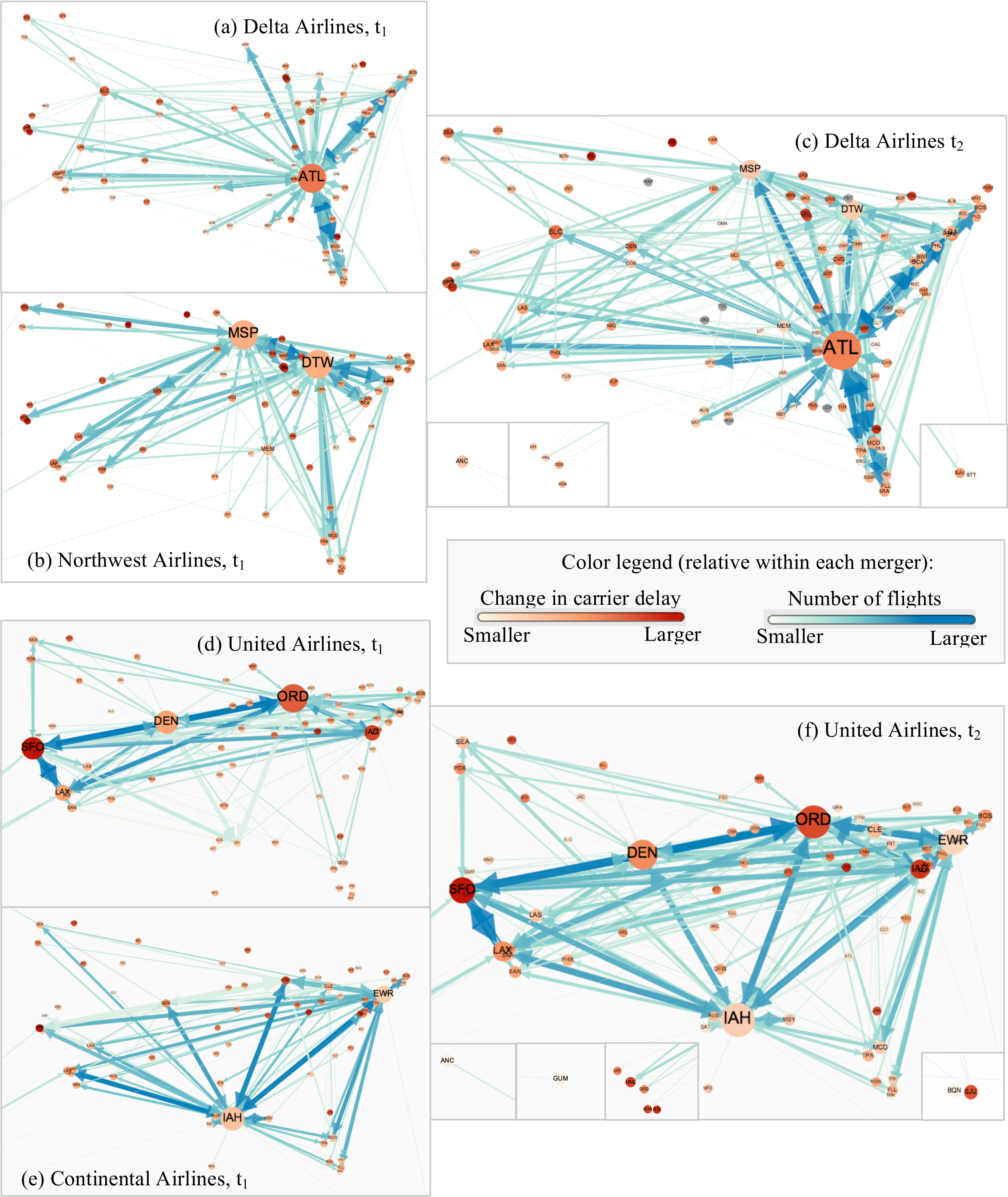


Figure 3. Both merger networks constructed in Gephi, with networks shown at $t_1$ prior to the mergers in (a),(b),(d,),(e), and at $t_2$ after the mergers in (c),(f).

## 2.3 Methods

To identify common themes for flights that experienced changes in carrier delay following the mergers, route characteristics are: identified and quantified (2.3.1), examined for their prevalence among highly problematic routes (2.3.2), and modeled for their effect on carrier delay change using multivariate regression (2.3.3).

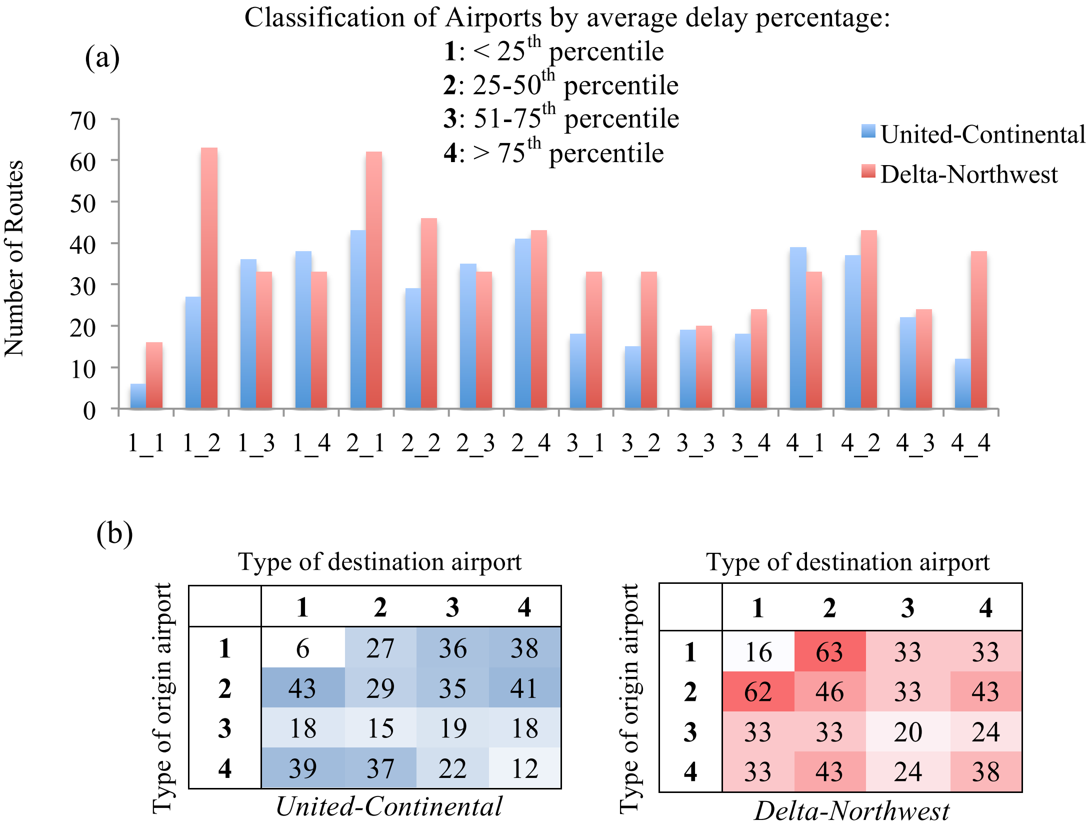
### 2.3.1 Route characteristics

A series of categorical variables are calculated to designate routes by their origin and destination airports' levels of delay and hub size, merging carrier status, and change in flights, each of which are described below:

#### *Origin and destination delay*

Delay classifications are created to understand the nature of delays at the routes' two endpoint airports. It was hypothesized that overall delay at routes' origins and destinations could have an impact on routes' changes in carrier delay, either in the positive or negative direction. Plausible hypotheses include that routes to or from highly delayed airports could have simply experienced exacerbated problems with the merger (a positive relationship), or conversely, that air carriers may have chosen against routing more flights through highly delayed airports with route-restructuring decisions in order to avoid congestion costs (a negative relationship). In all likelihood, and as discussed in the literature review, any route restructuring changes made by air carriers are not solely based upon airport delay levels, but rather upon which routes will provide the most economic boost. However, understanding the delay profiles of the most affected routes post-merger is important information contributing to the understanding of the problem as a whole, and is the purpose of this variable.

An average of airports' air carrier, National Aviation System, and aircraft arriving late delays are used for this variable to give a more complete picture of airport performance in general, inclusive of weather-related delay. Airports are placed in categories, 1-4, based on airport delay percentile. A frequency distribution of routes for each of the sixteen delay profiles is shown in Figure 4a, where bars represent the number of routes present within each of the 16 origin-destination delay profiles. The same values are similarly shown in matrix form in Figure 4b.



Type of destination airport

Type of origin airport

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **1** | 6 | 27 | 36 | 38 |
| **2** | 43 | 29 | 35 | 41 |
| **3** | 18 | 15 | 19 | 18 |
| **4** | 39 | 37 | 22 | 12 |

*United-Continental*

Type of destination airport

Type of origin airport

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **1** | 16 | 63 | 33 | 33 |
| **2** | 62 | 46 | 33 | 43 |
| **3** | 33 | 33 | 20 | 24 |
| **4** | 33 | 43 | 24 | 38 |

*Delta-Northwest*

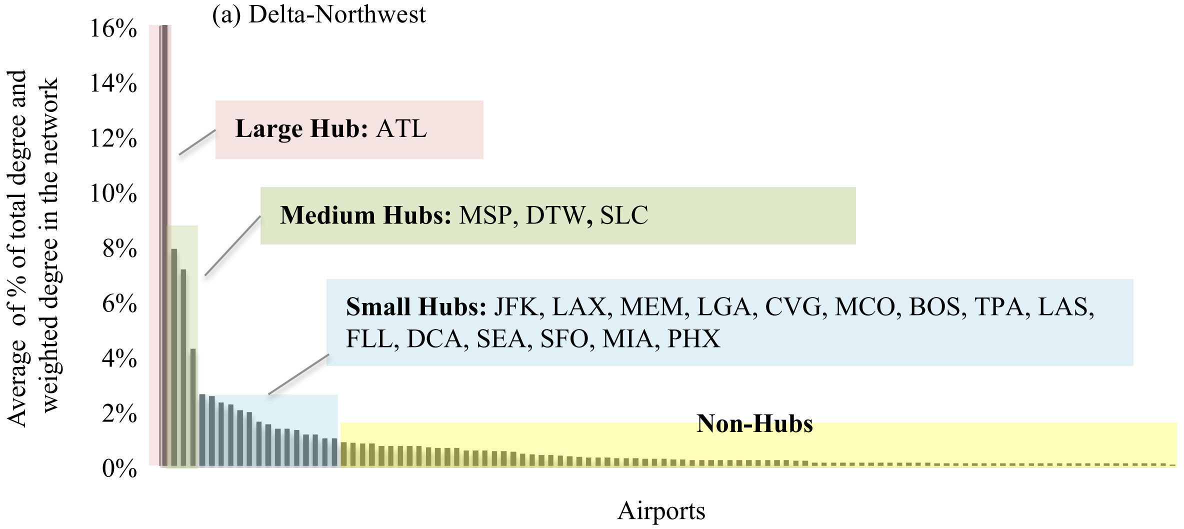
Figure 4. (a) Route frequencies for origin-destination delay profiles based on airport average delay percentage, shown in histogram form. For example, "1_4" indicates a route from an origin airport of type 1 to a destination airport of type 4. (b) Same route frequency values shown in matrix form, where darker shades represent larger values for each merger.

