The Impact of Amtrak Performance in the Northeast Corridor
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ABSTRACT

The performance of Amtrak's Acela and Regional services in the Northeast Corridor (NEC) is a topic that, while frequently discussed as substandard by some travelers, has received minimal attention in the compendium of open source research literature. Amidst leading discussions in U.S. Congress to reduce Amtrak's funding, the finances and policies required for track renovation, infrastructure maintenance and quality train operations are also compromised. This provides a backdrop and motivation for the work done in this thesis.

Amtrak is a vital transportation provider on the Northeast Corridor serving travelers between Boston, MA and Washington, DC, including major cities such as Providence, RI; New Haven, CT; New York, NY; Philadelphia, PA; and Baltimore, MD. In Fiscal Year 2014, Amtrak had a record high of 11.6 million passengers on the Acela and Regional services combined. However, in FY 2014 only 3.9 million passengers arrived at their destination at the scheduled arrival time, that is, 7.4 million passengers experienced delays for a myriad of reasons. Furthermore, in 1981, Amtrak advertised Acela's predecessor (Express Metroliner) as trains that made the trip between Washington, D.C. and New York in 2 hours, 59 "civilized" minutes with a 92% on-time performance. Thirty-three years later, travel times in the NEC have barely improved; the Washington, DC – New York trip currently takes 2 hours 44 minutes on Acela and 3 hours 24 minutes on the Regional. Additionally, in FY 2014 overall on-time performance on the Acela and Regional services were 74% and 77%, respectively, despite a 10-minute delay threshold.

This thesis focuses on Amtrak's Acela and Regional passengers, as well as the travel time performance of these services in the last ten years (2005 to 2014). The thesis evaluates different factors that lead to variability in ridership and service performance, as well as the impact of service performance on ridership. Another objective of the thesis is to hypothesize about how service performance affects future demand on the Acela and Regional services. This research lays the foundation for future work on the impact of Amtrak's performance, and measures needed to strengthen and improve intercity passenger rail in the Northeast Corridor.

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In addition, I would like to acknowledge the people and families who were affected by the tragic Amtrak train derailment, which occurred near Philadelphia on May 14, 2015. The incident further emphasizes the need to work towards a more reliable and safer passenger rail system in the Northeast Corridor and the U.S. at large.

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1 INTRODUCTION

This thesis aims to assess the performance of the Amtrak passenger services in the Northeast Corridor. It focuses only on performance measures related to travel time reliability of the scheduled services. Furthermore, the thesis aims to evaluate the effect (if any) of performance on the demand for Amtrak services based on the fact that travelers place a high value on being able to get to their destinations "on time".

The introduction begins by presenting an overview of the study area – the Northeast Corridor in S**ection 1.1**. **Section 1.2** introduces the specific topic and provides a background for the research. The motivations for the thesis topic are discussed in **Section 1.3**. And the specific research objectives are outlined in **Section 1.4.** Lastly, **Section 1.5** presents the organization of each chapter in the thesis.

1.1 Area of Analysis

The Northeast Corridor (NEC) is a 457-mile stretch of fully electrified railway line between Boston and Washington D.C (mainline). The NEC network includes the additional feeder corridors to Springfield, MA and Harrisburg, PA. It crosses eight states – Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, as well as the District of Columbia and many other cities. Amtrak owns 79% (363 miles) of the track between Boston and Washington D.C., while New York Metropolitan Transportation Authority (NYMTA) and Connecticut Department of Transportation (ConnDOT) own the New Haven Line, a 56-mile section between New Rochelle, NY. and New Haven, CT., and the Massachusetts Bay Transportation Authority (MBTA) owns the 38-mile section between the Massachusetts-Rhode Island border and Boston-South Station, known locally as the Attleboro Line.

Figure 1.1 NEC Infrastructure Ownership (Source: NEC Commission)[i]

The section owned by NYMTA and ConnDOT is operated and controlled by Metro-North Railroad (MNR); however, Amtrak operates (dispatches and maintains the right-of-way) in the section owned by the MBTA under an agreement with the MBTA. The Northeast Corridor is a shared-use rail corridor; it operates a variety of services, including freight, commuter, and intercity "higher" speed services on the same track. Amtrak operates 153 trains a day on portions of the Northeast Corridor; in addition, there are more than 2,000 daily commuter trains, and 70 daily freight trains that utilize the corridor. The shared use character leads to a number of physical and operational challenges. The two main Amtrak services along the mainline (BOS – WAS) of the Northeast Corridor are the Acela Express (Acela) and Northeast Regional (Regional/NER). However, there are other Amtrak routes that operate on shorter segments of the NEC, and some others that do not run on the Northeast Corridor but terminate at a station in the NEC. The four groups of Amtrak services that are active in the NEC are introduced below:

i. **Acela Express (Acela)** is Amtrak's fastest rail service. It operates along the Northeast Corridor mainline between Boston and Washington. It began operations in December 2000 and serves major cities along the corridor, including Providence, New Haven, New York City, Philadelphia and Baltimore. The Acela Express service is currently the only existing "high-speed" operation in the United States and can attain a speed of 150mph (240km/h) but only for a relatively short distance due to infrastructure constraint. The term "high-speed" is used because there are different definitions for the speed criteria both within the U.S. and internationally. In brief, the most general consensus requires a sustained speed of more than 125mph (201km/h). Although Acela can theoretically attain a speed of 150mph, in reality the maximum operational speed is about 110mph and the average speed is in the 60mph to 70mph range. The Acela service is scheduled to cover the 457 miles between Boston and Washington in 413 minutes (~7 hours, average speed ~65 mph), the 226 miles between New York and Washington, D.C. in 171 minutes (~3 hours, average speed ~75 mph), and the 231 miles between New York and Boston in 223 minutes (~ 3.7 hours, average speed ~60 mph). Amtrak currently schedules 32 daily Acela trains on weekdays; 16 northbound and 16 southbound trains. The Acela currently stops at 13 main stations in the NEC, namely (Amtrak station codes provided in parenthesis): Boston MA (BOS), Back Bay MA (BBY), Route 128 MA (RTE), Providence RI (PVD), New Haven CT (NHV), Stamford CT (STM), New York NY (NYP), Newark NJ (NWK), Philadelphia PA (PHL), Wilmington DE (WIL), Baltimore MD (BAL), BWI Airport (BWI) and Washington DC (WAS). In addition, a few Acela trains also stop at New London CT (NLC) and Metropark NJ (MET).

ii. **Northeast Regional (Regional/NER)** is Amtrak's moderate speed rail service with more frequent local stops along the Northeast Corridor. It serves the same major markets between Boston and Washington D.C. as the Acela Express, and in addition serves local markets in Massachusetts, Rhode Island, Connecticut, New Jersey and Maryland. Some NER trains also extend beyond the Northeast Corridor to Richmond, Newport News and Lynchburg in Virginia. There are actually different Amtrak services that are considered as Northeast Regional – the regular NER (described above), includes some Keystone trains that serve local markets west of Philadelphia but also operate between Philadelphia and New York, some Vermonter trains that serve local markets in Vermont but also operate between Springfield, MA and Washington, the Carolinian that serves local markets in North Carolina but also operate between New York and Washington, and the Pennsylvanian that serves local markets in Pennsylvania but also operate between New York and Philadelphia. Altogether, Amtrak currently schedules 64 daily Regional trains on weekdays, 32 northbound and 32 southbound. The regular Regional services are scheduled to cover the 457 miles between Boston and Washington in 470 minutes (~8 hours, average speed ~59 mph), the 226 miles between New York and Washington, D.C. in 202 minutes (~3.4 hours, average speed ~66 mph), and the 231 miles between New York and Boston in 250 minutes (~ 4.2hours, average speed ~55 mph). Finally, the Regional service currently stops at 38 stations in the NEC.

iii. **Other Amtrak routes that use shorter portions of the Northeast Corridor** are the Cardinal, which runs from New York to Chicago, the Crescent service, which operates between New York and New Orleans, and the Palmetto, Silver Meteor and Silver Star, which operate between New York and Florida. The above-mentioned Amtrak routes operate one train each day in both directions, and they all use the NEC portion between New York and Washington. While these trains stop to receive and discharge passengers at some of the stations in the Northeast Corridor, Amtrak passengers wishing to travel solely within the Northeast Corridor are not able to purchase tickets on the trains.

iv. **Other Amtrak routes that do not use the Northeast Corridor but terminate at a station in the NEC** are the Downeaster, which originates in Portland, ME and terminates in Boston, MA. The Adirondack (Montreal, QC to New York, NY), the Empire Services (Albany-Rensselaer, NY and Buffalo-Exchange St., NY to New York, NY), the Ethan Allen Express (Rutland, VT to New York, NY), the Maple Leaf (Toronto, ON to New York, NY), and the Lake Shore Limited (Chicago, IL to Albany, NY and then separate trains go to Boston, MA and New

York, NY), which all terminate in New York, NY, and Capitol Limited (Chicago, IL to Washington, DC), which terminates in Washington, DC.

There are eight **Commuter Railroads** that operate on some sections of the Northeast Corridor. Collectively, they operate about 2,000 trains daily.

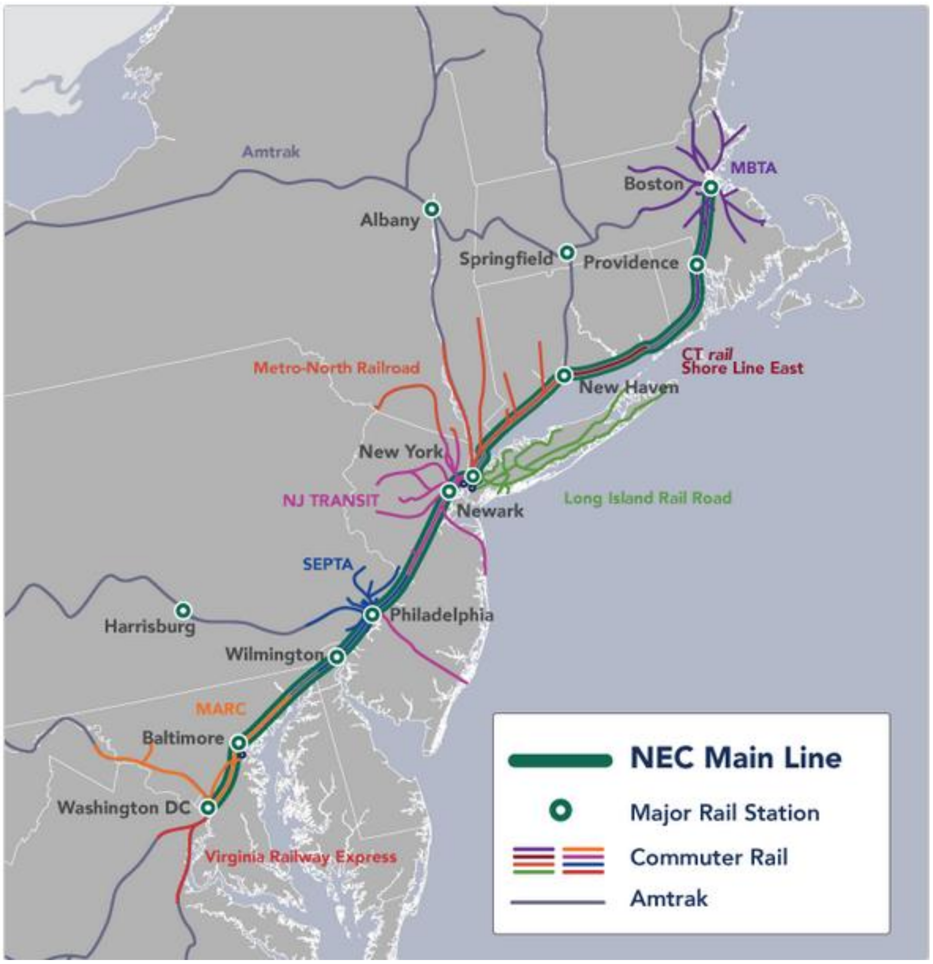

Figure 1.2 Commuter Railroads along the NEC (Source: NEC Commission)

The following commuter services operate in the NEC – including the cities served.

i. Massachusetts Bay Transportation Authority (MBTA) - Boston, MA
ii. Shore Line East (SLE) - New York City, NY; New Haven, CT; New London, CT
iii. Metro-North Railroad (MNR) - New York City, NY; New Haven, CT
iv. Long Island Rail Road (LIRR) - New York City, NY; Long Island, NY
v. New Jersey Transit (NJT) - New York City, NY; Newark, NJ; Trenton, NJ
vi. Southeastern Pennsylvania Transportation Authority (SEPTA) - Philadelphia, PA
vii. Maryland Area Regional Commuter (MARC) - Baltimore, MD; Washington, DC
viii. Virginia Railway Express (VRE) - Washington, DC

Although it is not a major freight corridor, there are four **freight railroads** that operate on parts of the Northeast Corridor Main Line. There are about 70 daily freight trains on the corridor, with the heaviest tonnage flows in Maryland and Delaware[ii]

i. **Norfolk Southern Railway** – operates south of Philadelphia
ii. **CSX Transportation** – operates between New York and New Haven, and in sections in Maryland
iii. **Conrail** – operates between Philadelphia and New York
iv. **Providence and Worcester Railroad** – operates between New Haven and Rhode Island.

1.2 Amtrak Performance Background

The primary goal of this research is to study the impact of Amtrak's performance in the Northeast Corridor. The two keys words in the subject statement are "impact" and "performance". Firstly, "impact" refers to any consequence or effect experienced by the stakeholders of Amtrak's service. The primary stakeholders include the service providers, Amtrak, the commuter operators, and the freight operators, and the service consumers, Amtrak passengers. This thesis focuses on Amtrak Acela and Regional train operations on the supply side and Amtrak passengers on the demand side. Secondly, "performance" refers to degree to which Amtrak achieves the task of service provision measured against some predetermined standards. In principle, the arrival and departure times of each train at each station should be in accord with the published timetables. In other words, performance is a measure of the repeatability and predictability of Amtrak's service compared to a given schedule and/or expectation.

The performance of Amtrak's system largely influences users' perception of the quality of the services, as well as the Amtrak brand. Travel surveys, including Amtrak in-house surveys show that the expected arrival time is a main driver of people's travel choices. Users across all transportation modes place a high value on being able to get to their destination "on time". Similar to travelers on other modes, Amtrak passengers incur some negative effect or disutility from delays and unreliable travel time experienced during their Amtrak trip. Amtrak's Northeast Corridor (NEC) served approximately 32,000 daily Amtrak riders (Acela and Regional), and in total, there were about 11.6 million total Acela and Regional passengers in Amtrak's Fiscal Year 2014 (October 2013 to September 2014). Furthermore, in FY 2014, the daily Acela ridership was as high as 18,600, although the median daily weekday ridership was about 11,300. And for Regional service in FY 2014, the highest daily ridership was 34,800, and the median was about 22,100 riders.

Amtrak recognizes the value of punctual performance of its services. For one, travel time reliability influences a traveler's decision to ride an Amtrak train, which impacts Amtrak's ridership and revenue totals. Amtrak currently measures the reliability of its service, and routinely publishes the following performance measures:

i. Delay minutes,
ii. End-point on-time, and
iii. All station on-time.

The **delay minutes** calculates the difference between the actual arrival time and scheduled arrival time for each train. Figure 1.3 shows the distribution of the delay minutes at the endpoint terminals for Amtrak Acela and Regional trains in FY 2014. If all trains arrived at the scheduled arrival time, we would see a spike up to 100% at the 0 delay minutes mark, and say the train had 100% schedule adherence. However, Amtrak is routinely not able to achieve arrivals at the scheduled time, and Figure 1.3 shows the distribution of actual FY 2014 deviations of Acela and Regional trains from the scheduled arrival times. The FY 2014 delay distribution shows a short spike at the 0 delay minutes mark and a very long tail. It illustrates the variability in arrival times across multiple trains and days, showing that a few trains are able to achieve on-time arrivals but many trains suffer from some delay, and further that a few trains suffer significantly large amounts of delay. In FY 2014, only 41% of all Amtrak trains arrived at the terminal station before or at the scheduled arrival time. An additional, 19% of trains arrived late but within 5 minutes of the scheduled arrival time, that is in total 60% arrived either on-time or within a 5-minute threshold. In total, 72% of Acela and Regional trains arrived within a 10-minute threshold, while the remaining 28% experienced more than 10 minutes of delay. Moreover, about 5% of trains in FY 2014 experienced delays greater than one hour.