*Origin and destination hub size*

Airport hub size is included as a variable to capture the role that a routes' origin-destination hub profile plays in carrier delay change. The Federal Aviation Administration classifies hub size by an airport's percentage of annual passenger enplanements, with a "large hub" accounting for greater than 1% of all passenger enplanements, and with decreasing portions for the categories of "medium" (0.25-1%), "small" (0.05-0.25%), and "non"-hubs (<0.05%) (FAA 2014). A slightly modified method of hub classification is used in this study to capture the role of airports within the given air carrier networks for each merger, rather than their role within the entire system. Additionally, instead of passenger enplanements, an airport's total number of flights and number of non-stop destinations are used as quantifying metrics to gain a sense of the airports' importance and busyness in the network structure. Given that the goal of this study is to examine the impact of delays on route network components, measures for airports and routes are thus used to classify hub status, rather than passenger counts. In a network, the total number of non-stop destinations is an airport's degree, while the sum of all flights to these destinations is its weighted degree.

Degrees and weighted degrees for all airports are calculated in Gephi (using the combined networks over $t_1$ and $t_2$), from which the average of each airport's degree and weighted degree as a proportion of the total in the network is obtained, and by which all airports for each merger are ranked. Classifications of large hub (>8%), medium hub (4-8%), small hub (1-3.9%), and non-hub (<1%) are then assigned accordingly for airports in each merger network based on their average of proportion of degree and weighted degree. Classifications were chosen by observing natural breaks in each network's degree distributions to divide the data meaningfully in terms of prominence in the network, and also to provide relatively equal sums of degree and weighted degree for all airports in each category. As such, although the number of airports in each category differs dramatically (for example, 1 large hub for Delta-Northwest compared to 89 non-hubs), the sum of degrees and weighted degrees for all airports in each category are relatively comparable. Degree distributions for each of the two networks and corresponding hub classifications are shown in Figure 5.

(a) Delta-Northwest



(b) United-Continental

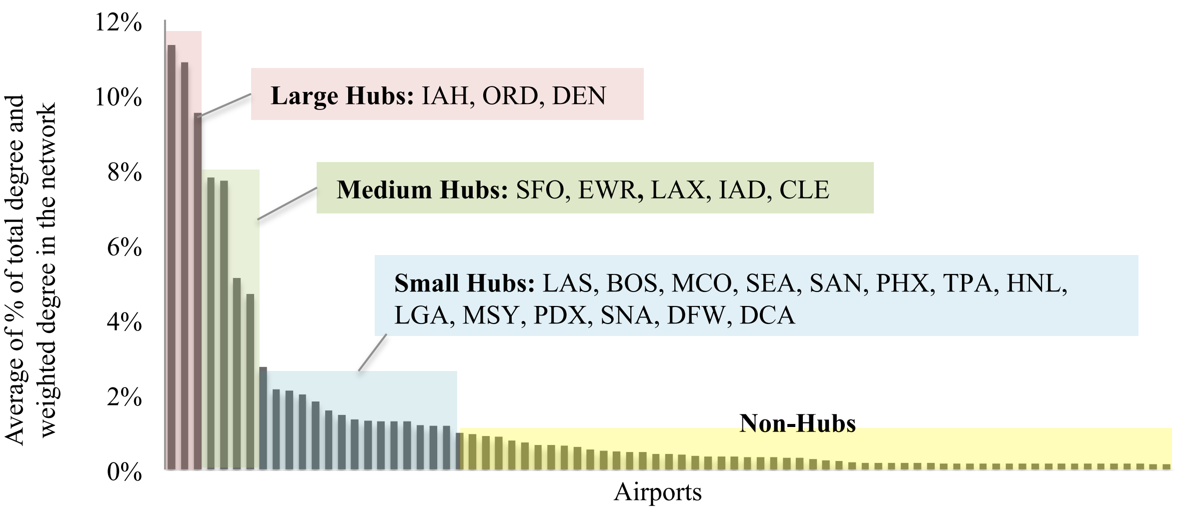
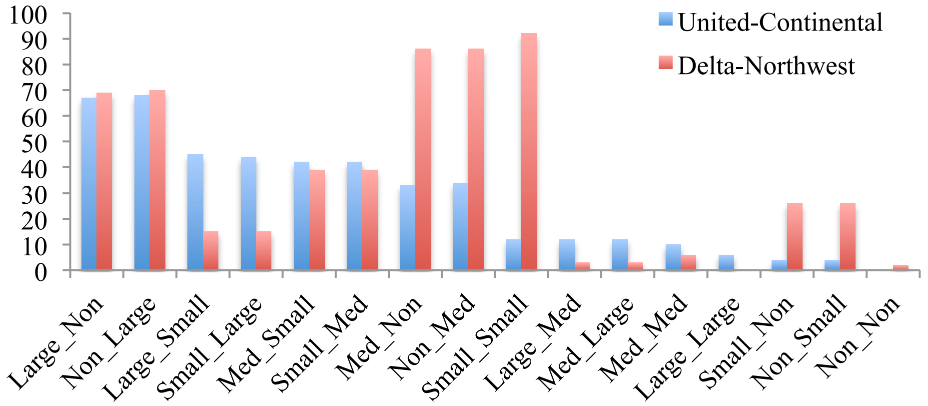


Figure 5. Classifications for airport hub size for (a) Delta-Northwest and (b) United-Continental, based on average of degree and weighted degree as a proportion of the total including: large (>8%), medium (4-8%), small (1-3.9%), and non-hubs (<1%).

General differences in the nature of each of the networks can be observed in Figure 5, with Delta-Northwest exhibiting one very prominent hub (Atlanta Hartsfield-Jackson), as opposed to United-Continental's less marked differences in prominence of its largest three hubs (Houston, Chicago O'Hare, and Denver). With categorical hub classifications for airports, each route then can be designated by its origin and destination hub characteristics (i.e. large to large, large to medium, small to medium, etc.), with route and flight frequencies for each category shown in Figure 6.

(a) Number of routes



(b) Number of flights

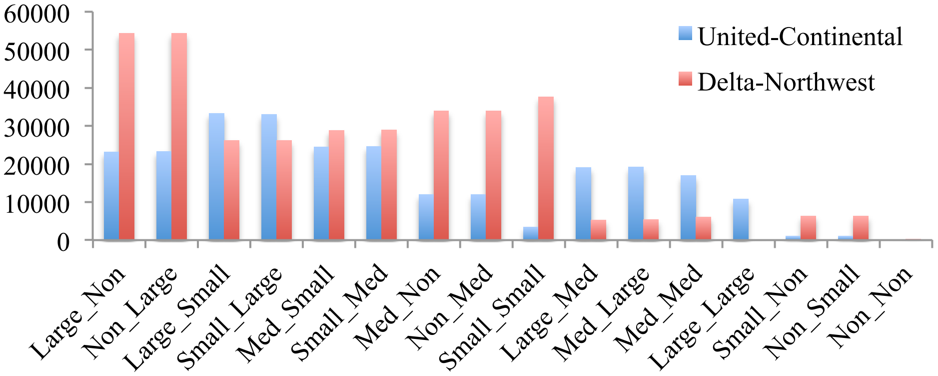


Figure 6. Frequency distributions for (a) routes and (b) flights among route origin-destination hub classifications for each carrier network over $t_1$ and $t_2$.

*Merging carrier status*

Routes are also characterized by their merging carrier status in order to distinguish those operated by the merging carrier (Northwest or Continental), acquiring carrier (Delta or United), both, or that were added or removed. A graphical representation of these categories is shown in Figure 7, using Delta-Northwest as an example. A delineation of each category by frequency is shown in Figure 8. For both merger networks, the highest frequencies of routes were those operated only by the acquiring carrier before and after the mergers, followed by those operated only by the merging carrier in $t_1$ and then switched to the acquiring carrier in $t_2$ (it should be noted that "only" means exclusive only of the other merging carrier, not exclusive of other air carriers not involved in the merger).

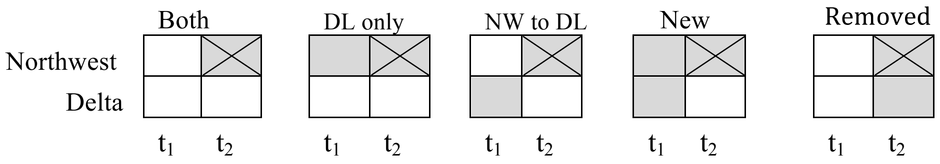


Figure 7. Graphic representation of all merging carrier classification groups, with un-shaded boxes indicating the presence of flights. Boxes are crossed out for Northwest during $t_2$, as Northwest did not exist in $t_2$. The same classifications apply for United-Continental.

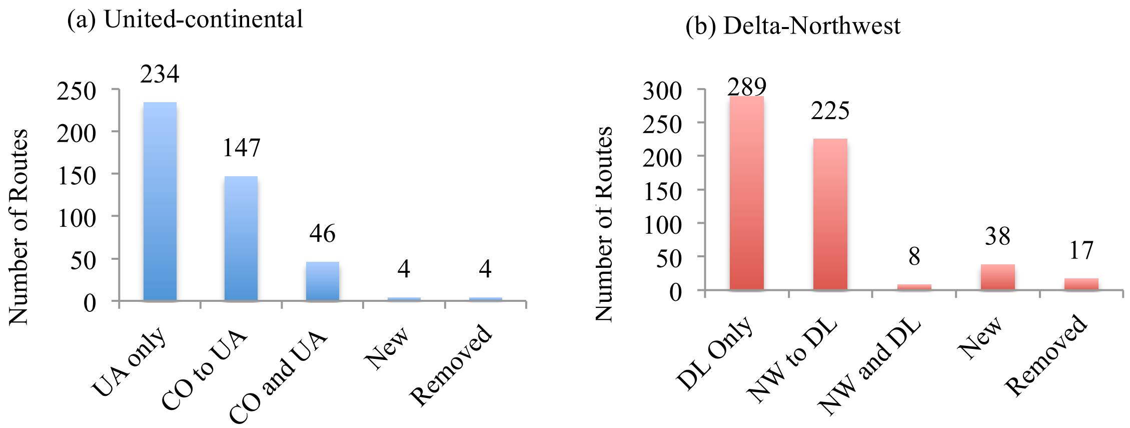


Figure 8. Frequencies of routes within each merging carrier status for (a) United-Continental and (b) Delta-Northwest.

It should be noted that route changes involved with a merger event are often not a mere "re-naming" of the route as it was operated by one carrier and then switched over to another (for example Northwest to Delta). Rather, more complex mechanisms are typically at play within the system, as network changes often involve a changing of frequency of flights as air carriers make strategic decisions to boost profitability (Richard 2003).

### *Change in number of flights*

Change in flight frequency, *ChgFlights,* for routes is calculated by taking the difference in number of flights from $t_1$ to $t_2$ as a proportion of total flights:

$$ChgFlights_{DLNW} = \frac{\sum flights_{DLt2} - \sum flights_{DLt1,NWt1}}{\sum flights_{DLNWt1,t2}} \tag{3}$$

$$ChgFlights_{UACO} = \frac{\sum flights_{UAt2} - \sum flights_{UACOt1}}{\sum flights_{UACOt1,t2}} \tag{4}$$

where *flights* is the number of flights along each route for Delta (*DL*), Northwest (*NW*), United (*UA*), and Continental (*CO*) at $t_1$ and $t_2$. Categories are then constructed to delineate a small increase (0.01 - 0.05), medium increase (0.06 - 0.25), large increase (> 0.25), no change (-0.004-0.004), small decrease (-0.01 - 0.05), medium decrease (-0.06 - -0.25), and large decrease (< -0.25) in number of flights. Routes that were added or removed are not included in these categorizations. A delineation of routes present in each category is given in Figure 9. It was hypothesized that an addition of flights along a route could lead to an increase in carrier delay, since more flights, especially along already-busy routes, could directly lead to higher levels of congestion.

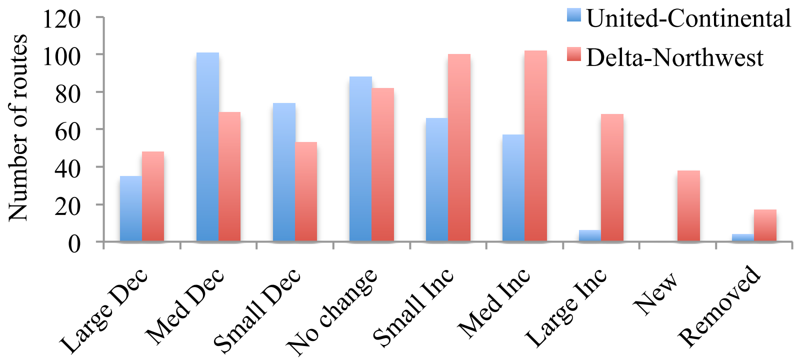


Figure 9. Distribution of routes for levels of change in number of flights (*ChgFlights)*.

### 2.3.2 Prevalence of characteristics among "problematic" routes

In Gephi, filters and ranking tools are utilized to examine the prevalence of the four calculated route characteristics (origin-destination delay, hub size, merging carrier status, change in flights) for progressing levels of carrier delay change. Routes with higher carrier delay change are in essence the "problematic" routes, as they increased in a measure of non-weather-related delay post-merger. Routes are filtered to four main thresholds of carrier delay change (all, greater than 0, greater than the 75th percentile, greater than one standard deviation above the mean), at which frequencies of the described route characteristics are observed. Results are discussed in section 2.4.1.

### 2.3.3 Regression Model

While route characteristic associations serve to identify and illuminate the prevalence of problematic routes' common characteristics, multivariate regression models are constructed to identify statistically significant relationships between individual variables and carrier delay change for each merger, net of the effect of all other variables. The variables discussed above are used in their continuous rather than categorical form in the models (with the exception of acquiring carrier status), and four additional variables are constructed and added to the models. Variable descriptions, summary statistics, and regression model results are described and analyzed in Section 2.4.2.

## 2.4. Results

### 2.4.1 Route characteristic associations

From examining frequencies of the described route characteristics for each merger, several commonalities are apparent for both events. A highly similar trend between the two mergers is that routes operated only by the acquiring carriers (Delta and United) tended to increase in their proportion of routes within subsets of increasing carrier delay change, as summarized in Figure 10. In other words, increasingly problematic routes were increasingly more likely to be operated by Delta or United, rather than having switched over from Northwest or Continental. This trend suggests that original Delta and United routes were negatively impacted post-merger more so than Northwest and Continental routes acquired by Delta and United, respectively.

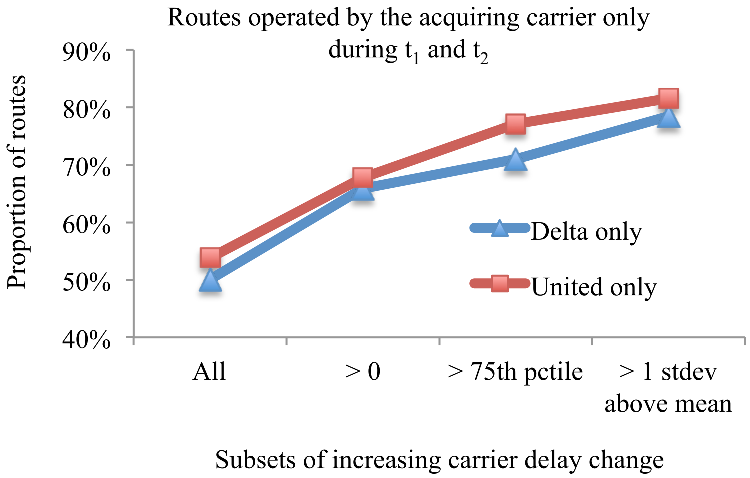


Figure 10. Proportion of routes operated by the acquiring carrier only (Delta or United), for subsets of increasing levels of carrier delay change.

Comparing hub characteristics, both carriers show similar trends of larger-origin (large or medium hub) to smaller-destination (small or non-hub) routes increasing in prevalence for subsets of increasingly problematic routes (Figure 11a), although United-Continental's increase is more dramatic than Delta-Northwest's. Such a trend points to the origin airport's role in producing (or perhaps being associated with) an increase in carrier delay, in that routes originating at busier hubs tend to be more problematic.

Along a similar vein as origin-destination hub characteristics, origin-destination delay characteristics also show increased prominence of high origin-airport delay with increasing levels of carrier delay change (Figure 11b). This fact highlights high-delay origins as a frequent characteristic of increasingly problematic routes. For both mergers, change in number of flights for routes with high-delay origins was greater than the network-wide average for change in flights, helping explain the overall increase in carrier delay despite decreasing levels of overall flights. In other words, more of the routes that actually *did* increase in flight frequency tended to be from origins with high overall delay.

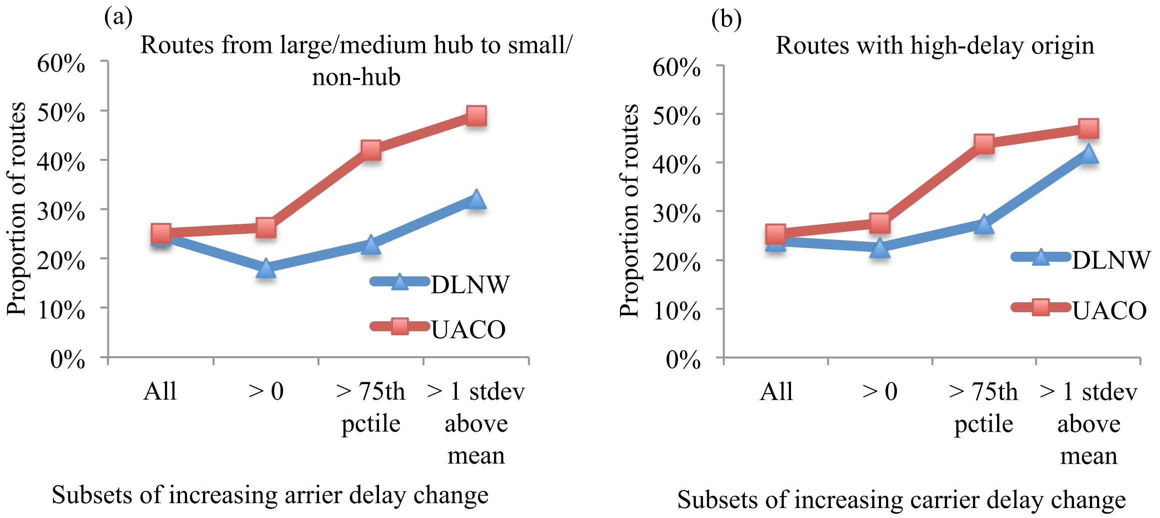


Figure 11. (a) Proportion of routes from a large/medium hub airport to a small/non-hub airport and (b) proportion of routes with high-delay origin (>75$^{th}$ percentile), for subsets of increasing levels of carrier delay change for both Delta-Northwest (blue) and United-Continental (red).

Although they exhibit similar patterns in both networks, routes' origin-destination hub and delay characteristics do not exhibit a strong correlation when compared directly to each other. In considering all airports, the correlation between number of flights (indicative of hub size) and overall departure delay is low, with adjusted $R^2$ values of 0.09 for United-Continental and 0.03 for Delta-Northwest, as shown in Figure 12 (a logarithm of number of flights is used to account for a skewed data distribution). Such results suggest that an airport being a larger hub does not mean that it will necessarily have a larger amount of delay. So while larger hubs and larger delays were associated with increased carrier delay change, these two variables are not strongly correlated with each other, and are thus thought to affect carrier delay change in different ways on an individual route level.