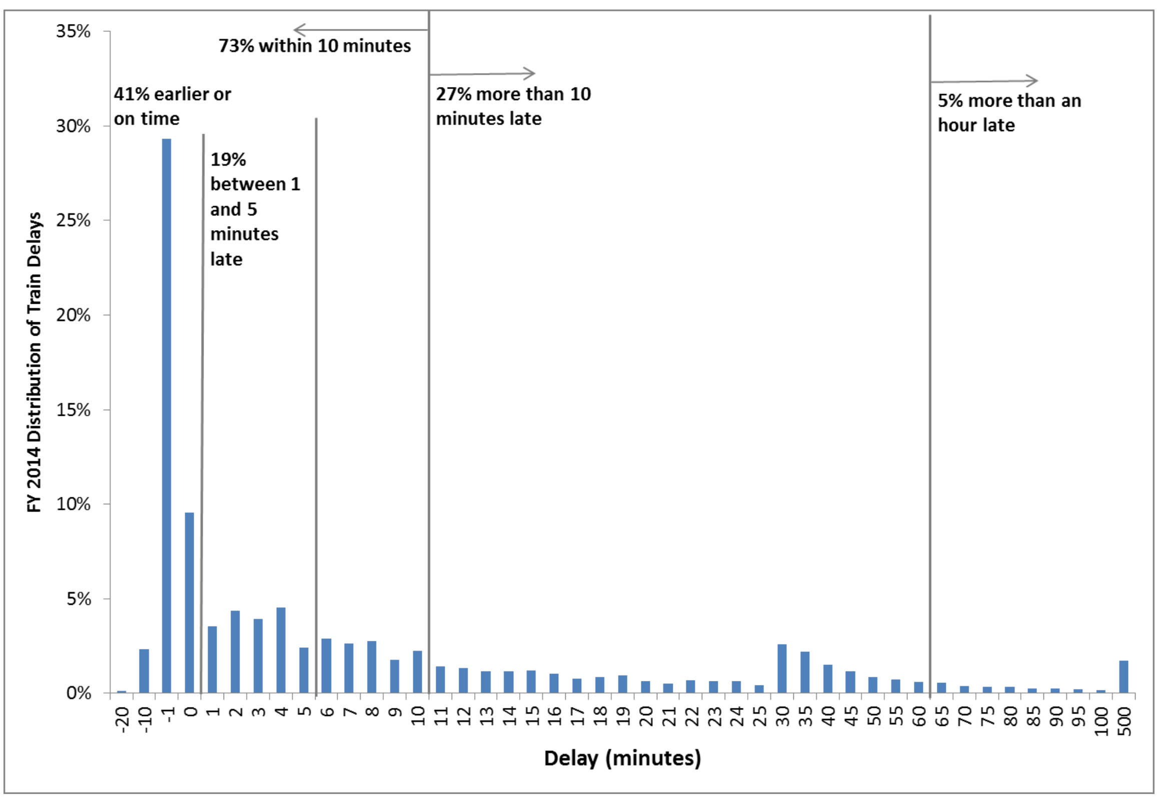

Figure 1.3: FY 2014 Distribution of Endpoint Delay

The **end-point on-time performance** measures the percentage of trains that arrive at their final destination on time, while the **all station on-time performance** measures the percentage of trains that arrive at each en-route station on time. In the Northeast Corridor, an Acela train is classified as "on time" if it arrives within 10 minutes of its scheduled arrival time, while a Northeast Regional train is classified "on time" if it arrives within 10 minutes for trips less than 250 miles, 15 minutes for trips between 251 and 350 miles, and 20 minutes for trips between 351 and 450 miles. In FY 2010, Amtrak set the endpoint on-time performance (OTP) target at 95% for Acela and 90% for Regional.

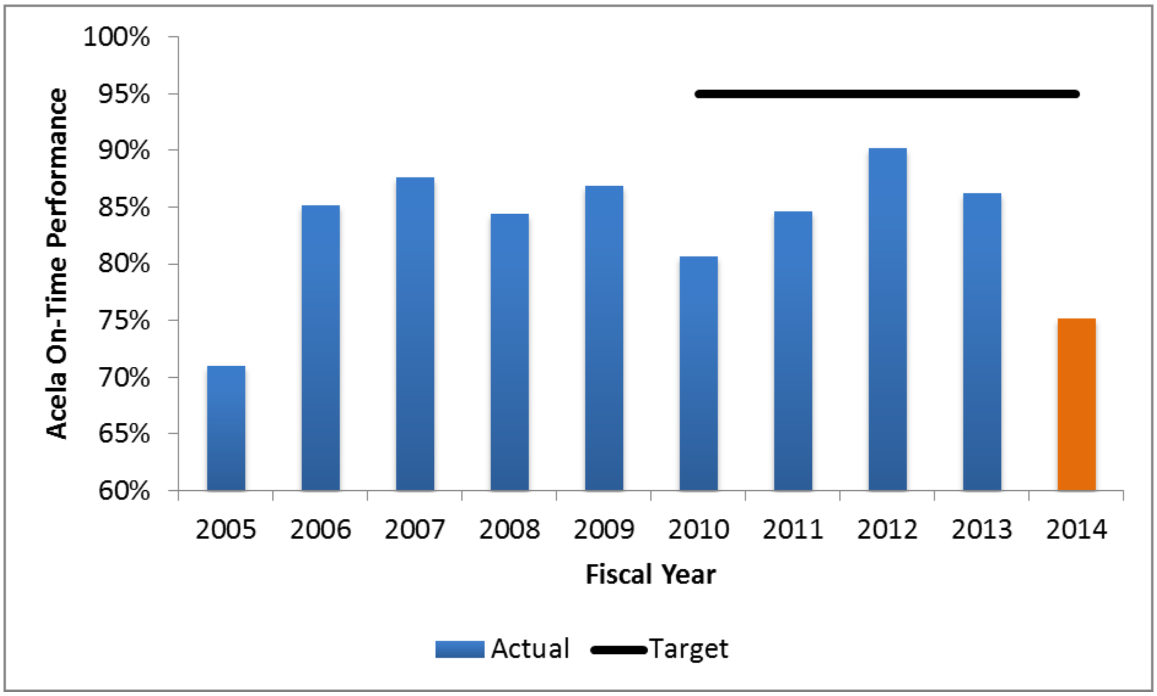

Figure 1.4: Acela Annual On-Time Performance

Figure 1.4 shows the annual average end-point OTP for the Acela service compared to the performance target. The black line represents the OTP target for Acela; prior to FY 2010, Amtrak did not have an established on-time target. The most recent fiscal year (FY 2014) is highlighted in orange. Between FY 20010 and FY 2014, despite the 10-minute arrival buffer, the performance on the Acela service has been about 5 to 20 percentage points below the target. Furthermore, compared to the 95% OTP target, Fiscal Year 2012 experienced the best service performance at 90% while FY 2014 experienced the worst at 75%. In other words, in FY 2014, 1 in 4 Acela trains arrived at their final destination more than the 10 minutes after the scheduled arrival time.

Under Amtrak policies, the Regional service is considered "on-time" if it arrives at the endpoint terminal within 10 to 20 minutes (depending on trip distance) of its scheduled arrival time. In addition, the OTP target for the Regional service was set to 90%. However, despite the lenient buffer and lower OTP goal, Figure 1.5 shows that the Regional service also underperformed by about 5to 20 percentage points between FY 2010 and FY 2014. Although still below target, similar to the Acela, the Regional service experienced the best performance in FY 2012 with an annual average OTP of 88%, and worst performance in FY 2014 with an annual average OTP of 77%.

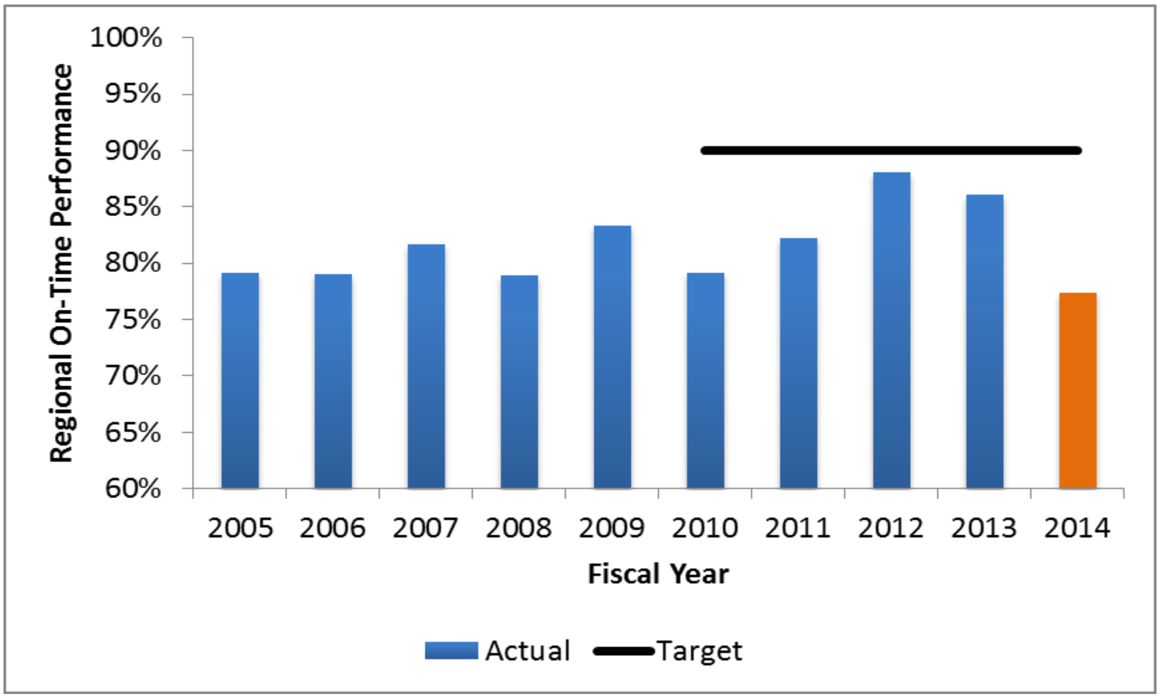

Figure 1.5: Regional Annual On-Time Performance

In comparison to the commuter services that operate on segments of the Northeast Corridor, Amtrak's performance is lower. The commuter operators reported better on-time performance than both Amtrak Acela and Regional services. Generally speaking, commuter trains are able to perform better than Amtrak services because they typically travel much shorter distances. That said, Table 1.1 reports the on-time performance rate for the commuter services compared with Acela and Regional on-time performance. The on-time performance for the commuter services ranged from 90% to 97%, in comparison with Acela's 75% and Regional's 77%. The "on-time" threshold for commuter services is within 5 and 6 minutes of the scheduled arrival time.

Agency		FY 2014 On - Time Performance	OTP Definition
Amtrak	Acela	75%	"On time" if train arrives terminal point within 10 minutes of scheduled arrival.
	Regional	77%	"On time" if train arrives terminal point within 10 - 20 minutes of scheduled arrival.
Commuter	MBTA	90%	"On time" if train arrives terminal point within 4 minutes and 59 seconds of scheduled arrival.
	SLE	92%	"On time" if train arrives terminal point within 5 minutes and 59 seconds of scheduled arrival.
	MNR	97%	
	LIRR	92%	
	NJT	94%	
	SEPTA	91%	
	MARC	92%	
	VRE	92%	

Table 1.1: FY 2014 Amtrak and Commuter On-Time Performance

Furthermore, compared to Amtrak Acela and Regional services, roughly similar rail services in Japan and China routinely achieve on-time performance greater than 99% with a zero-minute delay tolerance. For example, the Tokaido Shinkansen service in Japan that travels 320 miles between Tokyo and Shin-Ōsaka experienced only 0.9 minutes of delay per operational train on average in FY 2014. In Europe, Deutsche Bahn's punctuality for passenger rail transport in Germany was 95.6% in FY 2014. A Deutsche Bahn train is "on-time" if it arrives at each station within 6 minutes of its scheduled arrival time. In terms of performance, Amtrak appears to be behind its international counterparts.

Although Amtrak monitors the performance of its services, it has not been able to implement long-term operational changes due to political, infrastructure, financial and technical constraints. In general, this thesis aims to discuss some of the major constraints that undermine Amtrak's ability to provide reliable service to its passengers in the Northeast Corridor. A specific goal of the thesis is to analyze Amtrak's historical ridership and operations data to characterize the level of performance of Acela and Regional services, and to identify some causes of delays on Amtrak trains, including any catalytic effect of delays across the consecutive trains within a day. An additional goal of the thesis is to estimate the impact of service quality on demand.

1.3 Motivation

The Northeast Corridor (NEC) is the busiest railroad in the U.S, both in terms of service frequency and number of passengers. 2,200 trains operate on the corridor daily; 2,000 commuter trains, 153 Amtrak intercity passenger trains, and 70 freight trains. Between Amtrak and the commuter trains, there were approximately 750,000 daily riders, and in total about 260 million passenger trips made on the NEC in FY 2014. The dynamics of scheduling trains given demand growth, limited capacity, and different train speeds, while striving to achieve the diverse and sometimes conflicting objectives of different service operator is a complex challenge. NEC's multi-functional characteristic poses issues regarding train scheduling, timetable coordination, and train priority, among others. Furthermore, some segments along the NEC are presumed to be operating at or near capacity, and train slots are tightly scheduled with little-to-no slack or recovery leeway. As a result, theoretically minor disruptions on one train could propagate quickly, causing significant delays and deterioration of service quality in the system. There are some opinions that Amtrak's Acela and Regional services are of utmost importance, and thereby should always receive train priority. The counter argument to this school of thought is that the commuter rail and Amtrak services have a source-sink relationship. In other words, they supply and distribute traffic on each other's routes. Consequently, substandard service on commuter rail would likely negatively impact Amtrak demand, and vice versa. Altogether, the NEC is a complex sociotechnical system that deserves a great deal of attention. Furthermore, the NEC is the flagship of rail in the U.S. and at the core of one of 11 megaregions designated for high-speed rail, such that current performances on the corridor influences the view of passenger rail operations in the country, and the hopes for high-speed rail in the Northeast as well as states like Texas, California, and Florida.

From an economic point of view, the Amtrak services in the Northeast Corridor have played a role in the burgeoning economic development of the northeast region, which is one of the densest regions in the United States. The region includes major economic hubs that together had an estimated population of 56 million and generated about 20% of U.S. GDP in 2013. In comparison with the total population in the region, Amtrak served 11.6 million passengers in the NEC in Fiscal Year 2014. Part of the appeal of the Northeast region is the relative proximity between the major cities. The good transportation connectivity in the region widens the radius within which people and businesses can interact. As a transportation link connecting people and businesses, the NEC influences the attractiveness of the Northeast region as a place to live and do business. The labor force in the region have access to businesses, and vice versa, in addition businesses can reach customers and suppliers, and they both have access to other businesses, including retail and public services such as health care, education and entertainment. Amtrak's role, as the only intercity rail connection between the major cities in the NEC is important. Consequently, its performance in the NEC is crucial because it directly affects the economic development in the region.

Also from an economic point of view, Acela Express service generated $585.8 million and the Regional service generated $603.5 million in Amtrak Fiscal Year 2014. Both services currently achieve an operating (not including infrastructure costs) cost recovery ratio considerably greater than 1. It can be expected that an improvement in Amtrak services might reduce costs from inefficient operations, as well as increase demand (given sufficient capacity), thus reducing costs and increasing revenue over time.

The NEC is one of the oldest rail corridors in the U.S., which affords a wealth of valuable historical data for research. It is important to ensure that future developments in passenger rail keep up with innovation and advancing technology, and more importantly with the changes in the transportation environment and travel pattern. This research aims to study the performance of Amtrak in the Northeast Corridor, through the lens of the research community keen on solving complex problems. Given the current capacity and shared-use constraints in the Northeast Corridor, tackling service performance is a complex challenge. The research aims to develop a case study of Amtrak's current performance in the Northeast Corridor, investigate pros and cons of programs that have been tested to enhance service performance, and come up with new solutions that could provide incremental or perhaps transformational improvements. In addition, this research has the potential to highlight lessons that other intercity passenger rail networks might be able to learn from.