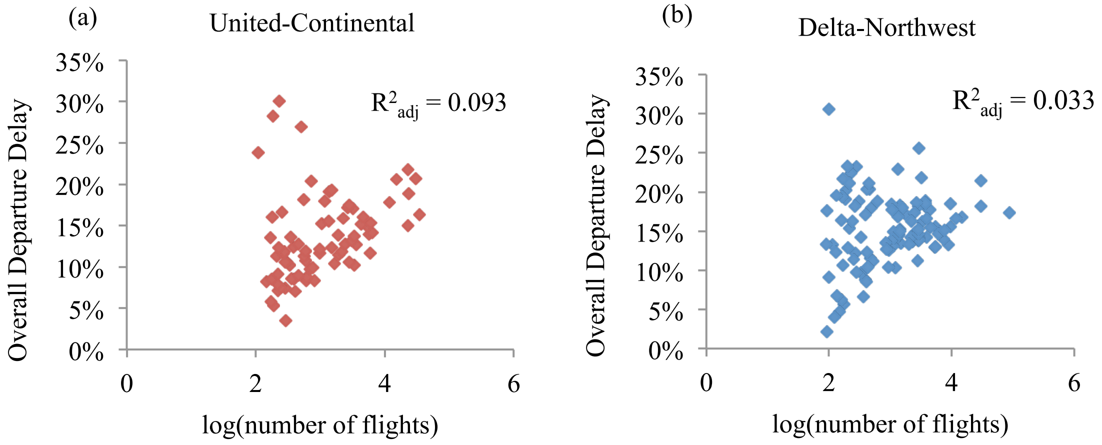


Figure 12. Correlation between log(number of flights) and Overall Departure Delay for (a) United-Continental and (b) Delta-Northwest, to understand the general relationship between hub size and delay. A strong relationship between hub size and delay is not apparent for either merger with both adjusted $R^2$ values less than 0.10.

Finally, while Delta and United exhibit similar patterns for route merging carrier status, hub characteristics, and delay characteristics in their relationships to carrier delay change, differing patterns are observed for change in number of flights. A probable reason for such variance is the differing levels of overall flight frequency change for both networks. While the combined Delta-Northwest network kept nearly the same number of flights from $t_1$ to $t_2$ (*ChgFlights* = 0.998; Equation 3), the United-Continental network experienced an overall decrease in flights of 6.3% from $t_1$ to $t_2$ (*ChgFlights* = 0.937; Equation 4). Many of Delta-Northwest's most problematic routes are those that increased in flight frequency, while many of United-Continental's are not. For United-Continental, other discussed factors such as having a high-delay origin, routes from a larger to a smaller hub, and being operated by only United seem to play a larger role in influencing carrier delay change than increasing number of flights. Relating merging carrier status to flight frequency change, 69.2% of Delta-only routes increased in number of flights post-merger, compared to 44.0% for Northwest routes. However, a similar relationship is not apparent for United-Continental, as 33.8% of United-only increased in flight frequency post-merger, compared to 38.8 % for Continental routes.

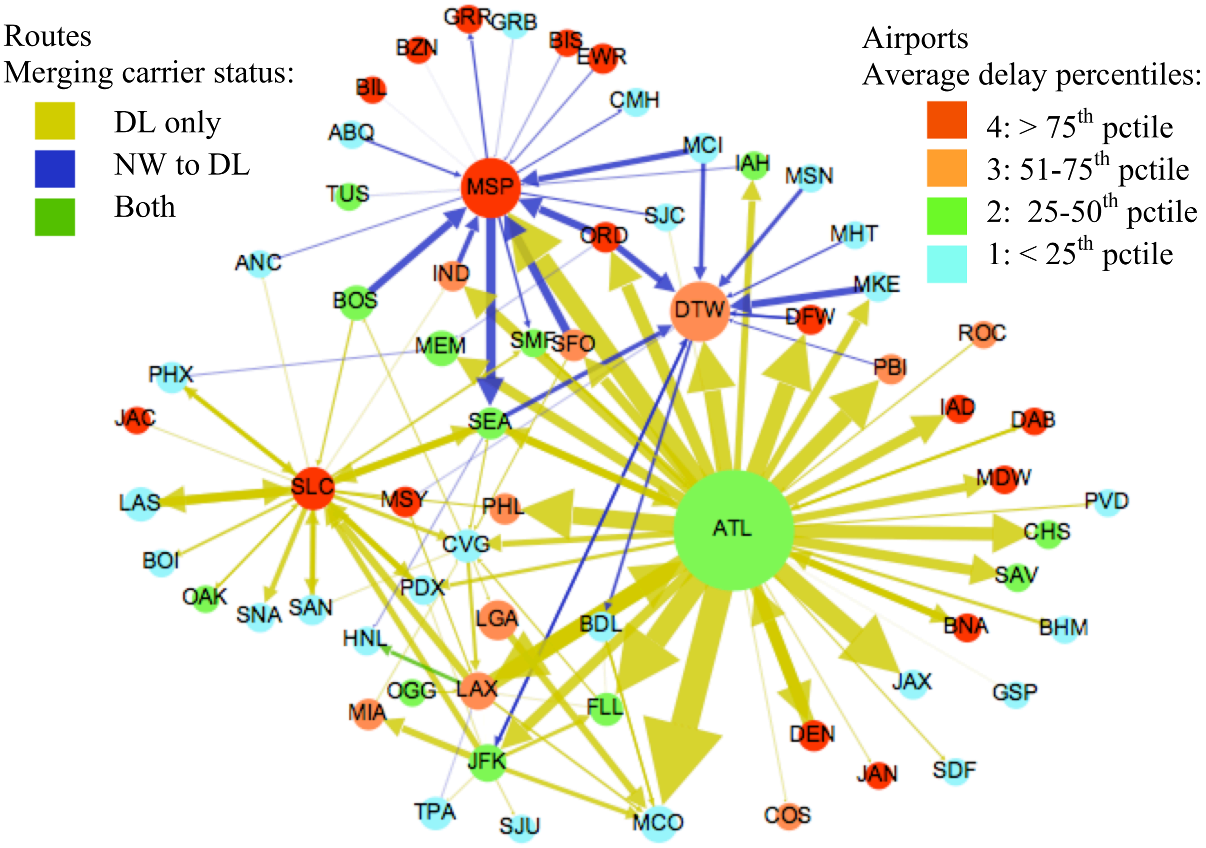
The original hypothesis that an increased flight frequency would directly lead to increased carrier delay was not confirmed, as correlations between change in flights (Equations 3,4) and change in carrier delay (Equations 1,2) for routes and airports for both mergers demonstrate low correlation, all with $R^2$ values less than 0.10. Rather, as the above analyses have demonstrated, changing carrier delay is a highly complex phenomenon, but with identified relationships within route subset characteristics including merging carrier status, origin-destination hub characteristics, and origin-destination delay characteristics.

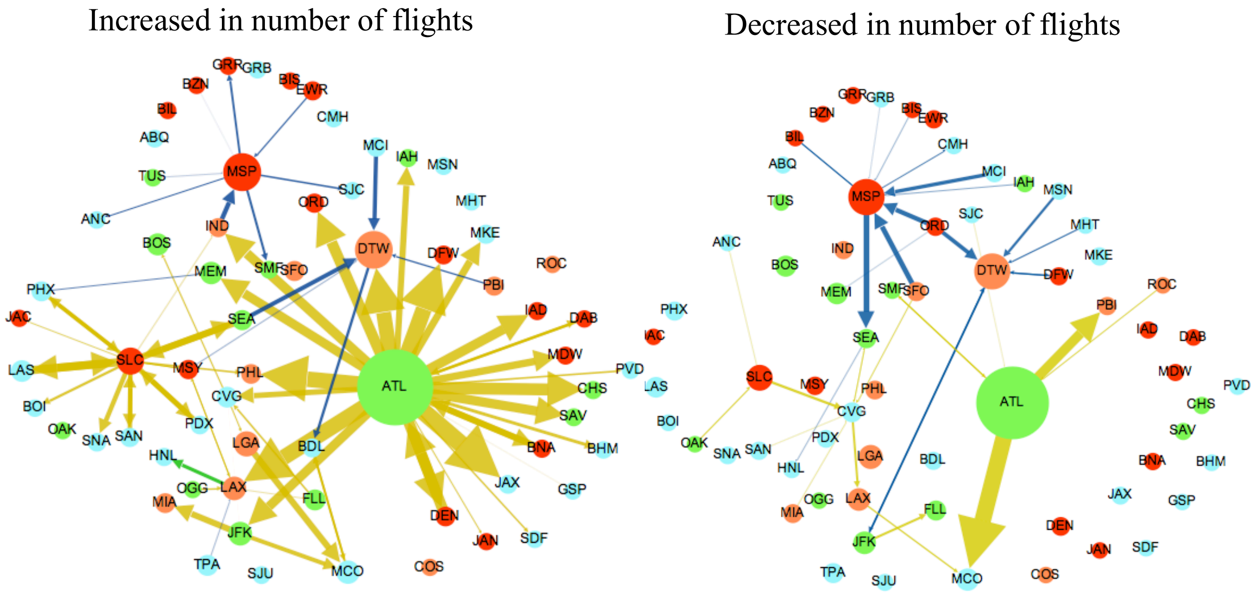
To visualize such variance in the route network characteristics, Figures 13 and 14 show each merger network filtered to only routes that experienced above the 75th percentile of carrier delay change, symbolized by origin and destination delay (node color), origin and destination hub size (node size), and merging carrier status (edge color). Thicker edges indicate larger total numbers of flights (for the merging air carriers) along each route. Additionally, two smaller images are included in each figure to show the networks further filtered to routes that experienced increases and decreases in flights following each merger. The trends for characteristics of problematic routes described above are identifiable, along with the inherent variability present in the situation.

The variability in the relationship between airport hub size and airport delay is apparent in Figures 13 and 14 as well, as not all larger airports exhibit higher delay, and not all smaller airports exhibit lower delay. Many of the problematic routes shown can be seen to originate from a larger hub airport and end at a smaller hub airport, with many routes also originating from a high-delay origin airport. It can also be observed how many of the routes are operated by Delta-only (Figure 13) and United-only (Figure 14). While such are common trends for each of the mergers, Figures 13 and 14 also demonstrate how these trends are not universal, as many exceptions are also present. Differences in change in flights for each merger are also observable, with more of the problematic routes increasing in number of flights (vs. decreasing) for Delta-Northwest (Figure 13), and less routes increasing in number of flights for United-Continental (Figure 14).

With general commonalities of route characteristics identified, the next step of analysis further quantifies such trends using multivariate regression models. Additional filtered network visualizations are presented in Figures 15 and 16 in the Appendix.

Delta-Northwest:
Routes with carrier delay change greater than the 75th percentile

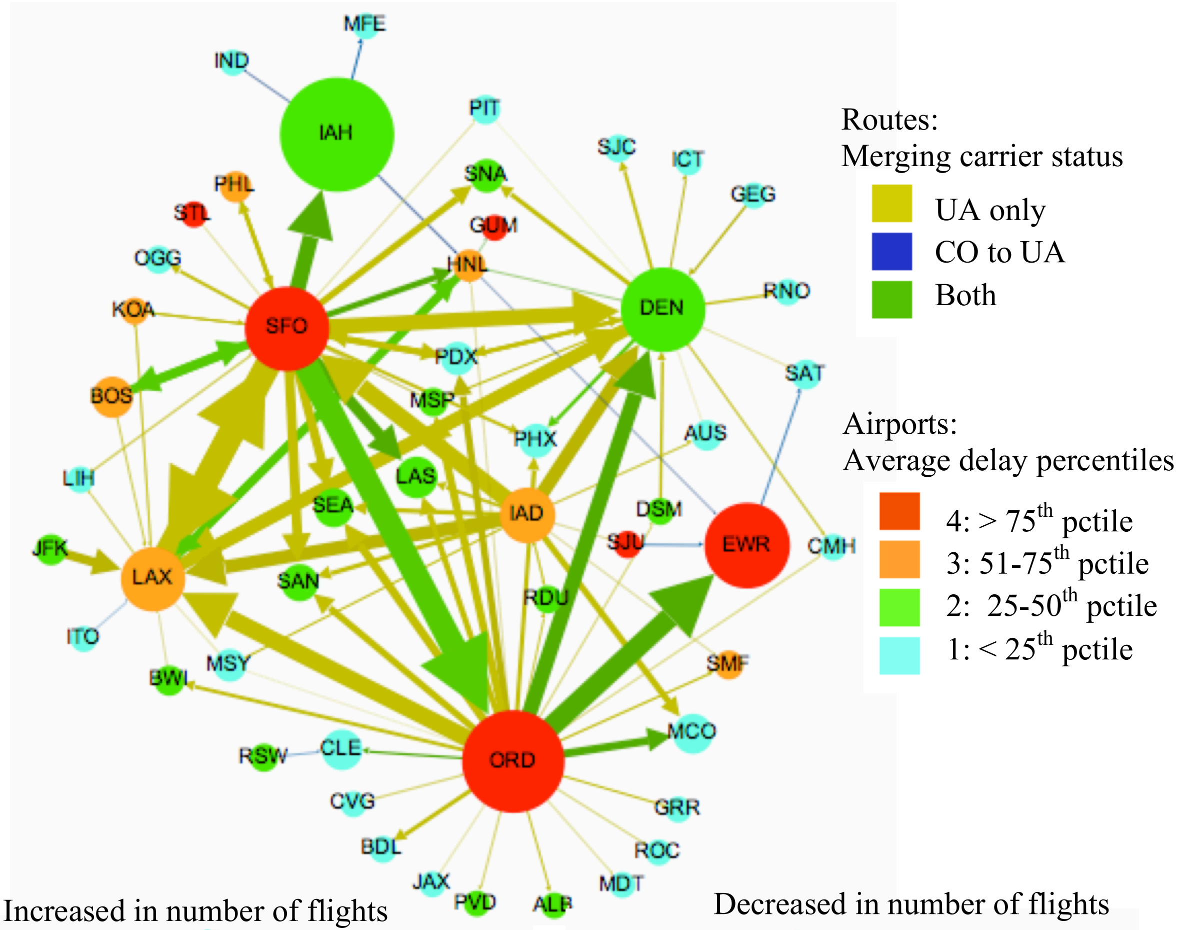


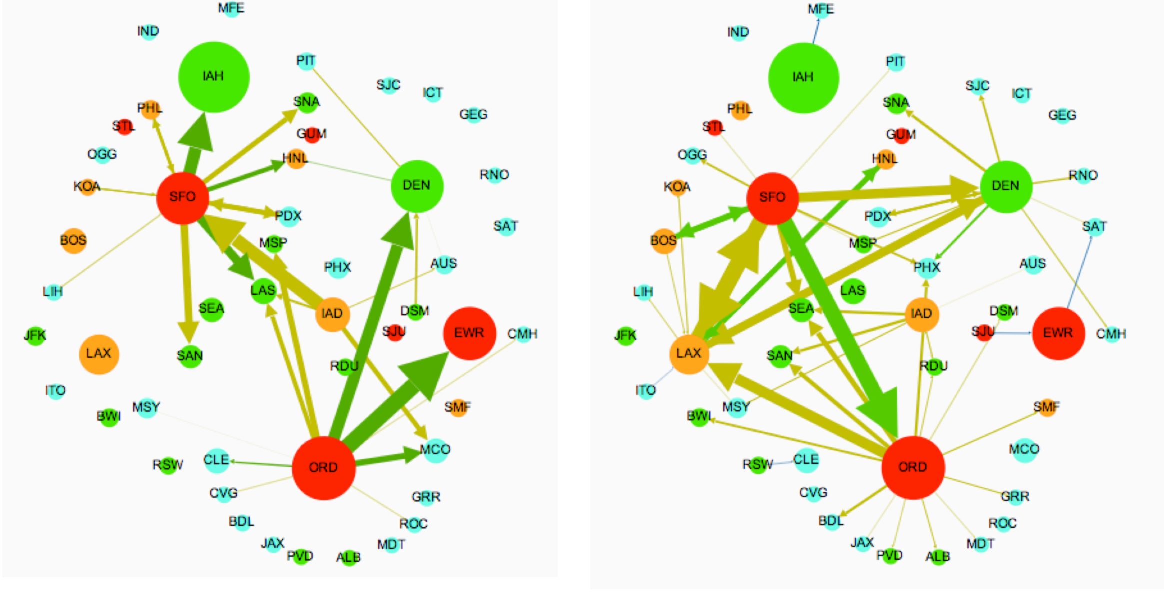

Increased in number of flights

Decreased in number of flights

Figure 13. Delta-Northwest route network filtered to only routes that experienced above the 75th percentile of carrier delay change amount, with additional filters for change in flights (bottom).

United-Continental:
Routes with carrier delay change greater than the 75th percentile




Increased in number of flights

Decreased in number of flights

Figure 14. United-Continental route network filtered to only routes above the 75th percentile of carrier delay change amount, with additional filters (bottom) for change in flights.

### 2.4.2 Regression models

*Variables*

Multivariate regression models are constructed for each merger to identify the extent of correlation between identified route characteristics and change in carrier delay. Variables for route characteristics discussed in Section 2.3.1 in addition to new constructed variables comprise the independent variables, while change in carrier delay (Equations 1 and 2) is the dependent variable. Variable names and definitions are provided in Table 3, with summary statistics for all variables provided in Table 4, and regression results in Table 5.

Table 3. Regression model variable names and definitions.

| Variable Name | Variable Description |
|---|---|
| ChgCarrDel | Change in percentage of flights with carrier delay from $t_1$ to $t_2$ |
| OrgDelay | Route origin airport overall percentage of delay |
| DestDelay | Route Destination airport overall percentage of delay |
| OrgFlights | Route origin airport number of flights |
| DestFlights | Route destination airport number of flights |
| DLonly , UAonly | Route operated only by Delta (DLonly) or only by United (UAonly) |
| ChgFlights | Change in number of flights from $t_1$ to $t_2$ |
| ChgFlights_minusAO | Change in number of flights greater than *all other* air carriers |
| RouteCarrDel | Percentage of flights that experienced carrier delay for a route |
| RouteDepDel | Percentage of flights that experienced departure delay for a route |
| RouteFlights | Number of flights along a route |

Note: Unless specified, variables refer to respective merging carrier values (DL-NW or UA-CO) during $t_1$.

Independent variables corresponding to the route characteristics discussed in Section 2.3.1 include origin and destination airport average delay (*OrgDel, DestDel)*, origin and destination airport weighted degree as an indicator of hub size (*OrgFlights, DestFlights),* acquiring carrier only (*DLonly, UAonly*), and change in flights from $t_1$ to $t_2$ (*ChgFlights)*. *DLonly and UAonly* are categorical variables, while *OrgDel, DestDel, OrgFlights, DestFlights,* and *ChgFlights* are continuous. Unless specified, all variables in the models refer to measures for Delta-Northwest and United-Continental airports and routes-- not other air carriers. Also, pre-merger values ($t_1$) are used for levels of delay and number of flights to allow a predictive relationship between the independent variables at $t_1$ and change in carrier delay from $t_1$ to $t_2$.

Four additional variables are calculated and included to capture the effects of other route-specific characteristics. In addition to origin and destination (airport) delay, routes' percentage of carrier delay, *RouteCarrDel*, is included to determine whether already-problematic routes are more or less prone to increase in carrier delay. *RouteDepDel* (departure delay) is similarly included to capture the effects not only of carrier delay, but also of overall departure delay for routes. While *RouteDepDel* produced unique and significant effects for United-Continental, it exhibited stronger correlation with *RouteCarrDel* for Delta-Northwest and no added model significance, and so was ultimately not included in the Delta-Northwest model.

It should be noted that with BTS flight-level delay data, amount of delay upon departure and arrival are reported for each flight (indicating where the delay was experienced: origin or destination), while carrier delay and other four broad delay types (see Figure 2) are reported for flights in general. In other words, a flight's carrier delay will have either originated at the origin or destination airport (or potentially both), but is recorded for the flight as a whole. If a flight has recorded arrival delay and carrier delay, but no departure delay, it can be inferred that the carrier delay took place at the destination airport, perhaps due to a delay waiting for an available gate. Rather than deciphering whether a flight's recorded carrier delay stemmed from the origin or destination airport, *RouteCarrDel* is sought for its indication of *specific route* performance (route = all flights along an airport pair), while *OrgDel and DestDel* account for delay amounts for airports at either end of a route.

Number of flights along a route, *RouteFlights,* indicates the specific “ busyness” of the route, rather than the busyness of the origin and destination airports, and is included in the models. A variable capturing the amount of change in flights experienced by the merging carriers greater than that experienced by all other carriers is also included, *ChgFlights_minusAO*, to capture the amount of change most likely to have occurred solely in relationship to the merger and less likely an effect of system-wide phenomena.