Due to the high density and productivity in the city hubs along the NEC, many of the trips are concentrated at major nodes. A significant number of the 56 millions people who live and travel in the corridor are making trips around the same time, for similar reasons, and with roughly similar origins and destinations. This is evident from peak period congestion across all modes of transportation, and around the central business districts in the corridor. Currently, the main travel alternatives in the Northeast region are rail, air, and highway, which include auto and bus. Rail has a significant advantage here because it has a much higher capacity than the other modes. The current Acela trainsets have a seating capacity of 304 (44 first class; 260 business class), while the Regional trainsets have a capacity ranging from about 500 to 750 seats, which both provide much higher capacities than the other modes. Consequently, intercity passenger trains will continue to be indispensable as the population in the northeast region continues to grow, assuming similar trends in future trip. Additionally, improvements in the service quality of Amtrak rail will further strengthen its competition in the NEC.

The transport sector is responsible for 23% of global CO_2 emissions and is also the fastest growing source of CO_2 emissions. At the same time, population in the Northeast region is expected to increase by an additional 15 million resident, and intercity travel is expected to increase by 45% to 75% between 2014 and 2040/2050. Many of the discussion to mitigate the current trend in CO_2 emissions, and lower carbon emission per trip have included an improvement in the quality of "low emission" modes such as walking, cycling and some common-carrier modes. Amtrak fits under the common-carrier modes umbrella. In addition, the NEC as it stands today is fully electrified, which makes it a sustainable mode of the future. For example, trains consume 17% less energy per passenger-mile than airline, and 34% less than automobile. Improving Amtrak's service performance has the potential to reduce Amtrak's energy consumption and CO_2 emissions by reducing unnecessary braking, and also produce mode shift from air, auto and bus. The need to reduce the transportation sector's CO_2 footprint further emphasizes the need for an improvement in Amtrak's performance in the Northeast Corridor.

All of the above motivations provide a glimpse as to why the Northeast Corridor and Amtrak services are vital and important to study. Finally, the performance of Amtrak's Acela and Regional services in the Northeast Corridor (NEC) is a topic that, while frequently discussed as substandard by some travelers, has received minimal attention in the compendium of open source research literature. Amidst leading discussions in U.S. Congress to reduce Amtrak's funding, the finances and policies required for track renovation, infrastructure maintenance and quality train operations are also compromised, further motivating this research.

1.4 Research Objectives

The author will evaluate available Acela and Regional ridership data, as well as measures of performance using train operations data to assess Amtrak passenger rail service performance in the Northeast Corridor. The objectives of this research are to understand the factors that influence the service performance of Amtrak Acela and Regional in the Northeast Corridor, and to evaluate the impact of service performance on current and future ridership. The research focuses on the variability in ridership and service performance between Fiscal Year 2005 and Fiscal Year 2014, as well as discusses specific factors that lead to travel time variability and delays. In the process, studies regarding service performance within the transportation context in both the U.S. and internationally will be reviewed, and different metrics to quantify service performance will be examined. Additionally, the thesis will provide an overview of Passenger Rail Investment and Improvement Act (PRIIA) Section 207, the most recent measure taken to address the service performance of Amtrak trains in U.S. Overall, the research aims to understand what causes delays on Acela and Regional trains, and subsequently to provide suggestions and active steps on how Amtrak can monitor and improve service performance in the Northeast Corridor.

1.5 Thesis Organization

This thesis is organized into eight chapters including the introduction. The **second chapter** reviews the literature relevant to the subject of performance of transportation services. The **third chapter** examines the performance metrics and standards that were introduced under Passenger Rail Investment and Improvement Act (PRIIA) Section 207, as well as the effectiveness and current status of the program. The **fourth chapter** provides an overview of the data on Acela and Regional ridership and service performance received from Amtrak. The **fifth chapter** and **sixth chapter** examine the factors leading to ridership and service performance fluctuations on the Acela and Regional services, respectively. The **seventh chapter** discusses the time series and regression analysis. Finally, the **eighth chapter** concludes the thesis with a summary and recommendations.

The next chapter reviews the literature relevant to the topic of service quality and performance in the transportation context.

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2 LITERATURE REVIEW

In order to integrate service performance metrics into transportation models, it is important to understand how variability in service performance impact demand. This section is divided into three parts. **Section 2.1** briefly discusses various definitions and measures of reliability. **Section 2.2** reviews previous research on methods to evaluate reliability and its effect on demand. And **Section 2.3** presents a summary of the results obtained in the literature.

2.1 Definitions and Measurements of Reliability in Literature Review

Accuracy measures how close a measured value is to the standard (true) value, while precision measures how close sets of measured values are to each other. Consequently, precision is synonymous with repeatability. Following an analogous concept, a train service that arrives at a destination at the exact scheduled time is considered accurate, while a train service that <u>always</u> arrives, for example, five minutes late, though inaccurate is precise, due to the repeatability of the service. These two schools of thought represent the general concept by which people often describe the service performance of passenger rail systems. On one hand, reliability could refer to consistent on-time rail service, and on the other hand to predictable service, which could include some expected level of delay. Consequently, travel time reliability studies measure the variability in travel times across multiple scheduled trips.

As a result of unreliable service quality, individuals spend a longer time traveling than expected or desired, which leads to stress associated with the uncertainty and sometimes consequences of late arrivals at their destination (e.g. reduced pay or work termination). To account for expected travel time variability, travelers can decide to change their departure time, but sometimes also change their routes and/or mode as a result of unreliable service quality.

In transportation systems, travel time variability introduces uncertainty to travel plans, and therefore is often formulated as additional costs and disutility. In the U.K., the Passenger Demand Forecasting Handbook (PDFH) measures passenger rail performance by using the terms 'reliability' and 'punctuality', where 'reliability' refers to the rate of cancellation, and 'punctuality' refers to the percentage of operated trains (trains that were not cancelled) that arrive under a given 'lateness' threshold. 'Lateness' measures the difference between the actual departure/arrival times and the published timetables, while 'delay' measures the difference between the actual time and en-route adjusted schedules. The Public Performance Measure (PPM) is a synthesis of both 'reliability' and 'punctuality', and it measures the percentage of all scheduled trains that are operated and arrive under a given 'lateness' threshold. A train that arrives under the given 'lateness' threshold is considered 'on-time'. However, globally, the 'on-time' notion varies across train service, total travel time or distance, operator and country. It ranges from exactly on time to within five and/or ten minutes of published timetables. Furthermore, some long distance services in the U.S. even consider trains that arrive under 15-20 minutes of the published schedule as 'on-time'. In the U.S., Amtrak measures on-time performance (OTP) as the percentage of trains that achieve the 'on-time' target compared to the total number of trains in service. Furthermore, Amtrak defines the acceptable 'on-time' target differently for end-point and station-to-station OTP. All of this is to say that measures of travel time reliability using PPM and OTP, while useful in characterizing a specific system/service, are not consistent with each other, and across different passenger rail systems, and therefore not directly comparable. In addition, the most obvious metric, delay-minutes, the difference between the actual time and the published timetables can also be misleading because a 20 minute delay on a 30-minute trip is very different from a 20 minute delay on a 6-hour trip. To account for this, in the U.S. Amtrak normalizes the delay-minutes metric to 10,000 train miles to provide a consistent reporting basis, and to allow for comparison across services.

Additionally, across the literature on travel time variability, reliability is measured as the standard deviation (or variance) of the travel time distribution or by the number of minutes travelers are willing to arrive earlier or later than a preferred arrival time (PAT). Another ambiguity is found in this definition; in some studies, travelers experience a disutility from arriving either early or late, while in others disutility is only as a result of a late arrival.

A final reliability metric that is common in the literature on travel time variability is the value of reliability (VOR). VOR is similar to the concept of value of time (VOT), and measures a traveler's willingness to pay for reduction in travel time variability (increase in travel time reliability). In addition, the reliability ratio (RR) evaluates the tradeoff between mean travel time and travel time variability (VOR/VOT). The reliability ratio is sometimes alleged to offer a more consistent and comparable metric for assessing the impact of travel time variability.

In summary, the different performance metrics across the transportation literature are:

Performance Metric	Definition
Reliability	Rate of cancellation
Lateness	Difference between the actual arrival/departure times and the published timetables
Punctuality	Percentage of operated trains that arrive under a given 'lateness' threshold
Public Performance Measure (PPM)	Percentage of all scheduled trains that are *operated* and arrive under a given "lateness" threshold
On-Time Performance (OTP)	Percentage of trains that achieve the "on-time" target compared to the total number of trains in service (*All-station vs End-point)*
'**On-time**'	Varies across train service, total travel time or distance, operator and country from no tolerance to a 10-15 minute threshold
Total Delay Minutes	Difference between the actual arrival/departure times and published timetables
Delay-minutes Per 10,000 train miles	Difference between the actual time and published timetables, normalized for train miles to ensure a consistent reporting basis
Effective Speed	Ratio between train mileage and the total travel time planned into the timetable, to ensure that service speeds are not simply reduced on the timetables in order to achieve a given performance standard
Schedule Delay Early/Late (SDE/SDL)	Disutility from arriving either early or late
Value of Reliability (VOR)	Willingness to pay for reduction in travel time variability (increase in travel time reliability) similar to the concept of value of time (VOT)
Reliability Ratio (RR)	Tradeoff between mean travel time and travel time variability (VOR/VOT)

Table 2.1: Performance Metrics Definitions

2.2 Theories/Models/Methods to Measure the Effect of Unreliability

The theories in the literature used to measure the effect of service performance on demand can be categorized under three main methods:

i. Econometric model
ii. Mean-variance model
iii. Scheduling model

Although the underlying theory of most studies is rooted in one of these three approaches, each study tends to adopt variations in the formulations within each method.

2.2.1 Econometric Model

In the U.K., the relationship between demand and average lateness at destination station is based on the formulation established in the British Passenger Demand Forecasting Handbook (PDFH). In this context, lateness refers to the difference between the actual and public timetable arrivals at destination stations:

$$I = \left[1 + \frac{w(\bar{L}^{+}_{scenario} - \bar{L}^{+}_{base}}{GJT_{base}}\right]^{\varphi}$$

where,

I is change in rail demand

$\bar{L}^{+}_{base}$ is average lateness in the 'base' case

$\bar{L}^{+}_{scenario}$ is average lateness in the 'scenario' case being forecasted

GJT is Generalized Journey Time in the base case

w is lateness multiplier to convert average lateness to equivalent GJT

φ is elasticity of rail demand to GJT

The plus notation $\bar{L}^{+}_{*}$ imposes a non-negativity constraint on the average lateness variable. That is, on-time or early arrivals at the destination station are given a value of 0. Under the forecasting framework, Generalized Journey Time (GJT) is the sum of the service characteristics (in-vehicle time, frequency, and transfer time) converted into time units. The main criticism of this approach is that it might not adequately estimate the demand elasticity to lateness because the elasticity of GJT is fixed and the demand response is largely given by adjustments to the lateness multiplier more than the magnitude of $(\bar{L}^{+}_{scenario} - \bar{L}^{+}_{base})$.

Batley et al. (2011) developed an econometric model to estimate the elasticity of demand for rail in terms of ticket sales at O–D levels with respect to changes in performance metrics. Three performance metrics were modeled:

i. **Average Lateness Minutes (ALM)** - an average of the difference between actual running time and en-route adjusted schedules weighted by passenger loadings at each station
ii. **Average Performance Minutes (APM)** - an average of the difference between actual running time and all published schedules (that is, including canceled services)
iii. **Public Performance Measure (PPM)** - the percentage of trains that arrive at their destination within a specific margin of the publicly available timetables (five minutes for short distance and ten minutes for long distance)

Batley et al. (2011) used panel data, a combination of cross-section data and time-series data accumulated from several O-D pairs over a number of years, and subdivided into 13 4-weekly periods. They formulated a static and dynamic model. The static model was a constant elasticity demand model

$$\ln V_{ijt} = \mu_{ij} + \sum_{k=2}^{13} \kappa_\kappa D_\kappa + \phi \ln F_{ijt} + \varphi \ln GJT_{ijt} + \gamma \ln G_{it} + \eta \ln R_{ijt} + \varepsilon_{it}$$

where,

V_{ijt} is the volume of rail demand between stations i and j at period t

μ_{ij} are O–D-specific effects which account for time-invariant differences between flows not specified in the other variables of the model, i.e. 'fixed-effects';

D_κ are 12 dummy variables to account for seasonality in the 4-weekly data;

F_{ijt} is rail fare for O–D ij at period t divided by the retail price index;

GJT_{ijt} is generalized journey time for O–D ij at period t

G_{it} is Gross Value Added at Government Office Region of origin i at time t

R_{ijt} are the performance metrics for O–D ij at time t

The dynamic model was an autoregressive distributed lag model (ADL), which included lags of both the dependent and independent variables

$$\ln V_{ijt} = \mu_{ij} + \sum_{k=2}^{13} \kappa_\kappa D_\kappa + \sum_{s=0}^{S} \phi_s \ \ln F_{ijt-s} + \sum_{l=0}^{L} \varphi_l \ln GJT_{ijt-l} + \sum_{m=0}^{M} \gamma_m \ \ln G_{it-m} + \sum_{u=0}^{U} \eta_u \ \ln R_{ijt-u} + \sum_{w=0}^{W} \lambda_w \ln V_{ijt-w} + \varepsilon_{ijt}$$

where,

s, l, m, u *and* w are the lags for the associated variable at period 0 to time maximum lag length denoted by the upper case letter.

The results from both models revealed a marginal but statistically significant effect of lateness and reliability on rail passenger demand, ranging from -0.01 to -0.06 for ALM and APM, and from 0.02 to 0.27 for PPM. In the dynamic model, the lag for each performance metric was 1 * 4-weekly period.

Halse et al. (2014) developed a panel data fixed-effect model (treating O-D pairs as separate observations) to estimate the demand effects of rail reliability in Norway. The fixed-effect regression method was used to control for unobserved factors that account for cross-sectional differences in reliability across segments. The results showed low elasticity (~-0.01) of demand to delay. The specifications of the static and dynamic models used are as shown below:

Static model:

$$Q_t = \alpha + \beta_s Delay_t + \beta_2 Canc_t + \theta_1 DOW_t + \theta_2 Week_t + \delta \cdot t + \gamma \mathbf{X_t} + \varepsilon_t \quad (1)$$

With lags:

$$Q_t = \alpha + \beta_1 Delay_t + \beta_2 Canc_t + \sum_{k=1}^{K} \lambda_{1k} Delay_{t-k} + \sum_{k=1}^{K} \lambda_{2k} Canc_{t-k} + \theta_1 DOW_t + \theta_2 Week_t + \delta \cdot t + \gamma \mathbf{X_t} + \varepsilon_t \quad (2)$$

Paul Schimek (TRB 2015) applied a similar econometric model to estimate the elasticity of demand to fare changes. He analyzed panel data (cross-sectional time-series data) using both fixed- and random-effect models, and found the fixed-effect models to be better. The models were estimated in double log form, that is, both independent and dependent explanatory variables were log-transformed in order to better capture large variability, and directly interpret coefficients as elasticities. He also included lagged dependent variables, and estimated a dynamic pooled model using the software Gretl.

2.2.2 Scheduling Approach

This approach was motivated by discrete choice models and utility maximization theory under the assumption travelers attach a utility to arriving at their destination at a particular time, commonly referred to as the preferred arrival time (PAT). Under this framework, travelers associate a cost due to an early or late arrival at their destination that leads to a reduction in utility.

Empirical research by Small (1982) mostly based on Gaver (1968) and Vickery (1969) suggest a travel disutility influenced by the departure time and given by:

$$U(t_d) = \alpha T + \beta(SDE) + \gamma(SDL) + \theta D_L$$

where,

t_d is the travelers departure time choice

T is travel time

SDE is schedule delay early and given by $Max(0, PAT - [T + t_d])$

SDL is schedule delay late and given by $Max(0, [T + t_d] - PAT)$

D_L is a binary variable equal to 1 when SDL >0 and 0 otherwise

α, β, γ *and* θ are cost of travel time, cost per minute of arriving early or late, and lateness penalty, respectively, and expected to be negative.