Table 4. Summary statistics for variables included in the two regression models to explain route-level change in carrier delay, *ChgCarrDel*, for both merger events.

| United-Continental | Mean | St. Dev | Min | Max | Delta-Northwest | Mean | St. Dev. | Min | Max |
|---|---|---|---|---|---|---|---|---|---|
| *ChgCarrDel* | *0.03* | *0.06* | *-0.34* | *0.26* | *ChgCarrDel* | *0.02* | *0.05* | *-0.14* | *0.25* |
| OrgDel | 0.08 | 0.02 | 0.01 | 0.20 | OrgDel | 0.10 | 0.02 | 0.02 | 0.20 |
| DestDel | 0.08 | 0.02 | 0.01 | 0.20 | DestDel | 0.10 | 0.02 | 0.02 | 0.20 |
| OrgFlights | 7,276 | 6,285 | 61 | 17,914 | OrgFlights | 10,617 | 13,576 | 22 | 40,191 |
| DestFlights | 7,292 | 6,262 | 61 | 17,914 | DestFlights | 10,644 | 13,573 | 22 | 40,191 |
| UAonly | 0.55 | 0.5 | 0 | 1 | DLonly | 0.56 | 0.5 | 0 | 1 |
| ChgFlights | -0.04 | 0.16 | -0.98 | 0.68 | ChgFlights | 0.03 | 0.26 | -1.00 | 0.98 |
| ChgFlights_ minusAO | -0.06 | 0.35 | -1.17 | 1.69 | ChgFlights_ minusAO | -0.04 | 0.51 | -1.93 | 2.00 |
| RouteCarrDel | 0.10 | 0.07 | 0.00 | 0.59 | RouteCarrDel | 0.08 | 0.05 | 0.00 | 0.33 |
| RouteDepDel | 0.12 | 0.06 | 0.00 | 0.53 | (RouteDepDel) | 0.16 | 0.07 | 0.00 | 0.60 |
| RouteFlights | 307 | 254 | 17 | 1,351 | RouteFlights | 325 | 272 | 1 | 1,483 |
| *n = 426* | | | | | *n = 520* | | | | |

Throughout the process of examining a series of variables to produce the most meaningful and robust models, variables for *system-wide* measures of hub size, airport delay, and route delay were included to capture any significant effects that measures of other air carriers could exert. However, results introduced moderately high levels of multicollinearity to the model when included with the merger-specific carrier variables (Variance Inflation Factors above 5), and did a poorer job of explaining *ChgCarrDel* when included alone, so were ultimately excluded from the final models. Additionally, a variable for route distance was included and tested to account for any effect of route length on carrier delay change. Route distance was significant with a slightly positive coefficient for United-Continental, meaning that longer routes tended to experience greater changes in carrier delay following the merger, with all other variables being held constant. This was not a significant variable for Delta-Northwest, likely related to the route network structure and location of hubs. The post-merger United network includes hubs on both coasts as well as many flights to Hawaii, compared to the more relatively central nature of Delta-Northwest's major hubs in Atlanta, Detroit, and Minneapolis-St. Paul, and thus larger number of shorter routes. While it is interesting to note that route distance and *ChgCarrDel* shared a positive relationship for United-Continental's network, the variable was ultimately excluded from the final models as it proved to be a confounding factor for the *OrgDel* and *DestDel* variables, whose relationships with *CarrDelChg* were of focus in this study.

Table 5. Regression results for both mergers.

| Delta-Northwest | | | | United-Continental | | | |
|---|---|---|---|---|---|---|---|
| Variable | Standardized Coefficient | p-value | | Variable | Standardized Coefficient | p-value | |
| CONSTANT | 0.000 | 0.001 | *** | CONSTANT | 0.000 | 0.534 | |
| **OrgDel** | **0.072** | **0.021** | ** | **OrgDel** | **0.136** | **0.038** | ** |
| DestDel | -0.020 | 0.769 | | DestDel | -0.010 | 0.098 | * |
| **OrgFlights** | **0.122** | **0.045** | ** | **OrgFlights** | **0.127** | **0.019** | ** |
| **DestFlights** | **-0.095** | **0.040** | ** | **DestFlights** | **-0.105** | **0.072** | * |
| **DLonly** | **0.060** | **0.089** | * | **UAonly** | **0.323** | **0.000** | *** |
| ChgFlights | 0.068 | 0.237 | | ChgFlights | 0.065 | 0.179 | |
| ChgFlights_minusAO | -0.043 | 0.495 | | ChgFlights_minusAO | -0.102 | 0.040 | ** |
| **RouteCarrDel** | **-0.619** | **0.000** | *** | **RouteCarrDel** | **-0.330** | **0.000** | *** |
| | | | | RouteDepDel | -0.310 | 0.000 | *** |
| RouteFlights | -0.025 | 0.541 | | RouteFlights | 0.133 | 0.038 | ** |
| $R^2$ | 0.3709 | | | $R^2$ | 0.3781 | | |
| $R^2$ Adjusted | 0.3598 | | | $R^2$ Adjusted | 0.3631 | | |

* Significant at the 10% level, **5%, and ***1% . Note: **Bold** variables indicate significance in both models.

### *Regression results*

Results of both regression models are shown in Table 5. For both mergers, the original route characteristics variables analyzed in Section 2.4.1 exhibited significant coefficients with the exception of *ChgFlights*. This was not an unexpected finding as change in flights experienced the least definitive relationship when broad route characteristics were analyzed. *OrgDel* exhibited significant positive coefficients for both mergers, confirming that higher overall delay at route origin airports is associated with greater changes in carrier delay. *DestDel* exhibited either non-significant or weak positive coefficients for both mergers, further confirming the notion that routes *originating* at airports with higher levels of delay tended to experience greater increases of carrier delay after the mergers more so than routes *to* heavily delayed airports.

Origin and destination airport hub status also produced significant relationships with carrier delay change, with positive coefficients for *OrgFlights* and negative coefficients for *DestFlights* for both mergers. Such findings confirm the earlier identified trend of routes from a busier airport to a less busy airport being associated with increases in carrier delay change following the mergers.

Merging carrier status also was an influential variable in both models, with significant positive coefficients for the categorical variables indicating a route being Delta-only or United-only in $t_1$ for each merger, respectively. These routes not operated by Northwest or Continental were more likely to experience an increase in carrier delay after the merger, indicating a negative effect of the merger on these routes. Both Northwest and Continental airlines exhibited higher amounts of overall carrier delay than Delta and United during $t_1$, perhaps influencing this trend, as already-highly-delayed routes were less likely to experience a further increase in carrier delay.

*ChgFlights* was not a significant variable for either merger's regression model, and change in flights greater than all other carriers (*ChgFlights_minusAO*) was a significant variable for United-Continental with a negative coefficient. The lack of statistical significance for *ChgFlights* and negative relationship for *ChgFlights_minusAO* does not support the original hypothesis that a positive change in flights would be positively correlated with a change in carrier delay, associated with increased congestion. As discussed in Section 4.2.1, a positive change in flights was in fact a more prominent characteristic for Delta-Northwest than United-Continental, but still with a relatively high level of variability. Such variability is reflected in the regression models, highlighting the complexity of the parameters involved with predicting change in carrier delay.

Given that merger-involved air carriers are typically in a situation of financial trouble, cost-cutting decisions are inevitably made. A possible scenario supporting a *decrease* in number of flights and *increase* in carrier delay could be if an air carrier were to reduce flight frequencies at an airport and also reduce ground crew operations to cut costs, meaning that fewer resources are available to ensure the timely operation of flights as they are readied for takeoff. Untimely ground operations (baggage handling, food loading, passenger boarding, etc.) contribute to air carrier delays, which could more easily occur if ground or crew resources are stretched too thinly in the wake of budget cuts. Thus, the high variability found with the change in flight variable may be attributed to the many possible scenarios leading to increases in carrier delay, including both an *increase* in flights leading to increased congestion, and a *decrease* in flights potentially leading to fewer available ground crew resources and the increased possibility for air carrier inefficiencies.

*RouteCarrDel* was an influential variable for both mergers, producing highly significant negative coefficients. As *RouteCarrDel* is the percentage of flights that experienced carrier delay along each route pre-merger, negative coefficients suggest that routes with already-high carrier delay did not tend to further increase in carrier delay following the mergers. The fact that routes with lower levels of carrier delay pre-merger tended to become more problematic post-merger suggests that overall negative changes were experienced in the system following the mergers. As discussed above regarding changes in flight frequencies, possible scenarios exist where either an increase or a decrease in number of flights could reasonably be associated with carrier delay increase. Such types of changes could feasibly happen in concordance with lower route-level carrier delay pre-merger. The negative coefficients for *RouteCarrDel* present an inverse relationship to that of the acquiring carrier only routes (*DLonly* or *UAonly*) experiencing *higher* carrier delay after the mergers; and are likely related to the fact that both merging carriers (Northwest and Continental) tended to have higher carrier delay in $t_1$ than the acquiring carriers (Delta and United), on average. To assess the potential for such a relationship between variables to add undue multicollinearity to the models, variance inflation factors (VIFs) were computed for all variables, but with none deemed particularly problematic given all values were below 3.5 and the majority below 2 for both models.

In all, significant relationships are present among the studied independent variables and change in carrier delay, largely confirming general route characteristics identified in Section 4.2.1. While a fair portion of variance in carrier delay change is explained with the models (rounded $R^2_{adj}$ of 0.36 for both models), a considerable amount of uncertainty still remains in predicting change in carrier delay. Such variability can be observed in Figures 13 and 14 and in Figures 15 and 16 in the Appendix, where numerous mechanisms surrounding problematic routes are visually apparent. It is unreasonable to expect that route characteristics can perfectly predict change in carrier delay, given the multitude of economic considerations involved with merger events that are often at the forefront of decision-making processes. Nevertheless, the identification of statistically significant trends in post-merger problematic routes is achieved, and is valuable information for the further understanding of the problem as a whole.

## 2.5 Discussion

With common characteristics of routes involved with two mergers being identified, subsequent analysis of other merger events may yield interesting results. At the time of writing, the merging of Southwest Airlines with AirTran and American Airlines with US Airways are both in progress or recently operationally completed, and will be promising subjects for ongoing and future analysis. Additional considerations for future work also include the incorporation of international data in addition to domestic data, and increasing the study periods of comparison from three-month to one-year intervals. Such considerations were not included in this study due to data limitations, but may broaden realm of route network variability in future work.

An interesting commonality between the Delta-Northwest and United-Continental merger events is that both acquiring carriers (Delta and United) merged with carriers (Northwest and Continental) that on average displayed higher levels of air carrier delay prior to the mergers. While such a relationship may "boost" the amount of carrier delay reported post-merger by the acquiring carrier (i.e. routes switching from NW to DL or CO to UA), the fact remains that carrier delay increased *as a whole* for both carrier networks, meaning that additional net factors influencing carrier delay change are at play. While average reported carrier delay was higher for

Northwest and Continental than Delta and United prior to the mergers, levels of departure delay between the two sets of carriers were nearly identical. Further work may investigate any discrepancies that exist among reporting practices of delay types by different air carriers to determine if reporting methods play any role in differences among delay type frequencies, or to confirm that any differences are purely due to air carrier performance.

## 2.6 Conclusion

In this study, a further understanding of increasing non-weather-related delay in the aviation system is achieved through the analysis of route-level air carrier delay surrounding two merger events: Delta-Northwest and United-Continental. Trends in problematic network components are identified through route characteristic associations and multivariate regression, and successfully shed light on factors contributing to the observed system-wide increase in non-weather delay as a whole. Given that neither the Delta-Northwest nor United-Continental combined route networks increased in overall number of flights following their respective mergers, findings confirm that it is not necessarily an addition of flights to the system that can cause non-weather delay increases, but rather a shifting of flights and flight frequencies. Through this study, these “shifting” components are studied by examining characteristics of routes with changes in carrier delay for both mergers, focusing on origin and destination delay, hub status, merging carrier status, and change in flights.

As was the goal of this study, characteristics of the most problematic routes in terms of carrier delay increase are identified and analyzed for both merger events, with most prominent characteristics for problematic routes being: origin airport with high delay, route from a larger hub to a smaller hub, and being operated by the acquiring carrier. Such associations are statistically confirmed through multivariate regression, with origin airport delay, destination airport delay, origin airport hub status, and acquiring carrier identified as positive significant explanatory variables for change in carrier delay, and with route carrier delay as a significant negative indicator for both mergers. In terms of merging carrier status, the most problematic routes were more often operated by the acquiring carrier (Delta or United), rather than the merging carrier (Northwest or Continental), indicating a more negative impact post-merger for Delta and United. While route-level change in flights was not a consistent predictor for carrier delay change, a complex relationship likely exists with this variable, as both an increase in flights could cause congestion, as well as a decrease in flights being associated with the reduction of resources for ensuring timely operation of flights, thereby also leading to non-weather delays. In all, the identified characteristics of problematic routes are largely similar for both merger events, and help to explain the specific nature of the trend of increasing non-weather delay in the aviation system during this time.

With volume-caused flight delays projected to increase in the future (FAA FACT 2007), a further understanding of delays within human control is imperative for making the most efficient policy decisions possible regarding future delay reduction. While much of the existing literature on mergers concerns economic impacts as they relate to delay, this study focuses upon observed changes in network component characteristics to understand the felt effects of changes as they are manifested in the aviation network, and with meaningful general trends being identified. Such trends help to characterize the most problematic routes present within the two studied merger events, and have set the stage for continued investigative work in understanding root causes of such problems at the air carrier decision-making level, and how they can be alleviated in the future.

# CHAPTER 3

# CONCLUSIONS

The problem of flight delays is analyzed through this research, with a specific focus on non-weather-caused delays surrounding two major air carrier merger events. With large increases in air carriers' reported non-weather delays having taken place directly following the Delta-Northwest and United-Continental mergers, route-level constituents of such trends were examined in detail. The research objective of further understanding increases in non-weather caused delays was achieved through tabular, network, and regression analyses, with common characteristics of problematic routes including: origin airport with high delay, route from a larger hub to a smaller hub, and being operated by the acquiring carrier (Delta or United). In all, such findings support that while air carriers may make route-restructuring decisions during a merger that produce the most direct economic benefit, these decisions can ultimately lead to an increase in delay that negatively impacts their route network as well as the aviation system as a whole.

Given that neither the Delta-Northwest nor United-Continental combined route networks increased in overall number of flights following their respective mergers, findings confirm the notion that it is not necessarily an addition of flights to the system that causes non-weather delays to increase, but rather a shifting of flights and flight frequencies. Through this study, these "shifting" components were studied by examining characteristics of routes with changes in carrier delay within both networks, focusing on change in number of flights, hub status, delay level, and merging carrier status. The complex nature of factors at play in the system was particularly highlighted through the *change in number of flights* route characteristic, which examined the difference in a route's number of flights from pre to post-merger. While an increase in number of flights post-merger was hypothesized to correlate positively with an increase in non-weather delay due to introduced congestion, such a relationship was not confirmed through regression analysis. However, one possible scenario supporting a *decrease* in number of flights and an *increase* in non-weather delay could be if an air carrier were to reduce flight frequencies at an airport post-merger and also heavily reduce ground crew operations to cut costs, meaning that fewer resources are available to ensure the timely operation of flights as they are prepared for takeoff. Untimely ground and gate operations (baggage handling, food loading, passenger boarding, etc.) contribute to air carrier delays, which could more easily occur if ground or crew resources are stretched too thinly in the wake of budget cuts. Given that merger-involved air carriers are typically in a situation of financial trouble, cost-cutting decisions are inevitably made, and which may have ramifications across many levels and facets of the aviation system. A stretching of system capacities in ways that are more prone to produce inefficiencies and delay, but that may directly increase profits, is a phenomenon suggested by this research, and one that would be well-suited for further research and analysis

While an overall solution to the problem of flight delays is not within the realm of this research, the furthered understanding of delay cause mechanisms was achieved and is valuable information for planning of solutions to be set forth. Solutions for flight delays are a large topic of concern and debate in the economics literature and in policy, with varying viewpoints on the extent of regulation that should be implemented (Swaroop et al. 2012; Rupp 2009; Morrison and Winston 2008; Todd and Sinai 2003). As discussed in the literature review, much of the research surrounding flight delays is from an economic standpoint rather than from its relationship to route network structure. While economics are undeniably the driving force behind many airline industry decisions, and delays and economics are inextricably linked through congestion costs, an evaluation of the problem to *focus* on observed network characteristics of delayed routes is not apparent in the literature. This research has sought to add such a perspective, with its focus on characteristics of highly delayed routes following network structural changes.

Additionally, through this research special attention is also paid not only to delays as a whole, but to those specifically caused by non-weather-related factors. Delays are most commonly analyzed as a measure of actual vs. scheduled arrival time or scheduled vs. minimum travel time in the literature (Baumgarten et al. 2014; Rupp 2009; Mayer and Sinai 2003), rather than by their specific causes. As such, the focus on air carrier delay as an approximation for non-weather delay in this research delves into a lesser-discussed aspect in the literature, shedding light on those delays that humans are theoretically most capable of influencing.

As evidenced by the large amount of literature in the economic realm on airline mergers, many economic factors are at play in decisions made by both air carriers and passengers surrounding mergers. Modified route network structures following mergers can have influences on passenger demand for flights, airline operating costs, ticket prices, and competition from other carriers, all of which may impact observed flight frequencies and delay within a given network. Further work may include the examination of economic variables to understand the effects of such factors and the direct influence they may have on route characteristics and carrier delay change. While this research has thoroughly examined the observed effects of air carriers' network characteristic changes during merger events, a further analysis of air carriers' specific decisions leading to such observed effects may shed additional light on causal factors for such changes. Additionally, as this study focuses only on domestic flight data, the inclusion of international flights may also provide significant points for future analysis, along with the comparison of larger time periods.

With volume-caused flight delays projected to increase in the future (FAA FACT 2007), a further understanding of delays within human control and how they are manifested in the aviation network is imperative for making the most efficient policy decisions possible regarding future delay reduction. Despite ongoing debate surrounding the best solutions for flight delays, the findings of this study, including the characterization of problematic routes, may be of interest to air carriers and policymakers when considering route network changes in the wake of merger events. There are undeniably many factors involved in decisions regarding route network changes during a merger, most of which stem from financial considerations; however, knowing which routes and airports are likely to be affected by congestion-related delay is a topic sparsely covered in the literature and that should be more closely considered.

The rather dismal outlook for the fate of delays in the future (Fleming 2010), and particularly those caused by congestion, suggests that all possible measures should be taken by air carriers to ensure that the best route structuring decisions are made. Knowing which types of routes tend to be associated with increases in non-weather delay provides information that can be considered with future merger events, as well as in regarding the status of problematic routes in general. If air carriers were to more fully project and report anticipated merger-related changes and their impacts, as is done with this research *after the fact*, then perhaps problematic increases in non-weather delay could be more preemptively addressed or avoided. In addition to their relationship with merger events, non-weather delays are an important phenomenon to understand as they relate to route network characteristics in general, as is also achieved by the findings of this research.  Only when the problem is fully understood from all perspectives will the most effective solution be reached.

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# APPENDIX

Figure 15 shows only routes with greater than the 75th percentile for carrier delay increase, and which experienced a medium or large increase in number of flights following the merger. Node size represents an airport's total number of combined Delta-Northwest flights (weighted degree), and edge thickness (weight) represents number of flights along a route. Green airports increased in number of flights from $t_1$ to $t_2$ while purple airports experienced a decrease. Darker red route colors represent higher changes in carrier delay. A general trend from Figure 15 is ATL (Atlanta) and especially SLC (Salt Lake City)'s connecting airports' prevalent increase in flights (green nodes), as well as routes with some of the highest changes in carrier delay (red edges). However, there are large exceptions to this rule as well, including ATL to ORD (Chicago) and IAH (Houston). Such exceptions are demonstrative of the relative difficulty of predicting causation of carrier delay from change in flights, both at the airport and route levels, and also speaks to the importance of considering airport characteristics when predicting route-level effects.