Noland and Small (1995) further developed this framework to include the effect of uncertainty based on maximum expected utility theorem. As a result of travel time uncertainty and a traveler's inability to plan exactly, a traveler taking into account travel time uncertainties will choose the option that has the highest value of expected utility. The expected utility is thus given by:

$$E[U(t_d)] = \alpha E[T] + \beta E[SDE] + \gamma E[SDL] + \theta P_L$$

Where, $P_L = E[D_L]$ is the probability of experiencing a late arrival, that is, the proportion of time in which a late arrival occurs (it is independent of the magnitude of the late arrival). Moreover, a more variable travel time results in a larger expected value of SDE and SDL. The scheduling approach treats SDE and SDL separately and tends to capture greater disutility from late arrival, and is thus cited by some studies as a better evaluation of variability

The publications by Noland et al. (1998) and Small et al. (1999), also included in the overview by Noland and Polak (2002), are among the best examples of the schedule delay function approach.

2.2.3 Mean-Variance (Centrality-Dispersion) Approach

Under this framework, a traveler maximizes utility by minimizing both travel time and variability in travel time (unreliability), based on the formulation:

$$U = \beta_T \mu_T + \beta_\sigma \sigma_T$$

where,
μ_T is average travel time
σ_T is travel time variability (standard deviation or variance)
α, β are model coefficients.

The average travel time is included as the mean (centrality) variable, while the travel time variability represents the variance (dispersion) term. Travel time variability is typically measured by standard deviation or variance of travel time, as well as by travel time distribution percentiles. An alternative formulation includes the expected utility as well as travel fares:

$$E[U] = \beta_T E[T] + \beta_\sigma \sigma_T + \beta_C C$$

where, $E[T]$ is expected time, σ_T is standard deviation of travel time, C is travel cost, and $\beta_T, \beta_\sigma, \beta_C$ are estimated coefficients. The value of time (VOT) is measured as β_T/β_C, to estimate the willingness to pay for reduction in travel time. Similarly, the value of reliability (VOR) is the ratio of β_σ/β_C, and represents a travellers willingness to pay for reduction in travel time variability. In addition, the reliability ratio (RR), β_σ/β_T is defined as the marginal rate of substitution between average travel time and travel time variability (VOR/VOT).

Publications by Varian (1978), Jason and Jucker (1982), Senna (1994), Copley et al. (2002) and Hollander (2006) are among the best examples of the mean-variance model

2.3 Overview of Different Approaches and Results in Different Studies

As highlighted in Section 2.2 the various studies reviewed were based on the different theoretical frameworks. The estimated reliability ratios (RR) from the studies ranged from 0.1 to 2.51, and the estimated value of reliability (VOR) ranged from $0.79 to $56 per hour in 2009$. These results suggest that on one hand, travelers place barely any value on reliable travel, and on the other hand, travelers are willing to pay up to $56 to reduce unexpected travel delays by an hour. Similarly, a reliability ratio of 2.5 suggests that travelers are willing to pay 2.5 times more for an hour reduction in variability than for an hour reduction in total travel time. The significant variation among the results is a consequence of the different theoretical approaches, as well as the various data sources used, year of study, transportation mode, time of day (peak versus off-peak), trip purpose, and study country. A comprehensive review of value of reliability studies, including theoretical approaches and results is presented in Carrion and Levinson (2012), Li et al. (2010), and Noland and Polak (2002). Overall, De Jong et al. (2009) proposed some recommended reliability ratios based on available international evidence, especially from the UK, The Netherlands and Sweden; a reasonable reliability ratio for car travel was 0.8, and for interurban train and public transport (bus, tram, metro) was 1.4. Bates et al. (2001) concluded from their research that reliability is highly valued by travelers, and that a plausible reliability ratio for car travel was around 1.3, and no more than 2.0 for public transport.

To the best of the author of this thesis' knowledge, there has not been any study to identify the value of reliability, reliability ratio, or elasticity of demand to reliability/service performance for rail in the U.S. More specifically, to the best of the author's knowledge, there is no prior research studying the value Amtrak travelers in the Northeast Corridor place on service performance, or to quantify the effect of service performance on demand in the Northeast Corridor. This void in open-source literature further motivated the work done in this thesis.

The next chapter discusses recent measures of service performance of Amtrak trains in the Northeast Corridor introduced under the Passenger Rail Investment and Improvement Act (PRIIA) of 2008.

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3 PASSENGER RAIL INVESTMENT AND IMPROVEMENT ACT (PRIIA) SECTION 207

3.1 Overview

The Passenger Rail Investment and Improvement Act (PRIIA) of 2008 is the most recent measure taken to address the service performance of passenger trains in the U.S.. PRIIA was established as a platform through which the National Railroad Passenger Corporation (Amtrak), the U.S. Department of Transportation (US DOT), Federal Railroad Administration (FRA), states, and other stakeholders could collaborate to strengthen and improve intercity passenger rail. The 'other' stakeholders included the Surface Transportation Board, freight railroads, rail labor unions, and passenger rail organizations. PRIIA Section 207 focused on metrics and standards to measure the performance and service quality of intercity passenger rail operations. The two main performance indicators utilized were on-time performance (OTP) and train delay.

3.2 Background

The FRA and Amtrak were in charge of establishing performance indicators to monitor the reliability of intercity passenger rail operations. Although Amtrak is the sole intercity passenger rail operator in the U.S., and it owns 79% of track in the NEC, outside the NEC, Amtrak primarily runs on tracks owned and operated by freight railroad companies. Consequently, the main groups that would be affected by the metrics, in terms of administering changes were Amtrak as the rail operator, and the host railroads, which include both Amtrak and the freight railroads.

In 1973, Congress granted Amtrak the right of preference, which obligated host railroads to grant dispatching preference to Amtrak passenger service over freight operations. The host railroads were also required to pay Amtrak in the event of any violations of the right of preference that led to Amtrak train delays. However, Amtrak and the host railroads measured delays and violations of the right of preference differently, which led to disagreements and difficulty in enforcing the rule. In addition, Amtrak and the host railroads had other service quality agreements that differed by state and host railroad. Furthermore, each of the states served by the State-supported routes had the right to negotiate state operating and performance contracts with Amtrak and the other railroads. As a result, the existing performance indicators lacked uniformity. A main motivation for PRIIA Section 207 was to create a standardized method to measure the performance and service quality of intercity passenger train operations using on-time performance and minutes of delay. The statute was designed to improve any existing metrics and develop new standards and minimum standards that were consistent and comparable over time, and across Amtrak routes, states, and host railroads. The stricter laws with monetary penalties for not meeting the standards were expected to transform train priority and lead to a dramatic improvement in passenger rail performance.

The FRA and Amtrak jointly developed performance measures for Amtrak and the host railroads based on historical operational and performance data provided by Amtrak. On March 13, 2009, FRA and Amtrak released the first draft of proposed metrics and minimum standards, and solicited feedback from the other stakeholders and invested parties. The stakeholders and invested parties included freight railroad companies that host intercity passenger trains, state department of transportation, commuter passenger rail agencies, labor unions that represent Amtrak employees, and groups to represent Amtrak and commuter passengers. After receiving feedback between March 13 and March 27, 2009, the proposed metrics and standards for intercity passenger rail service were clarified or revised, and finalized.

3.3 Final Metrics and Standards for Intercity Passenger Rail Service

The metrics and standards addressed on-time performance and minutes of delay separately. The on-time performance metric dealt with the repeatability of reliable service, while the minutes of delay metric dealt with the precision of service or amount of deviation from the published schedules. Although PRIIA Section 207 was established for all Amtrak services in the U.S., only the metrics and standards relevant to the Northeast Corridor routes will be highlighted in the rest of this section. Furthermore, in terms of the enforcement of PRIIA standards and the penalties for not meeting the standards, because Amtrak owns 79% of track in the NEC, it serves as both rail operator and host railroad in the NEC. The other host railroad is Metro North Railroad (MNR), which operates and controls a 56-mile section on the NEC between New Rochelle, NY. and New Haven, CT. Consequently, Amtrak would essentially be meting out penalties to either MNR or itself if service quality failed to meet the standards established under PRIIA.

3.3.1 On-Time Performance

The on-time performance (OTP) metric monitors the repeatability of service. In other words, it measures the variability of travel time over repeated trips, and the percentage of Amtrak trains that achieve the 'on-time' target compared to the total number of trains in service. Under PRIIA Section 207, three metrics were established and used to monitor OTP:

Percent on-time at the endpoint

Under PRIIA, an Acela train was considered 'on-time' if it arrived its endpoint terminal within 10 minutes of the scheduled arrival time. Comparably, a Northeast Regional train was considered 'on-time' if it arrived within 10 minutes for trips less than 250 miles, 15 minutes for trips between 251 and 350 miles, and 20 minutes for trips between 351 and 450 miles. Table 3.1 summarizes the on-time definitions for Acela and Regional. Starting in FY 2010, endpoint OTP was required to be at least 90% for Acela and 85% for Regional. By FY 2014, this threshold was required to increase to at least 95% for Acela and 90% for Regional. These thresholds were measured against either the published timetables or adjusted schedules (Amtrak occasionally releases an adjusted timetable for a specified period of days due to major renovation, track work, or other major time-impeding projects on the corridor).

"On-time"	
Acela	Regional
10 min	10 min; < 250 mi 15 min; 251 and 350 miles 20 min; 351 and 450 miles

Table 3.1: "On-Time" Definition for Acela and Regional

Percent on-time at all-stations served

The tolerances for the all-station OTP ensured that the scheduled times at all stations (departure time from origin station and arrival times at all subsequent stations) were within 10 minutes for Acela trains, and 15 minutes for Northeast Regional trains. Starting in FY 2012, all-station OTP was also required to be at least 90% for Acela and 85% for Regional. By FY 2014, this threshold was required to increase to at least 95% for Acela and 90% for Regional. Similar to the endpoint OTP, these thresholds were measured against either the published timetables or adjusted schedules.

<u>Change in effective speed</u>

Effective speed was defined as the ratio between train mileage and the total travel time. The total travel time was calculated as the sum of the scheduled end-to-end travel time and average endpoint delay. It was calculated on a rolling four-quarter basis, and compared to a fixed FY 2008 baseline. The effective speed metric was included to ensure that train schedules were not simply lengthened in order to achieve the OTP standards. This metric emphasized the importance of shortening (or at least preventing deterioration in) end-to-end travel times, and guarded against schedule creep.

Table 3.2 shows a summary of the three metrics that were established to monitor the on-time performance of Amtrak trains in the NEC, and the standards that were fixed under PRIIA:

Metric	Endpoint OTP		All-station OTP		Change in Effective Speed vs. FY 08
	Acela	Regional	Acela	Regional	
First Year (FY 2012)	90%	85%	90%	85%	>=0
By FY 2014	95%	90%	95%	90%	>=0

Table 3.2: On-Time Performance Metrics and Standards

3.3.2 Train Delays – On NEC

The minutes of train delay metric dealt with amount of deviation from the published schedules. This metric was required under PRIIA section 207, in addition to the OTP metrics in order to keep track of all delays encountered even when trains arrived 'on-time'. The train delay metric was measured in minutes per 10,000 train miles to ensure a normalized reporting basis because some trains in the NEC operate on only half of the corridor (i.e. Boston, MA to New York, NY or New York, NY to Washington, DC) while other trains operate on the full length of the corridor (i.e. Boston, MA to Washington, DC). In addition, all Amtrak routes operated well over 10,000 train-miles every month. Specifically, both Acela and Regional services operated over 10,000 train-miles daily. Table 3.3 shows that total daily train-miles on the Acela services is almost 12,000.

Direction	Acela Markets	Distance (miles)	# of daily Trains	Train-Miles
SB	Boston - Washington	457	10	4,570
	New York - Washington	226	6	1,356
NB	Boston - New York	231	1	231
	New York - Washington	226	7	1,582
	Boston - Washington	457	9	4,113
	Total train-miles :			**11,852**

Table 3.3: Acela Daily Total Train-Miles

The acceptable minutes of delay per train-miles metric was calculated separately for Acela and Northeast Regional services. The FY 2008 data was used for the analysis, to evaluate the amount of delay minutes were incurred on days when the OTP was above a specified minimum OTP standard. The OTP standards used in the calculations were 90% for Acela, and 85% for Northeast Regional.

For Acela, an existing mathematical regression model was used to estimate a delay threshold of 285 minutes of delay/10,000 train-miles. This value was the mid-point of the high-low delay minutes range that corresponded with a 90% endpoint on-time arrival rate. The threshold for Acela was later adjusted to 265 minutes/10,000 train-miles, to include only Amtrak-responsible and host-responsible delays (but not third-party responsible delays). For Northeast Regional, the FY 2008 OTP versus delay data were plotted, and used to calculate a delay threshold of 470 minutes/10,000 train-miles. This value was the mid-point of the high-low delay minutes range that corresponded with a 85% endpoint on-time arrival rate. For similar reasons to those above, the threshold for Regional was also later adjusted to 475 minutes/10,000 train-miles.

The 265-minute (Acela) and 475-minute (Regional) standards were intended to absorb routine/seasonal maintenance, track work, and other routine construction projects[iii]. However, in the event of a major construction or maintenance project, an additional delay buffer (above the allowable threshold) was permitted. Amtrak owns or operates most of the track in the NEC, except the section owned and operated by Metro North. As a result, Amtrak serves as the host-railroad along the NEC and thus was required to follow the strict standards outlined above. The standard for Metro North railroad was more lenient, with a delay threshold of 900 minutes/10,000 train-miles. Table 3.4 summarizes the minutes of delay standards established under PRIIA.

Delay Metric (Minutes per 10,000 Train-Miles)	Acela	Regional	Metro-North
Total train delays	265	475	900
Cause of delay	Yes	Yes	Yes

Table 3.4: Minutes of Delay Metrics and Standards

In addition to the minutes of delay metric, under PRIIA regulations, the cause of delay and the responsible party, categorized by Amtrak-, host- and third-party-responsible delay had to be reported.

i. **"Amtrak-responsible"** refers to delays coded on *Amtrak Conductor Delay Reports* as Passenger-Related (ADA, HLD), Car Failure (CAR), Cab Car Failure (CCR), Connections (CON), Engine Failure (ENG), Injuries (INJ), Late Inbound Train (ITI), Service (SVS), Crew and System (SYS), or Other Amtrak-Responsible (OTH).

ii. **"Host-responsible"** refers to delays coded on *Amtrak Conductor Delay Reports* as Freight Train Interference (FTI), Passenger Train Interference (PTI), Commuter Train Interference (CTI), Slow Orders (DSR), Signals (DCS), Routing (RTE), Maintenance of Way (DMW), Debris Strikes (DBS), Catenary or Wayside Power System Failure (DET, used in electrified territory only), or Detours (DTR).

iii. **"Third-party"** refers to delays coded on *Amtrak Conductor Delay Reports* as Unused Recovery Time (NOD), Customs (CUI), Police-Related (POL), Trespassers (TRS), Drawbridge Openings (MBO), Debris (DBS), or Weather-Related (WTR).

3.4 Other Issues Regarding Metrics and Standards

The issues raised regarding the administration of the metrics and the standards were as follows:

A number of the comments received were with regards to the administration of the metrics and standards. Some of the host railroads noted that the proposed performance measures would present an administrative burden and would require significant operational changes to make current Amtrak schedules realistic. Furthermore, they stated that Amtrak schedules would need to be revised using computer modeling techniques that account for current traffic and seasonal pattern in order to meet the performance standards. From an implementation and data collection point of view, they argued that automated and technically advanced data collection mechanisms would be needed in place to reliably track the performance on actual operations. In addition, they cited the poor infrastructure, and the need for ongoing and future rail infrastructure improvements.

FRA and Amtrak responded to the issues raised citing them as valid reasons confirming the importance of the metrics in assisting to detect areas and causes of poor performance, in order to ultimately strengthen and improve intercity passenger rail.

3.5 Performance Following PRIIA Section 207

Both the OTP and delay minutes metrics were established to provide a comprehensive indicator of intercity train performance and service quality. The metrics and standards were in effect as of May 12, 2010. Following PRIIA Section 207 in 2010, all Amtrak routes experienced a record high in on-time performance. Although Amtrak owns most of the track in the Northeast Corridor, Acela and Regional also experienced performance improvements due to the stricter rules introduced under PRIIA Section 207. That said, there were other interrelated factors that contributed to the improved performance. The beginning of PRIIA coincided with the economic recession, which led to less freight rail traffic interfering with passenger rail services. Figure 3.1 shows the on-time performance for Acela between FY 2004 and FY 2014. The blue markers indicate the annual average OTP while the vertical lines represent the highest and lowest monthly OTP in each fiscal year. Following the establishment of PRIIA in 2010, Acela experienced an improvement in OTP in FY 2011, further improvement in the following years, and a record high performance in FY 2012.

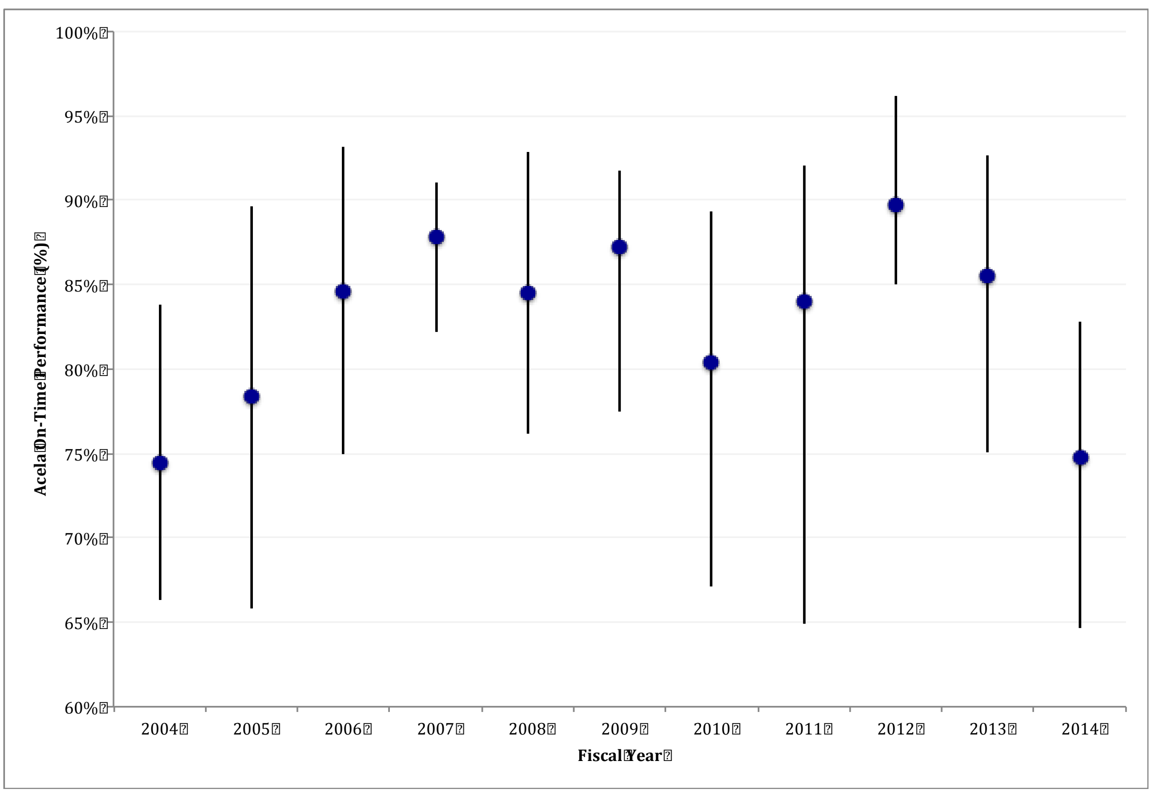

Figure 3.1: Acela FY 2004 to FY 2014 On-Time Performance

Figure 3.2 is similar to Figure 3.1 and shows the on-time performance for the Regional service between FY 2004 and FY 2014. The Regional service also experienced OTP improvements between FY 2010 and FY 2011, and a record high OTP of 88% in FY 2012, only 2 percentage points lower than the PRIIA standard. Following FY 2012, the on-time performance on the Regional service has been deteriorating.

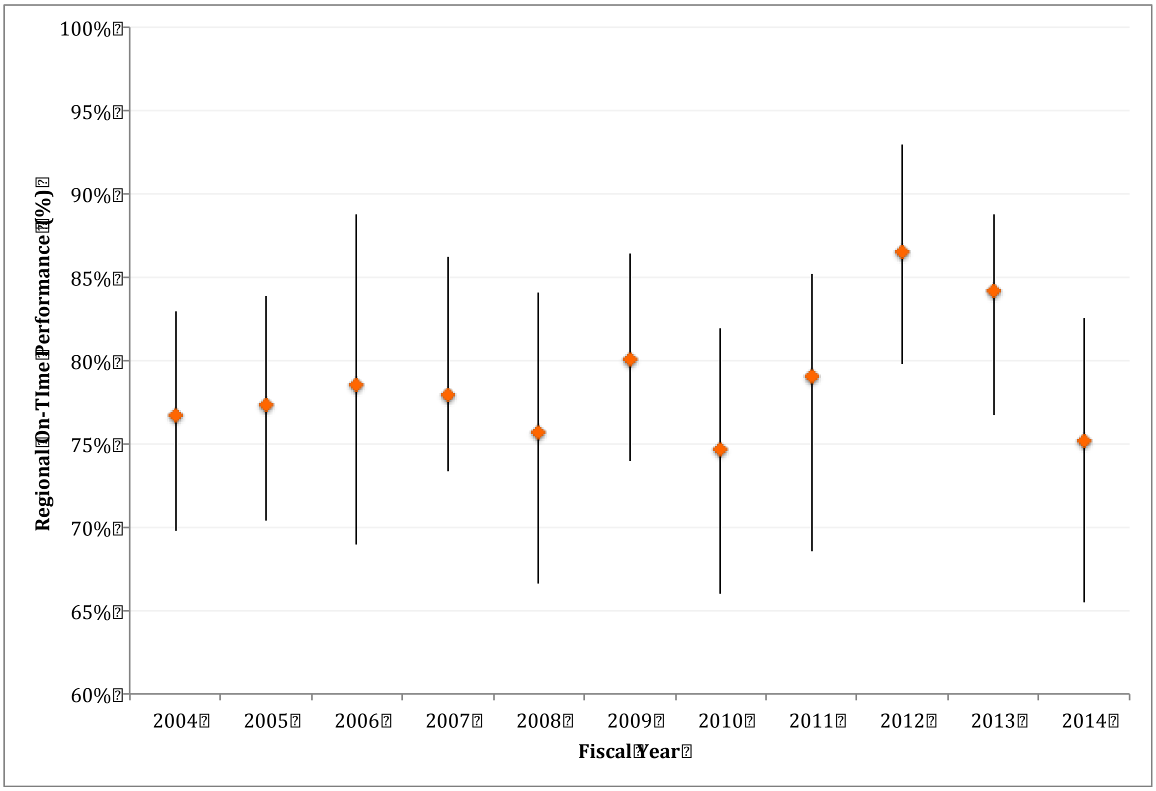

Figure 3.2: Regional FY 2004 to FY 2014 On-Time Performance

3.6 Current Status of PRIIA Section 207

On May 31st, 2012, the Association of American Railroads (AAR) filed a suit in the U.S. District Court for the District of Columbia – *Association of American Railroads (AAR) versus Department of Transportation, et. al., Civil Action 11-1499*. The AAR represents the railroad companies that host both Amtrak and freight trains around the U.S. They stated that it was “unconstitutional delegation of lawmaking and rulemaking permitting the FRA and Amtrak to jointly set the metrics and minimum standards for measuring Amtrak passenger train performance and service quality.” They argued that Amtrak was created by Congress to operate and be managed as a for-profit corporation that would benefit financially when host railroads were unable to meet the strict rules under PRIIA Section 207. On May 2012, the Federal District Court dismissed the charges ruling that Amtrak is a government entity whose top goal is to strengthen and improve intercity passenger rail in the U.S.

prior to any profit-making motives. The AAR appealed to the U.S. Court of Appeals for the D.C. Circuit (*Association of American Railroads v. U.S. Department of Transportation, et al., No. 12-5204*), and PRIIA Section 207 was eventually overturned on July 2, 2013. Amtrak is currently preparing a counter-suit alleging that the railroads have inadequate dispatching practices, and showing performance improvements while PRIIA section 207 was in place, and worsened performance since it was overturned.

3.7 General Discussion of PRIIA and Amtrak Performance Pre/Post PRIIA

Even though Amtrak owns most of the track in the Northeast Corridor, and Metro North Railroad (MNR) is the sole host railroad in the corridor, both Acela and Regional services experienced an unprecedented high in performance in FY 2011 and FY 2012 while PRIIA Section 207 was active. And surprisingly as shown in Figure 3.1 and Figure 3.2, the performance on both Acela and Regional services deteriorated since PRIIA Section 207 was overturned in FY 2013. This suggests that the existence of the metrics and standards were beneficial in improving Amtrak's performance and service quality even within the NEC. As part of this thesis, the performance of Acela and Regional will be discussed in detail, and a particular focus would be given to FY 2012 and FY 2014, which experienced the record best and worst in Amtrak performance in the last ten years.

The next chapter presents an overview and description of the data on historical ridership, operations, and performance provided by Amtrak, which were used for the analysis in this thesis.

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4 DESCRIPTION OF AMTRAK DATA

The purpose of this chapter is to describe the reporting procedure of the data provided by Amtrak, which were used in this thesis. Amtrak provided a detailed **demand database**, which included ridership, revenue and passenger-miles for a 10-year period dating from October 2004 to September 2014. They also provided a detailed **train operations database**, which included scheduled and actual running times for each scheduled Amtrak train between October 2004 and September 2014.

This Chapter describes the structure and level of detail in the demand and train operations databases received from Amtrak. **Section 4.1** describes the data that shows Amtrak ridership on the Acela and Regional and **Section 4.2** describes the data that shows the performance of each scheduled Acela and Regional train. Finally **Section 4.3** discusses how both datasets were combined for the purpose of analyzing and portraying various aspects of Acela and Regional service performances.

4.1 Overview of Ridership, Revenue and Passenger-miles Database

Amtrak's demand database includes the following columns:

i. Route Code
ii. Passenger Train Number
iii. Date
iv. Bi-directional Station Code
v. Class
vi. Trip Type
vii. Number of Passengers
viii. Total Revenue
ix. Passenger-miles

Descriptions of the data contained in these nine columns are discussed in the following subsections**.**

4.1.1 Route Code

The system of Amtrak trains is organized by routes; each route has a name and route code number. The routes indicate various travel options offered by Amtrak, and are differentiated by the U.S. region and markets they serve, as well as the train stopping patterns within the region/market. The two routes relevant to this thesis work are Route code 1, which is named Acela Express, and Route code 5 named Northeast Regional.

4.1.2 Passenger Train Number

All Amtrak trains are identified by a passenger train number that indicates its direction, the day(s) of the week it operates, and an associated train schedule in the timetable. Acela trains are given numbers between 2100 and 2299. The first two-digits give information about the day of week the Acela train operates on. Trains that begin with 21 are weekday trains operating Monday through Friday, while those beginning in 22 are weekend trains operating on Saturday and/or Sunday, as well as on public holidays that fall on weekdays. Northeast Regional (Regional) trains are given numbers between 100 and 199. However, Amtrak trains that serve the Northeast Corridor (NEC) but extend to markets outside the NEC (e.g. Vermonter, Pennsylvanian and Carolinian) have numbers under 100, and the Keystone trains that extend to Harrisburg, PA have numbers in the 600s. Note that for the Amtrak trains in the 100s and 600s, the ridership in the segments on the NEC mainline between Boston and Washington, DC are considered a part of the Regional service. Unlike the Acela train numbers, Regional train numbers are not formulated to give additional information indicating the day of week service pattern. Furthermore, the last digit of **all** Amtrak train numbers reveals the train direction. Northbound and eastbound trains end in even numbers, while southbound and westbound trains end in odd numbers. For example, one can tell that train 151 is a south-west bound train because it ends with a 1, while train 2228 is a north-east bound train because it ends with an 8. Although trains are actually defined as north-east bound or south-west bound, the convention in this thesis and generally in the Northeast corridor is to identify north-east bound trains as *northbound* trains, and the south-west bound trains as *southbound* trains.

Altogether, an Amtrak train number provides substantial information on the operating pattern of the train that is unique to the train and does not change over time. For example, train 151 is a Northeast Regional southbound train operating on Mondays through Fridays and corresponds to the train on the timetable scheduled to depart from New York Penn Station at 4:40am and terminate in Washington Union Station at 8:15am. Likewise, train 2228 is an Acela northbound train that operates only on Sundays, and corresponds with the train on the timetable scheduled to depart from Washington Union Station at 8pm and terminate in New York Penn Station at 10:55pm.

4.1.3 Class

The class represents the quality of seating and service, and gives an indication of ticket fares. The two class options available on Acela trains are First class (F) and Business class (B). First class is the highest class of service available on the Acela and offers an exclusive seating area and premium amenities, including spacious seating configurations, at-seat attendant service, at-seat meal and beverage service, etc. Business class is the minimum and general seating available on the Acela, featuring wide comfortable seats with moderate spacing configurations. Acela trains have one exclusive first class car with 44 seats, and four general business class cars with 65 seats each, summing to a total of 260 business class seats, and a train capacity of 304 seats. As expected, passengers pay a higher fare for first class seats than business class seats.

Alternatively, the two class options available on the Regional are Business (B) and Coach (C). Business class is the highest seating class available on the Regional, while Coach class is the minimum and more general seating. Regional trains usually have one dedicated business car, but sometimes Business class is just a dedicated seating area with limited seating capacity. Business class passengers pay a higher fare and receive complimentary soft drinks and a newspaper, in addition to the premium and more spacious seating configuration. There are various types of trainsets used to operate the Regional service, and they vary in the number of passenger cars (ranging from having 7 to 10 cars) and seating capacity (ranging from about 500 to 750 seats). Consequently, unlike the Acela that has a definitive capacity of 304 seats per train each day, the capacity on the Regional depends on the train equipment operated on different days.

4.1.4 Date

The date field indicates day, month and year. The dates can be aggregated into either Calendar year or Amtrak Fiscal year (FY). Unlike the calendar year that goes from January to December, Amtrak Fiscal years is the same as the Federal Fiscal year that starts in October of the prior year and end in September. For example, the 2014 Calendar year is from January 2014 to December 2014, while the Amtrak Fiscal Year 2014 (FY 2014) goes from October 2013 to September 2014.

4.1.5 Bi-directional Station Code

The bi-directional station code has the format XXX – YYY and it shows station pair ridership for each northbound and southbound Amtrak train. Each station code (XXX) is a unique three-letter code tied to a specific geographical location and used to identify each Amtrak station. The station pair code is 'bi-directional' because it does not distinguish the origin from the destination. For example, the BOS-NYP code represents the station pair for a passenger on a northbound train who boards in New York Penn (NYP) and alights in Boston (BOS), as well as for a passenger on a southbound train who boards in Boston (BOS) and alights in New York Penn (NYP). The bi-directional code is organized in alphabetical order, and therefore, continuing with the same example, would be presented as BOS-NYP (as opposed to NYP-BOS). Given the train number and direction, and the bi-directional code, one can decipher the actual origin and destination of each passenger.

Furthermore, in the Northeast Corridor, the bi-directional codes are typically grouped into one of three markets, depending on the origin and destination station – north-end, south-end and through markets. As the names imply, the north-end market includes station pairs with both the origin and destination north of New York Penn (NYP) e.g. BOS-NHV, on the other hand, if both origin and destination stations are south of NYP they are grouped in the south-end market e.g. BAL-WAS. The through market includes station pair with an origin North of NYP and a destination south of NYP, and vice versa e.g. BOS-WAS. It should be noted that the through trains serve both the north end (BOS-NYP) and south end (NYP-WAS) markets.

4.1.6 Trip/Ticket Type

There are two types of trips based on the Amtrak ticket structure in the Northeast Corridor – Single-Ride tickets (ST) and Multi-Ride tickets (MR). As the names imply, Single-Ride tickets can only be used once for a particular trip, while Multi-Ride tickets can be used to take multiple trips within a set amount of time using the same ticket. Multi-Ride tickets are not available on any Acela trains, and are available only for certain destinations and time of day on Regional trains. Thus, the majority of trips in the Northeast Corridor are on Single-Ride tickets.