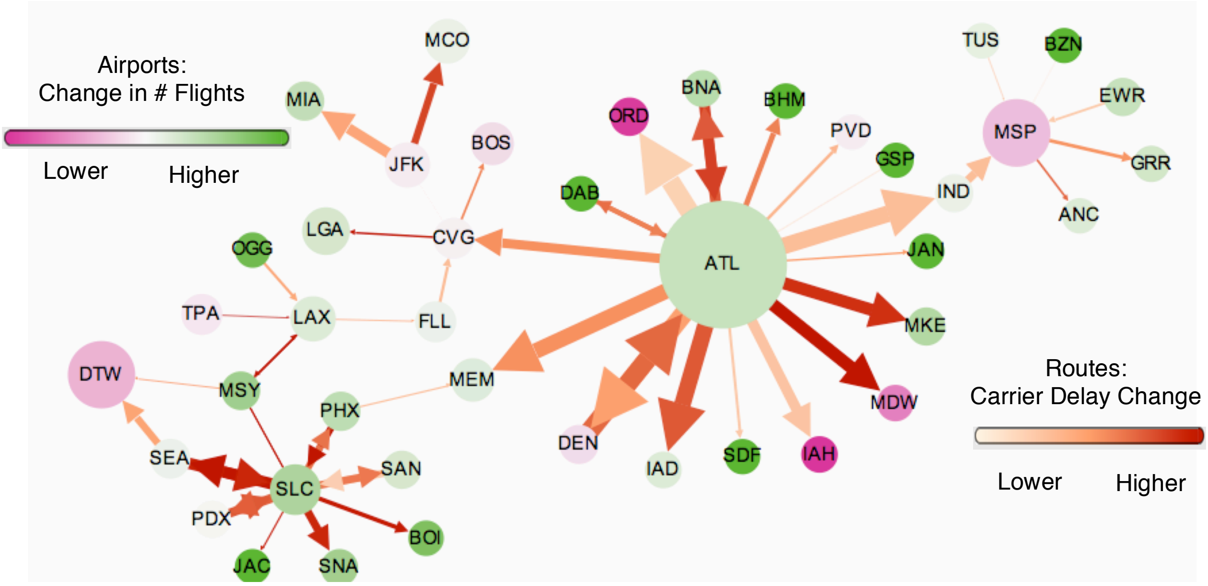

Figure 15. Delta-Northwest network filtered to routes with > 75th percentile carrier delay change, and with a medium or large increase in flights. Larger nodes and thicker edges represent a greater number of flights, respectively.

Figure 16 shows the United-Continental network filtered down to the most problematic routes (carrier delay increase of greater than one standard deviation above the mean), with both airports and routes symbolized by the delay categories described in Figure 4. Higher-delay to lower-delay routes are those from red/orange to green/blue airports (4_1, 4_2, 3_1, 3_2 route categories), which account for nearly half of all problematic routes (49.0 %), compared to only 25.0% of all routes. Delay characteristics of route origins and destinations are found to exhibit a similar trend to hub size (although the two variables are not significantly correlated): as routes are filtered down to those with the highest levels of carrier delay increase, the proportion of routes from high-delay airports to low-delay airports also increases. Routes from a high-delay airport to a low-delay airport (4_1) comprise 9.0 % of all routes, compared to 22% of all highly problematic routes.

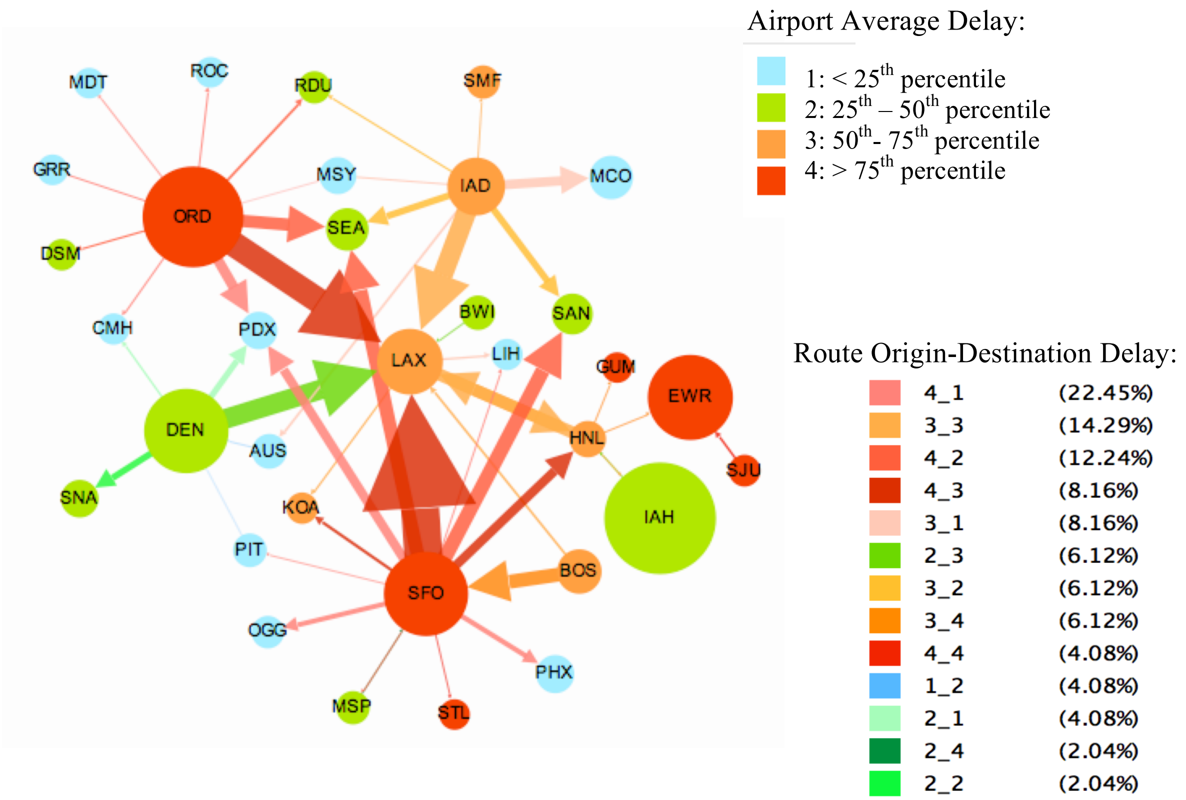

Figure 16. United-Continental network filtered to routes with carrier delay change of greater than one standard deviation above the mean, and symbolized by origin-destination delay characteristics. Note: not all route origin-destination delay categories are represented with the present filter.

Table 6. Listing of airport names and by International Air Transport Association (IATA) codes for 111 airports used in the study (table continued to next page).

| Code | Airport Name | Code | Airport Name |
|---|---|---|---|
| **ABQ** | Albuquerque International Sunport | **LGA** | La Guardia Airport |
| **ALB** | Albany International | **LIH** | Lihue Airport |
| **ANC** | Ted Stevens Anchorage International | **LIT** | Adams Field |
| **ATL** | Hartsfield Jackson Atlanta International | **MCI** | Kansas City International |
| **AUS** | Austin Bergstrom International | **MCO** | Orlando International |
| **BDL** | Bradley International | **MDT** | Harrisburg International |
| **BHM** | Birmingham-Shuttlesworth International | **MDW** | Chicago Midway International |
| **BIL** | Billings Logan International | **MEM** | Memphis International |
| **BIS** | Bismarck Municipal | **MFE** | McAllen Miller International |
| **BNA** | Nashville International | **MHT** | Manchester Regional Airport |
| **BOI** | Boise Air Terminal/Gowen Field | **MIA** | Miami International |
| **BOS** | General Edward Lawrence Logan International | **MKE** | General Mitchell International |
| **BQN** | Brunswick Golden Isles Airport | **MLB** | Melbourne International |
| **BUF** | Buffalo Niagara International | **MSN** | Dane County Regional Truax Field |
| **BWI** | Baltimore/Washington International Thurgood Marshal | **MSP** | Minneapolis-St Paul International/Wold-Chamberlain |
| **BZN** | Gallatin Field | **MSY** | Louis Armstrong New Orleans International |
| **CAE** | Columbia Metropolitan | **OAK** | Metropolitan Oakland International |
| **CHS** | Charleston Air Force Base-International | **OGG** | Kahului Airport |
| **CLE** | Cleveland Hopkins International | **OKC** | Will Rogers World Airport |
| **CLT** | Charlotte Douglas International | **OMA** | Eppley Airfield |
| **CMH** | Port Columbus International | **ONT** | Ontario International |
| **COS** | City of Colorado Springs Municipal | **ORD** | Chicago O'Hare International |
| **CVG** | Cincinnati Northern Kentucky International | **ORF** | Norfolk International |
| **DAB** | Daytona Beach International | **PBI** | Palm Beach International |
| **DAY** | James M Cox Dayton International | **PDX** | Portland International |
| **DCA** | Ronald Reagan Washington National | **PHF** | Newport News Williamsburg International |
| **DEN** | Denver International | **PHL** | Philadelphia International |
| **DFW** | Dallas Fort Worth International | **PHX** | Phoenix Sky Harbor International |
| **DSM** | Des Moines International | **PIT** | Pittsburgh International |
| **DTW** | Detroit Metropolitan Wayne County Airport | **PNS** | Pensacola Regional |
| **ELP** | El Paso International | **PVD** | Theodore Francis Green State Airport |
| **EWR** | Newark Liberty International | **PWM** | Portland International Jetport |
| **EYW** | Key West International | **RDU** | Raleigh Durham International |
| **FAR** | Hector International | **RIC** | Richmond International |
| **FLL** | Fort Lauderdale Hollywood International | **RNO** | Reno Tahoe International |
| **FSD** | Joe Foss Field | **ROC** | Greater Rochester International |
| **GEG** | Spokane International | **RSW** | Southwest Florida International |
| **GPT** | Gulfport Biloxi International | **SAN** | San Diego International |
| **GRB** | Austin Straubel International | **SAT** | San Antonio International |
| **GRR** | Gerald R. Ford International | **SAV** | Savannah Hilton Head International |
| **GSP** | Greenville Spartanburg International | **SDF** | Louisville International Standiford Field |
| **GUM** | Golden Triangle Regional | **SEA** | Seattle Tacoma International |

| | | | |
|---|---|---|---|
| **HNL** | Honolulu International | **SFO** | San Francisco International |
| **HSV** | Huntsville International Carl T Jones Field | **SJC** | Norman Y. Mineta San Jose International |
| **IAD** | Washington Dulles International | **SJU** | San Angelo Regional Mathis Field |
| **IAH** | George Bush Intercontinental Houston | **SLC** | Salt Lake City International |
| **ICT** | Wichita Mid Continent | **SMF** | Sacramento International |
| **IND** | Indianapolis International | **SNA** | John Wayne-Orange County Airport |
| **ITO** | Hilo International | **SRQ** | Sarasota Bradenton International |
| **JAC** | Jackson Hole Airport | **STL** | Lambert St Louis International |
| **JAN** | Jackson Evers International | **STT** | St Paul Downtown Holman Field |
| **JAX** | Jacksonville International | **TLH** | Tallahassee Regional |
| **JFK** | John F Kennedy International | **TPA** | Tampa International |
| **KOA** | Kona International At Keahole | **TUL** | Tulsa International |
| **LAS** | McCarran International | **TUS** | Tucson International |
| **LAX** | Los Angeles International | | |