4.1.7 Summary of Demand Database

Amtrak provided the detailed **demand database** from October 2004 to September 2014. The demand data shows station pair ridership, revenue and passenger-miles by route, as well as train number, date, class and trip type on all Acela and Regional train operated. The ridership column indicates the number of passengers who purchased a ticket for a given origin-destination pair, the revenue column indicates the total fare paid by all passengers, and the passenger-mile is a product of the number of passengers and the distance (in miles) between the origin and destination station.

4.2 Overview of Train Operations and Performance Database

This section discusses the **train operations database** showing scheduled and actual running times for each scheduled Acela and Regional train. For the Acela, Amtrak currently schedules 16 daily southbound trains; 10 through trains (BOS-WAS) and 6 south end only trains (NYP-WAS). All Acela trains serve New York Penn Station. As such, from an Amtrak customer's point of view, there are 10 Acela trains between BOS and NYP, and 16 Acela trains between NYP and WAS, since the through trains serve the south-end markets also. In the northbound direction, Amtrak currently schedules 17 Acela trains; 1 north end only train (NYP-BOS), 7 south end only trains (WAS-NYP), and 9 through trains (WAS-BOS). From an Amtrak customer's perspective, there are 10 northbound Acela trains serving the north-end market, 16 serving the south-end market, and 9 serving the through markets.

Service	Route	Market	Distance (miles)	Weekday Round Trips	Scheduled Travel Time (hr:min)
Acela	Boston - New York	North End	231	10	3:25 to 3.35
	New York - Washington	South End	226	16	2:44 to 2:50
	Boston - Washington	Through	457	9 to 10	6:30 to 6:40
Regional	Boston - New York	North End	231	9	4:00 to 4:20
	New York - Philadelphia	South End	91	33	1:20 to 1:25
	New York - Washington	South End	226	23	3:12 to 3:39
	Boston - Washington	Through	457	9	7:40 to 8:05

Table 4.1: Acela and Regional Scheduled Services

For the Northeast Regional, Amtrak currently schedules 63 to 64 trains between Mondays and Thursdays, 67 trains on Fridays, 51 trains on Saturdays, and 53 trains on Sundays (total trains in both directions). On a typical weekday there are 33 scheduled southbound trains; 9 through trains (BOS–WAS), 11 south-end only trains (NYP-WAS), 1 Carolinian train between NYP and WAS, 10 Keystone and Pennsylvanian trains between NYP and PHL, and 2 trains between SPG and WAS in both directions. Hence there are 9 Regional trains that serve the north-end market, 33 that serve the south-end market between NYP and PHL, 23 that serve the south-end market between NYP and WAS, and 9 that serve the through market.

Table 4.1 shows a summary of the Acela and Regional scheduled services. The scheduled travel times are provided as ranges to indicate that trains are sometimes scheduled with different end-to-end travel times based on the actual stopping patterns of the train.

Amtrak's **train operations database** indicates location, day and time information for each Amtrak train organized under the following columns – Train Number, Calendar Date, Location, Scheduled Departure Time, Actual Departure Time, Departure Performance in minutes, Scheduled Arrival Time, Actual Arrival Time, Arrival Performance in minutes, Scheduled Dwell in minutes, and Actual Dwell in minutes.

The Train Number corresponds to the train numbers described in Section 4.1. Amtrak train numbers are used to identify passenger trains and are typically associated with a unique timetable schedule. Amtrak's published timetable shows the Scheduled Departure Time from and Scheduled Arrival Time at each consecutive station along a train route. The scheduled times reflect either Amtrak's published or temporary adjusted timetables. On occasion, due to major renovation, track work, or other major time-impeding projects, Amtrak will release an adjusted timetable for a specified period of days. Amtrak does this as a means of factoring in additional time incurred due to major track-related projects, and also to inform Amtrak passengers to plan for the modified schedules and additional travel time. The adjusted timetables are usually pre-released, publicized, and given with advanced notice, thus real time or en-route travel time changes are not considered here. The provided data also includes a Scheduled Dwell Time in minutes, which is scheduled terminal time at certain stations to ensure enough time for passengers to board and alight at large stations, as well as for occasional train checks and safety measures. Next, as the names imply, the Actual Departure Time indicates the time each train actually departed from each station, and the Actual Arrival Time provides the same level of information in terms of arrivals at stations for each operated train. All departure and arrival time information in the database are given with to-the-minute-precision (e.g. 2:24PM as opposed to 2:24:30PM). Finally, two performance indicators are provided in the database - the Departure Performance in minutes and the Arrival Performance in minutes, which both calculate the difference between actual and scheduled departure and arrival times, respectively.

In addition to the performance indicators provided in the train operations database, On-Time Performance and Total Delay minutes were calculated. The On-Time Performance (OTP) evaluates the percentage of trains that achieve an 'on-time' target at the final destination compared to the total number of trains in service that day. Under PRIIA regulations (see Chapter 3), an Acela train is considered 'on-time' if it arrives at its endpoint terminal within 10 minutes of the scheduled arrival time, while a Regional train is considered 'on-time' if it arrives within 10 minutes for north-end and south-end only trains, and 20 minutes for through trains. In this thesis Amtrak's current on-time performance standard is referred to as Amtrak OTP, and is distinguished from the Pure OTP, which refers to a performance standard that categorizes a late train as one that arrives later than the scheduled arrival time. In other words, the Pure OTP is a no-tolerance delay metric while the Amtrak OTP is a 10 to 20-minute delay tolerance metric. Thus, the Pure OTP provides an objective perspective on the on-time metric. The Total Delay minutes measures the difference between the scheduled and actual arrival at the endpoint terminal (final station). Altogether, Amtrak's scheduled and operated train database is valuable for characterizing Amtrak performance in the Northeast Corridor.

4.3 Combining the ridership and performance databases

For the analysis in this thesis, the train performance data was joined to the *station pair* ridership data for each train operated in the last 10 years. The combined data was then aggregated to show total ridership, total number of operated trains, total minutes of delay, total number of delayed trains under the Pure 'on-time' metric (0 minutes threshold), total number of delayed trains under Amtrak's 'on-time' metric (10 - 25 minutes threshold), OTP (Pure and Amtrak), and the total number of passengers on delayed trains (Pure and Amtrak) for each day over the last 10 years. The daily data was further aggregated into a monthly database. The station pair combined data was also aggregated into a similar train level summary for each month between FY 2005 and FY 2014. In addition, station level arrival and departure train performance data were collated over the course of a year for certain trains. The station level granularity of the data provided location-specific trends in Amtrak delays on the NEC, based on the stations where the delay started and how the delay propagated through subsequent stations on the corridor.

The discussion in Chapter 5 (focus on Acela) and Chapter 6 (focus on Northeast Regional) were based on analysis of the newly generated combined data sets. The data analysis was used to identify the days and trains on which delays were incurred, which are useful in separating systematic trends from the random components in the delays. Some of the interesting questions regarding service performance of Amtrak trains in the Northeast Corridor discussed in Chapter 5 and Chapter 6 include: What percentage of scheduled Amtrak trains and passengers experience delays? Are some trains more susceptible to service disruptions? Are there characteristic times of day, days of week, and months of year when most delays are encountered? Are there certain stations that experience more delays? etc. Another interesting analysis highlighted in Chapter 5 and 6 is on quantifying and evaluating the impact of a wide spectrum of service disruptions, ranging from catenary wire issues to severe weather conditions. These questions and considerations are important because they provide an assessment of how Acela and Regional services have performed in the last 10 years, and might shed light on major causes of delays and inform the discussion on prescriptive measures to mitigate any systematic components of service disruptions.

NOTE: The analyses in the following sections are only as good as the data used to analyze them. The author cleaned the dataset prior to analyzing; however, there were a few minor outstanding issues in the datasets. The main issue with the data relates to data coding. In the train operations database for example, there are some stations with missing information suggesting that the train either did not make a stop at the station or that the train personnel failed to record the actual arrival and departure times of the train on the given day. This affects the analysis because the missing records are sometimes represented as a train with zero delays, which is incorrect. Another example from the ridership database relates to the coding of riders on a train that was cancelled. There are a few times when ridership details are included in the demand data for a train coded as cancelled in the train operations database. While the entire datasets are not filled with these types of errors, they are present and do slightly impact the analysis shown. That said, because most of the analysis are presented as aggregates or averages over multiple days, they are less biased by single errors.

The next chapter presents and discusses on Acela ridership and service performance and their impacts on the distribution of delay.

5 ACELA RIDERSHIP AND SERVICE PERFORMANCE

The chapter examines factors that lead to ridership and service performance fluctuations on the Amtrak's Acela service.

Travel time distribution is a measure of day-to-day fluctuations in demand and service performance. The key factors causing demand and service performance variations discussed in this chapter are shown in Figure 5.1. The demand fluctuations are captured under four main categories: i) seasonality and month of year, ii) day of week, and time of day, iii) demand fluctuations due to capacity levels on the trains, and iv) demand variations in response to travel information and service quality. The service performance variations are captured under six main categories: i) seasonality and month of year variations, ii) day of week, and time of day differences, iii) service performance fluctuations due to capacity levels on trains, iv) service disruptions due to accidents and incidents (e.g. signal failures, weather related, track work, etc.), v) disturbances due to interference from other trains, and vi) performance variations due to administration, management and control elements. Each of these factors will be further discussed in the rest of this chapter. The double directional arrow connecting demand and service performance fluctuations reflects how ridership fluctuations could theoretically cause service performance fluctuations, and vice versa. For example, high demand during peak hour could lead to additional delays on the train as a result of the large number of people in the system.

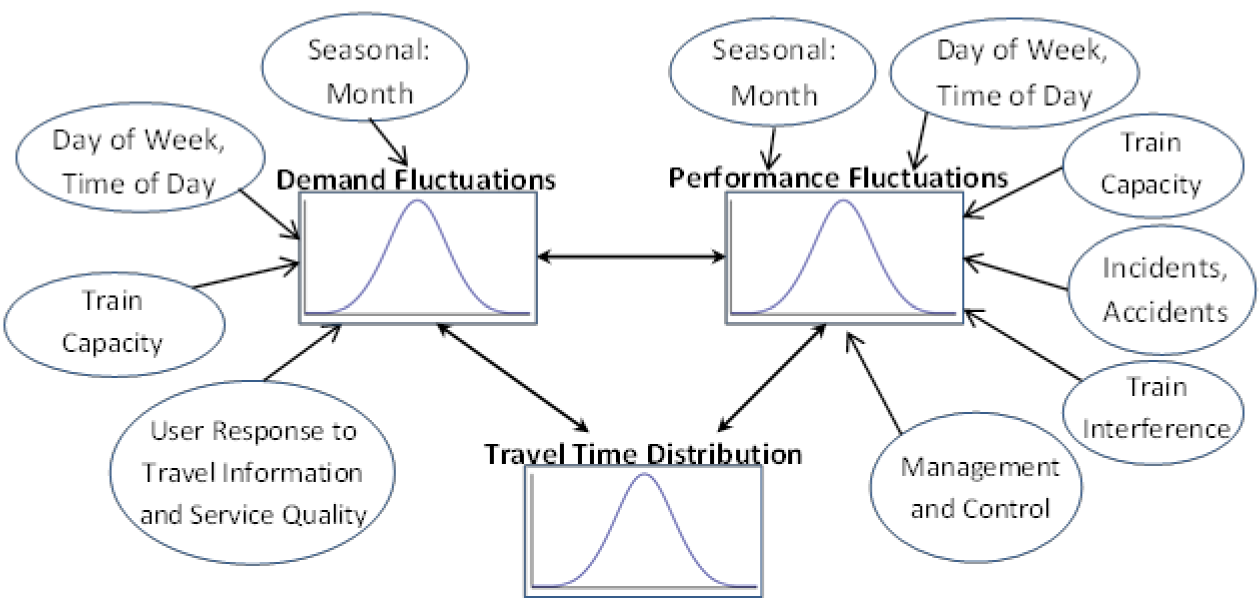

Figure 5.1: Factors Affecting Travel Time Distribution on the Acela service

The rest of this chapter is organized as follows. **Section 5.1** presents some performance metrics that characterize the travel time variability on the Acela service. Specifically, it shows the distribution of actual delays on Acela trains, and examines the relationship between delays and on-time performance. This section will directly answer the question about what metrics are useful in characterizing service performance. **Section 5.2** shows the annual and monthly fluctuations in Acela ridership and service performance between FY 2005 to FY 2014. **Section 5.3** drills further down into day of week and time of day variations in Acela ridership and service performance, and highlights any relationships between them. This section will directly answer the question about whether poor performance leads to even poorer performance. **Section 5.4** is on the First Train Analysis, which quantifies the effect of management and controls on service quality. It examines the delays on the first train of the day as a proxy of Amtrak train operator's culture and principle, as well as any inherent effects of Acela train timetables. **Section 5.5** investigates service disruptions caused by trains interfering with one another and how poor performance can cascade. **Section 5.6** focuses on service performance fluctuations due to accidents and incidents (e.g. signal failures, weather related, track work, etc.), and includes their effects on delays and train cancellations. **Section 5.7** analyzes the capacity on Acela trains between FY 2005 and FY 2014, which has the potential to affect both demand and supply variations. **Section 5.8** presents a preview of the impact of Acela rider's responses to service quality. Finally, **Section 5.9** concludes the chapter with a summary of the prior sections, and a discussion about what causes poor performance.

5.1 Performance Metrics Characterizing Travel Time Variability

Amtrak uses two performance metrics to quantify service performance – delay minutes and on-time performance (OTP) – however both metrics capture different aspects of performance. While the delay minutes reveal the **magnitude** of delay, the OTP indicates the **frequency** of good performance. Both metrics are discussed and compared in this section. The total end-to-end delay measures the difference between actual and scheduled travel times on Acela trains. The distribution of delays characterizes travel time variability, and indicates the degree to which actual end-to-end travel times deviate from the scheduled travel times. The OTP measures the percentage of trains that meet a certain 'on-time' standard, and indicates how often Acela trains attain the set standards. Both metrics highlight different perspectives of service performance but do each of them capture a substantive indication of service performance? This section shows the distribution of actual delays on Acela trains, and also examines the relationship between the delay minutes and on-time performance metrics.

5.1.1 Distribution of delay

Figure 5.2 shows the distribution of end-to-end delays encountered on the 9,604 Acela trains operated in FY 2014. Negative delay values (<0 minutes) represent arrivals that occur before the scheduled arrival times, while delay values equal to zero represent on-time train arrivals. Positive delays (>0 minutes) indicate trains that arrived after the scheduled arrival time. In FY 2014, delays encountered on Acela trains ranged from 1 minute to >100 minutes. The Unknown delay category represents train arrival records that are missing from the dataset either because the train was cancelled or the data was not recorded by the Amtrak crew (cancelled trains would be discussed in section 5.6.2). The delay distribution peaks at the zero-delay value and has a long right tail, representing a large proportion of Acela trains that arrive late. In FY 2014, 42% of Acela trains arrived earlier than or at the scheduled arrival time, and 58% of all scheduled Acela trains arrived at their final destination later than the scheduled arrival time. However, Amtrak's 'on-time' threshold for Acela trains currently includes trains that arrive within 10 minutes of the scheduled time. Under this classification, an additional 29% of FY 2014 trains would be categorized as 'on-time' as they arrived equal to or less than 10 minute late. Altogether, 71% of Acela trains arrived within 10 minutes of the scheduled arrival time, and 29% arrived more than 10 minutes late. The annual average OTP for FY 2014 was about 75%, and as one would expect it gives a rough indication of the delay distribution given the 'on-time' definition.

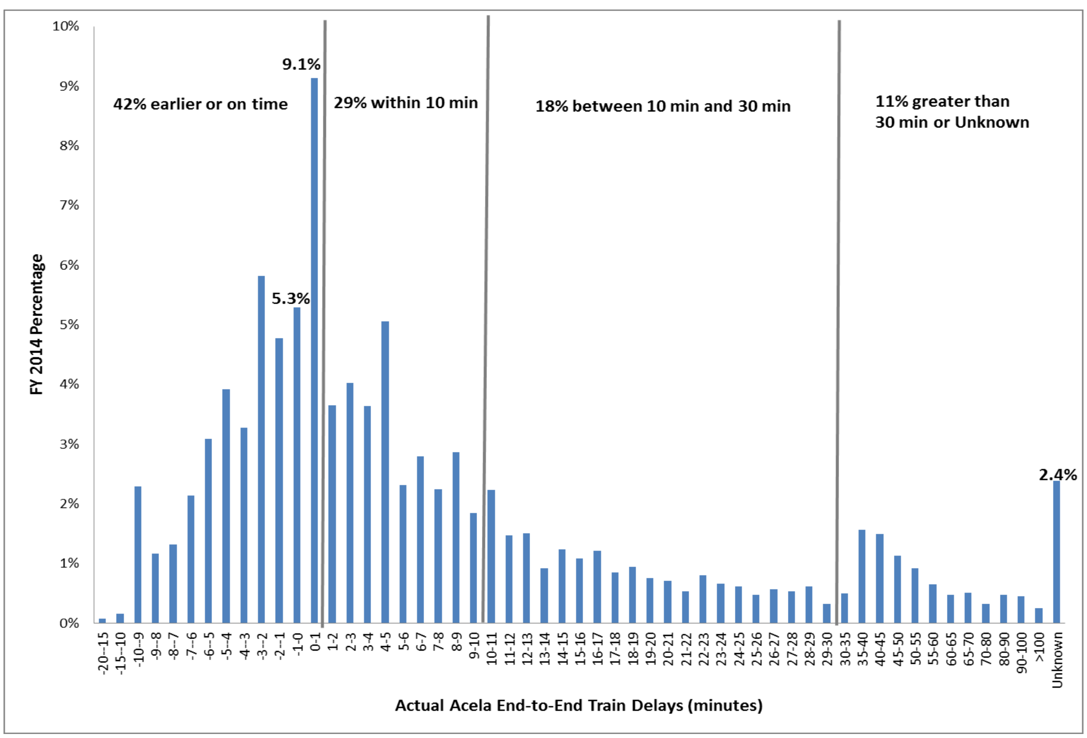

Figure 5.2: Distribution of Actual End-to-End Acela Train Delays

5.1.2 On-Time Performance and Delay Metrics

This section examines the relationship between the delay and on-time performance metrics, and measures the correlation between them. Figure 5.3 shows the relationship between the monthly on-time performance and average delay per train metric for Acela between FY 2005 and FY 2014. The blue and red data points distinguish between Pure OTP and Amtrak OTP. Pure OTP refers to a performance standard that categorizes a late train as one that arrives later than the scheduled arrival time, while Amtrak OTP refers to Amtrak's current performance standard that defines a late Acela train as one that arrives more than 10 minutes after the scheduled arrival time. In other words, the Pure OTP is a no-tolerance delay metric while the Amtrak OTP is a 10-minute delay tolerance metric. Although the difference between the Pure OTP and Amtrak OTP ranged from 16% to 34% between FY 2005 and FY 2014, the average, median and mode of the difference was about 29%. This suggests that while the Amtrak OTP metric is biased to portray a better service performance, the Pure OTP metric (zero-delay tolerance) for Acela can be quickly approximated as 29% lower.

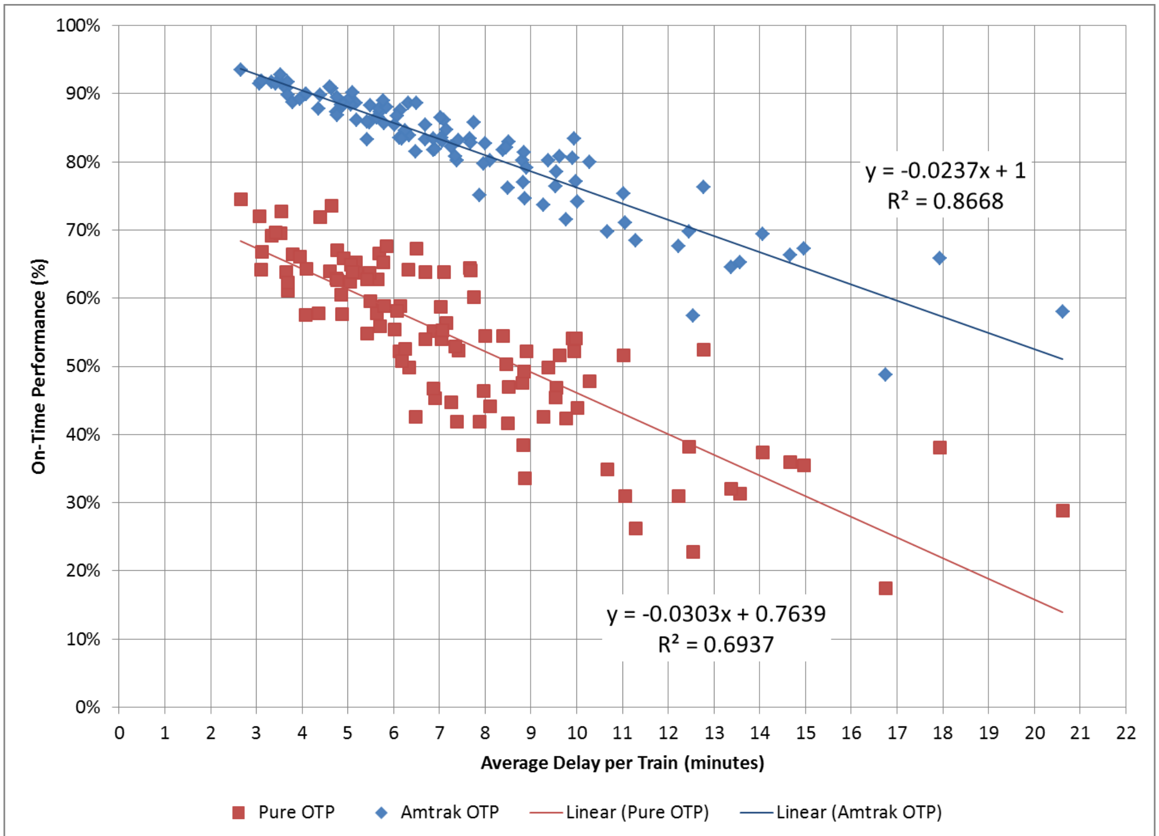

Figure 5.3: On-Time Performance versus Average Delay/Train

Furthermore, the simple regression shows a linear relationship between OTP and average delay per train, and includes the linear trend line and correlation factor. The correlation factor (R^2) between on-time performance (both Pure and Amtrak OTP) and average delay minutes per train is greater than or roughly equal to 70%. Although this correlation is not perfect (equal to 1), it is sufficiently high to propose that the two service quality indicators (on-time performance and delay) are related and can be substituted for one another if needed.

In summary, both on-time performance and average delay are useful in characterizing service performance, and in addition because they are correlated, thus can serve as substitutes for one another in characterizing service performance.

5.2 Acela Annual and Monthly Ridership, On-time Performance and Delays

There is a vast amount of valuable information that can be gleaned from analyzing Acela ridership and operations data over an extended period of time. However, prior to assessing any impacts on Acela ridership, it is important to evaluate annual trends and to account for certain systematic variations such as those introduced by seasonal and holiday factors, as well as one-time shocks or trends produced by economic factors. This section shows the annual and monthly fluctuations in Acela ridership and service performance between FY 2005 to FY 2014.

5.2.1 Annual Ridership

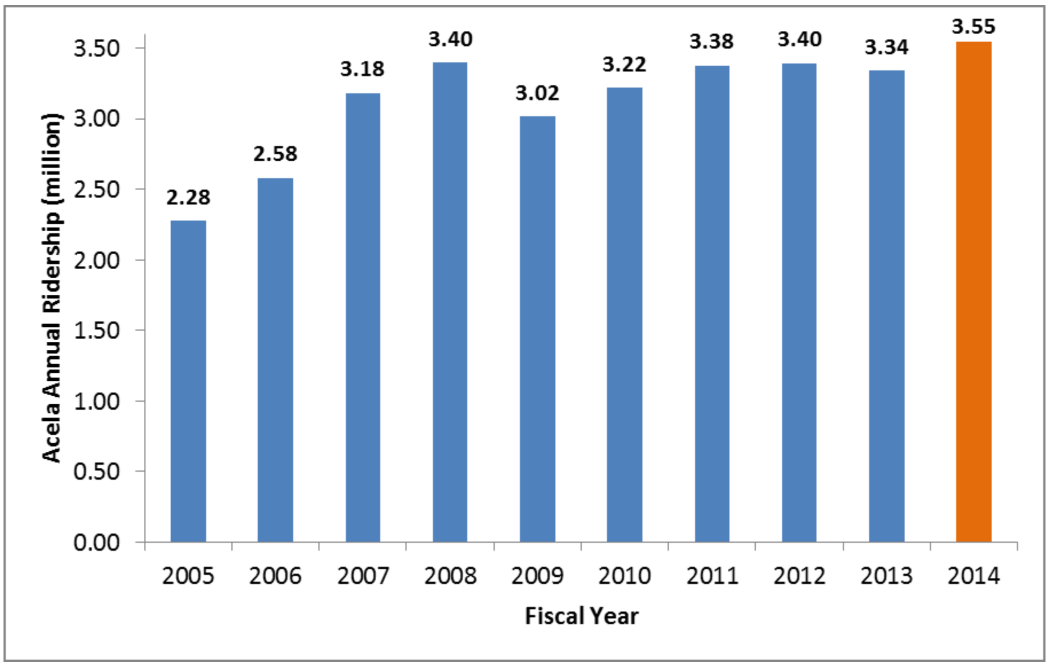

Figure 5.4: Acela Annual Ridership

Figure 5.4 shows the total Acela ridership between FY 2005 and FY 2014, highlighting the year-to-year variations. It shows a steady increase in total Acela ridership from 2.28 million to 3.40 million between FY 2005 and FY 2008. The year-over-year ridership growth rate was 13% between FY 2005 and FY 2006, 23% between FY 2006 and FY 2007, and 7% between FY 2007 and FY 2008. Adverse effects of the economic recession that lasted through 2008 and 2009 were likely responsible for the 11% drop in total Acela ridership to 3 million in FY 2009. The ridership increased again at a lower year-over-year growth rate between FY 2009 and FY 2014, and Acela experienced a record high of 3.5 million riders in FY 2014. However compared to FY 2008, the FY 2014 growths are modest. The variation in monthly ridership within each year is explored below.

5.2.2 Ridership by Month

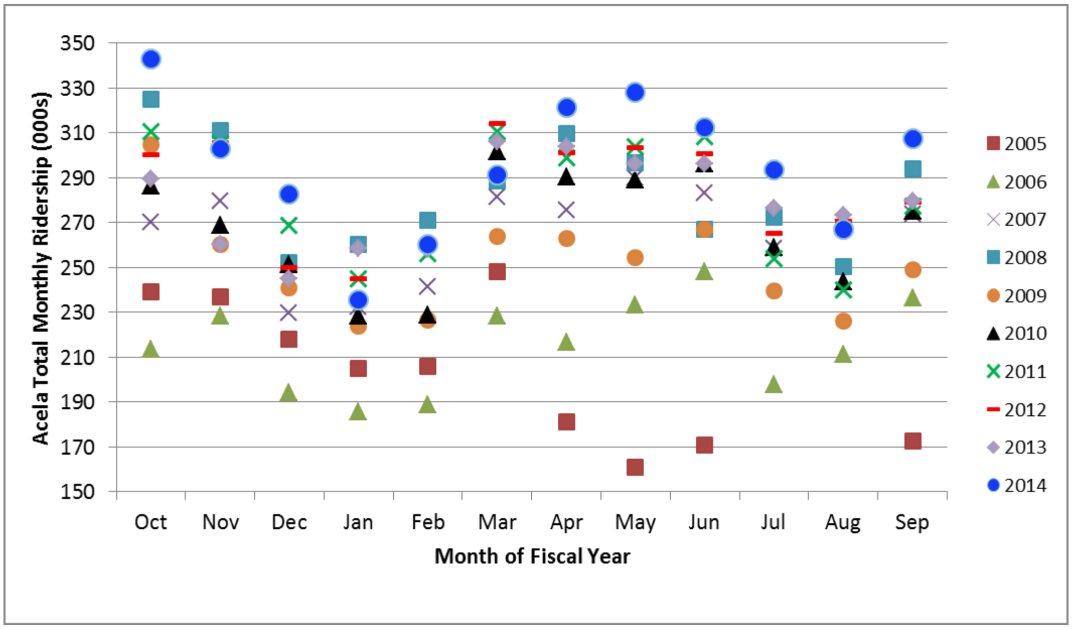

Figure 5.5: Acela Monthly Ridership FY 2005 to FY 2014

The seasons and holidays influence travel patterns and in turn, the monthly demand for Amtrak's Acela service. Figure 5.5 shows the total Acela ridership aggregated by month from FY 2005 to FY 2014. It compares total Acela ridership for a particular month from 2005 to 2014. The months with the highest ridership are in the fall months at the beginning of the fiscal year, overlapping with the start of the school year and New England's foliage season, and also during the spring months. Conversely, January and August typically have the lowest ridership likely due to vacation during the winter and summer holidays. It is important to note that the monthly ridership characteristics are not only due to seasonal trends but also include the effect of other external factors such as service performance, gas prices, economic indicators, unemployment rate, changes air fare, changes in Amtrak fares, etc.

5.2.3 On-Time Performance by Month

Amtrak monthly on-time performance (OTP) from one year to another reveals some inherent seasonal patterns as well. Figure 5.6 shows Acela on-time performance by month for FY 2005 to FY 2014 under the 10-minute delay tolerance standard. Unsurprisingly, the service performances in the winter months were largely dependent on the severity of the weather. One of the first noticeable features of the historical on-time performance is that the winter months - December, January, February and March had some extreme figures. For example, the Acela OTP in December and January FY 2005 (red squares) were as low as 57%, likely due to the impact of a severe winter. Quite surprisingly, the data shows that, the best service performances also occurred in the winter months (December, January, February and March), likely during mild winter conditions. The worst Acela service performances occurred in the summer months (June, July and August).

In terms of the year-over-year OTP variations for a given month, May and October (excluding the extreme figures in FY 2005) exhibited the least variance in year-over-year OTP, ranging from about 78% to 90% each year. Furthermore, comparing across years, the OTP in FY 2012 (red dashes) and FY 2007 (purple X's) were the highest, while the OTP in FY 2005 (red squares) and FY 2014 (blue dots) were the lowest. In FY 2014 the OTP for Acela was relatively one of the worst each month over the last 10 years – Acela experienced OTP as low as 65% in February and the highest OTP in FY 2014 was 81% in April. Conversely, the Acela performance in FY 2012 was one of the best each month between FY 2005 and FY 2014. It is also interesting to note that in the last 10 years, the OTP in May was never below 80% likely because of the favorable spring weather and minimal scheduled track work while the OTP in July was never above 86%, likely due to the larger amount of scheduled routine track work in the summer.

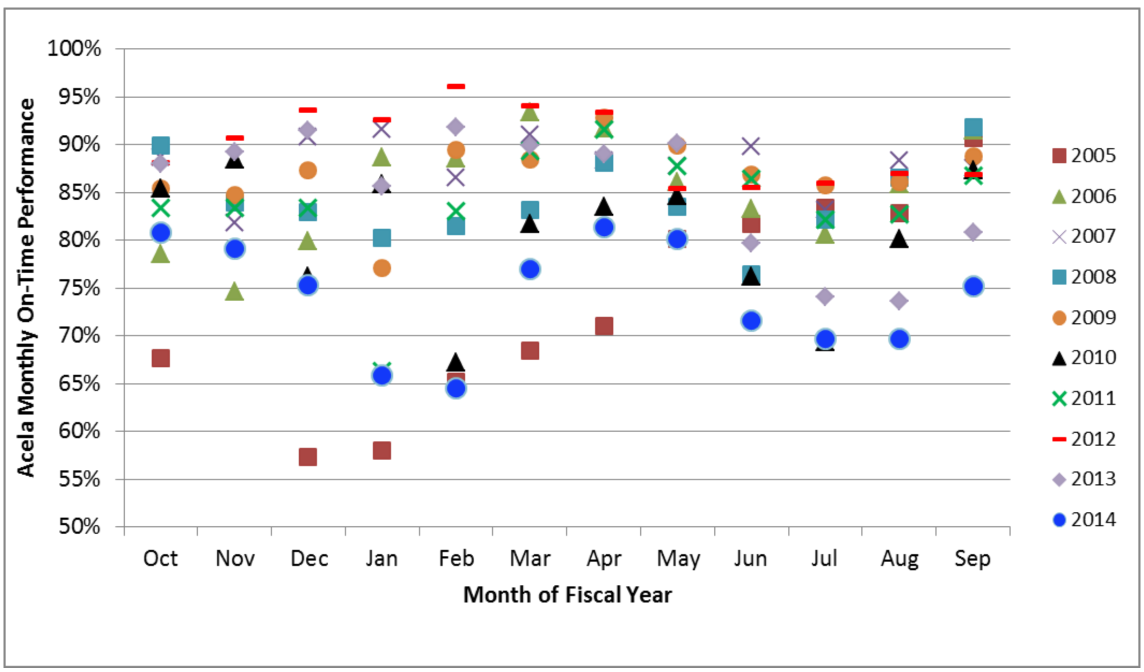

Figure 5.6: Monthly Acela On-Time Performance

5.2.4 Total Minutes of Delay by Month

Figure 5.7 shows total monthly delay for FY 2005 to FY 2014. The Acela delay shows characteristically similar trends but of course in reverse compared to the OTP. That is, months with high OTP show low total delay, and vice versa. Similar to the OTP trends, the winter months of January, February, and March historically experienced a wide variation in the total amount of delay (assuming the FY 2005 extreme figures in October and November are ignored). For example, Acela incurred about 15,000 minutes of total delay in January 2005 but only a total of 2,000 delay minutes in January 2012. Similar to the OTP data, the year-to-year variation of total monthly delay in October, November and May was relatively low, ranging from about 3,000 and 7,000 total delay minutes (again assuming the FY 2005 extreme figures in October and November are ignored).

Overall, the total monthly delay in FY 2012 (red dashes) and FY 2007 (purple X's) were the lowest (that is best performance-wise), while the total monthly delay in FY 2005 (red squares) and FY 2014 (blue dots), were the highest (that is worst performance-wise). The total monthly delay for Acela in FY 2014 was one of the highest with delays ranging from 6,100 in September to 12,000 minutes in January. In the last 10 years, the worst delay experienced on Acela was in January FY 2005; the second worst was in January 2014. On the other hand, the best Acela performance was in February 2012 and the second best were in March 2006 and March 2012.

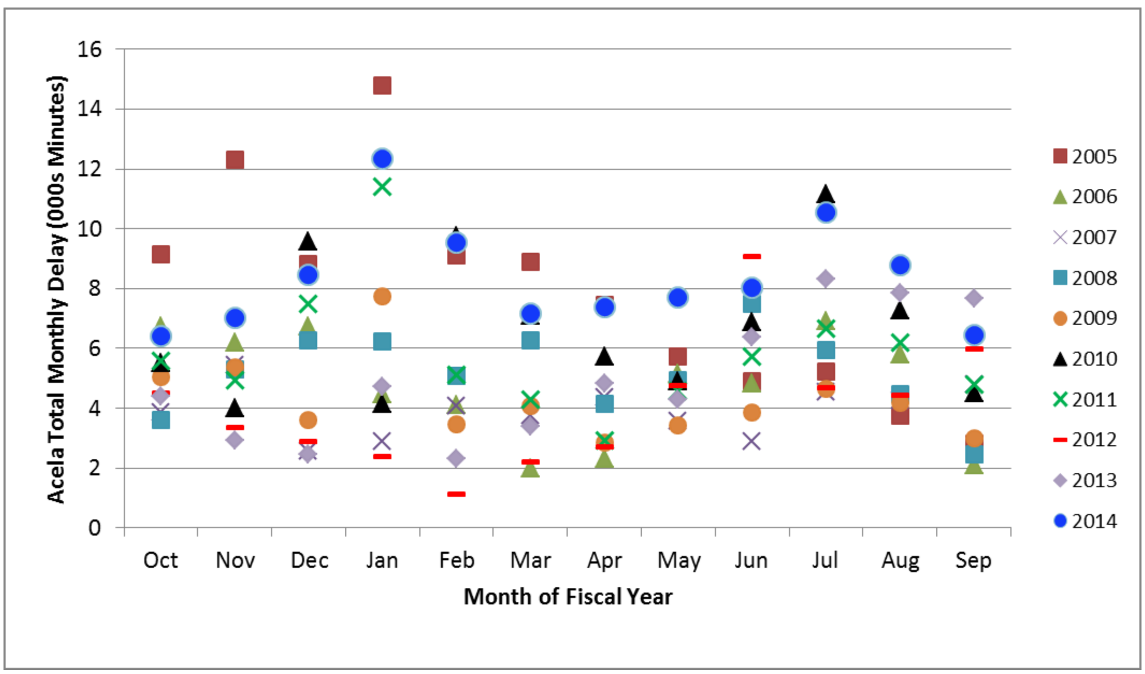

Figure 5.7: Total Monthly Delay

5.2.5 Monthly Ridership versus Monthly Delay

Figure 5.8 shows total monthly ridership (blue) and total monthly delay (orange) for Acela trains between FY 2005 and FY 2014. The vertical gridlines indicate the beginning of a fiscal year. The correlation coefficient (R^2) measures the strength and direction of the linear relationship between ridership and delay each month within each fiscal year. Correlation coefficients close to zero indicate a weak linear relationship between the ridership and delay in the same month, while correlations coefficients equal to 1 represent a perfect linear relationship between both variables. Additionally, negative R^2 values denote an inverse linear relationship between the demand and delay, and suggest that months with high demand are associated with low delays, and vice versa. The fiscal years with negative R^2 values are highlighted in red. For example, in FY 2014, the correlations coefficients was equal to -0.79, revealing a substantial correlation between low ridership volumes and high delays in months like January, and high ridership volumes and low levels of delay in months like May. It is important to note that these are not cause-effect relationships but are simply observations from the data. The fiscal years with positive R^2 values are highlighted in black –excluding FY 2005 (for same reasons as noted above), the R^2 values were all less than 0.5, indicating weak linear trends between high ridership and high levels of delay in the same month. Considering all, having more people in the system was sometimes associated with poor service performance.

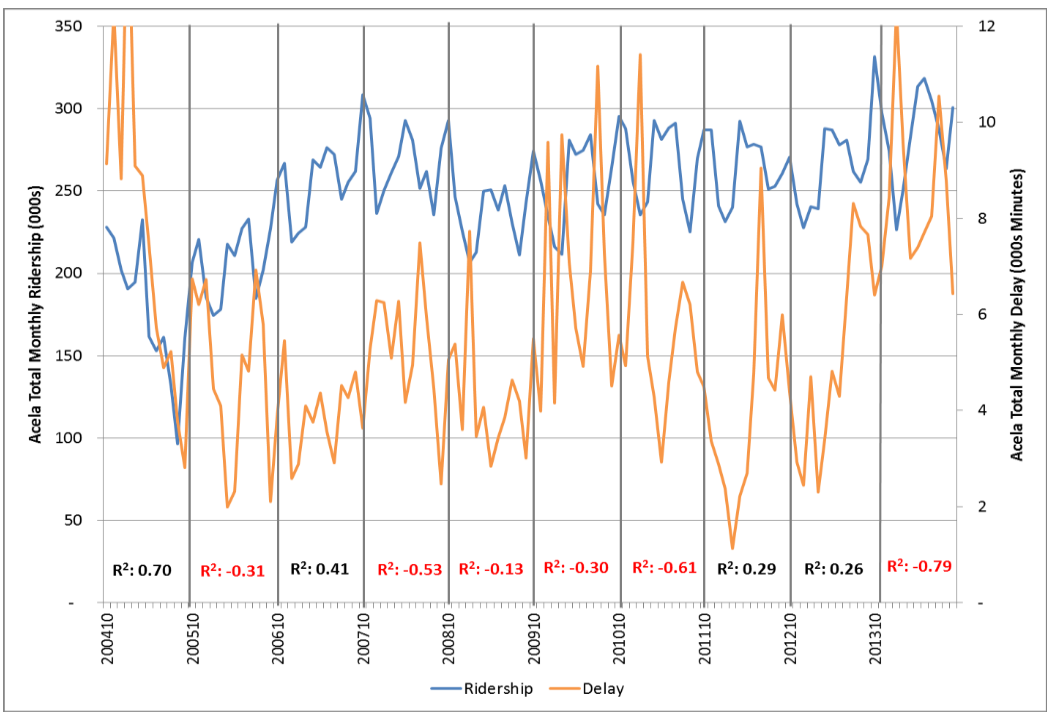

Figure 5.8: Monthly Ridership versus Total Delay

In summary,

i. In FY 2014 Acela service experienced a record high of 3.55 million riders

ii. The months with the highest Acela ridership are in the fall months at the beginning of the fiscal year, overlapping with the start of the school year and New England's foliage season, and also during the spring months. Conversely, January and August typically have the lowest ridership likely due to vacation during the winter and summer holidays.

iii. Similar to the ridership, the performance on the Acela service varied within the same month in different years. Compared to summer months, the winter months exhibited a large variance due to the effects of mild and severe winter seasons on performance. Nonetheless, the best on-time performances were usually in the winter months.

iv. Additionally, the performance on the Acela service varied across different months in the same fiscal year. Although the summer months exhibited less year-to-year variance, on a month-to-month comparison (excluding the severe winter months), the amount of delays were usually higher in the summer, and especially in July due to routinely scheduled track works, heat restrictions and infrastructures issues (catenary wire drooping). October and May exhibited the least year-to-year variance likely because of the favorable weather (fall and spring) and minimal scheduled track work.

v. Between FY 2005 and FY 2014, the best Acela performance was in FY 2012 while the worst performance was in FY 2014.

vi. The ridership to performance correlations suggests that having more people in the system was sometimes associated with poor service performance.

5.3 Daily Variations in Performance and Ridership

The travel time distribution on Acela trains is impacted by the day-to-day fluctuations on both the demand side and the supply side. On the demand side, the number of daily riders can be expected to vary by day of week (especially weekday versus weekend) and time of day (especially peak hours versus off-peak hours). On the supply side, there might also be systematic variations in the levels of delay and on-time performance by day of week and time of day. On any given day, on one hand, high demand might be associated with days with low levels of delays because riders choose to make trips on days with low delays based on past experiences, but on the other hand, high demand might lead to higher levels of delay because there are too many riders in the system. In reality, the Amtrak system probably experiences some level of both of these trends.

The analysis in this section focuses on the fiscal years with the best and worst performance. This is because unlike the monthly data, which can effectively be condensed into meaningful charts and discussions, the sheer amount data points contained in all days between FY 2005 and FY 2014 does not afford the same luxury. Furthermore, the systematic portion of daily trends can be understood from analyzing the averaged over all the days in any one given year. Regarding the use of the years on both extremes of service performance, the daily trends that are influenced by service performance can be captured by analyzing both extremes and assuming that the intermediate years lie somewhere in-between. From the earlier discussion, the overall Acela performance appeared to be the best in FY 2012 and the worst in FY 2014. Using the daily on-time performance, total delay and ridership values in FY 2012 and FY 2014, this section further explores and compares the distribution of end-to-end delays encountered on Acela trains.

The section begins by presenting the number of daily delayed trains and daily delayed riders on the Acela in FY 2012 and FY 2014. It then drills further down into day of week and time of day variation in ridership and service performance in both years, and highlights any relationships between them.

5.3.1 FY 2012 and FY 2014 Daily Delays: Trains

Figure 5.9 and Figure 5.10 show daily Acela scheduled and delayed trains in FY 2012 and FY 2014, respectively. The gray area shows the total number of scheduled trains. In FY 2012, there were 32 scheduled Acela weekday (Monday to Friday) trains while in FY 2014, there were 33 scheduled weekday trains. In both years, there were 9 Acela trains scheduled on Saturdays and 19 Acela trains on Sundays. The lower weekend schedules are portrayed in both figures as spaces between the high weekday peaks. Furthermore, there are usually fewer trains scheduled during the winter holiday between the weeks including December 25th and January 1st. Finally, the spike in both figures occurs on the days before Thanksgiving on which Amtrak typically schedules additional trains.

The blue area represents the total number of trains that arrived at their final destination with a delay greater than 0 minutes. In FY 2012, about 35% of all scheduled trains arrived at their final destination after the scheduled arrival time, while in FY 2014, about 56% of all scheduled trains arrived at their final destination after the scheduled arrival time. In other words, of the 32 scheduled daily weekday trains in FY 2012, about 11 on average were routinely late, and of the 33 scheduled trains in FY 2014, on average 18 trains were routinely late.

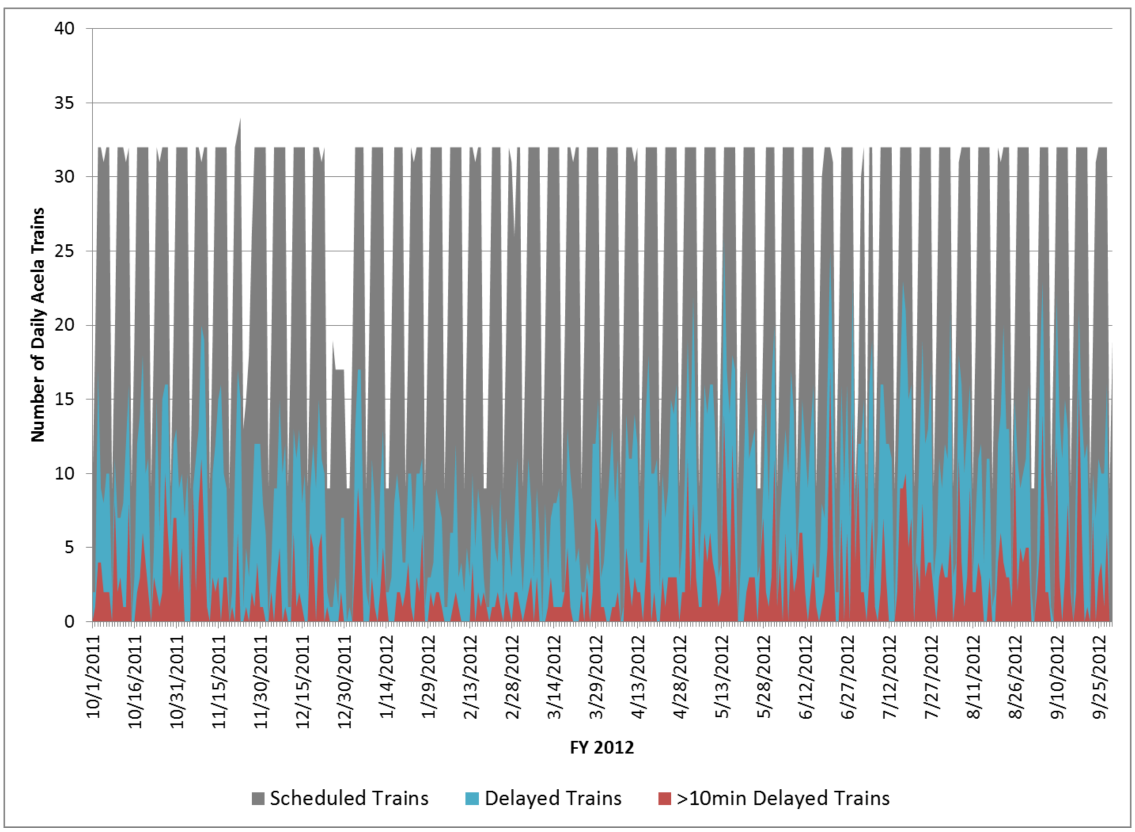

Figure 5.9 FY 2012 Scheduled and Delayed Acela Trains

Given Amtrak's 10-minute 'on-time' threshold, the red area represents the number of "late" trains by Amtrak's standards. In FY 2012, roughly 10% of trains (on average 3 of 32) and in FY 2014, roughly 26% of trains (on average 8 of 33) experienced delays greater than 10 minutes.

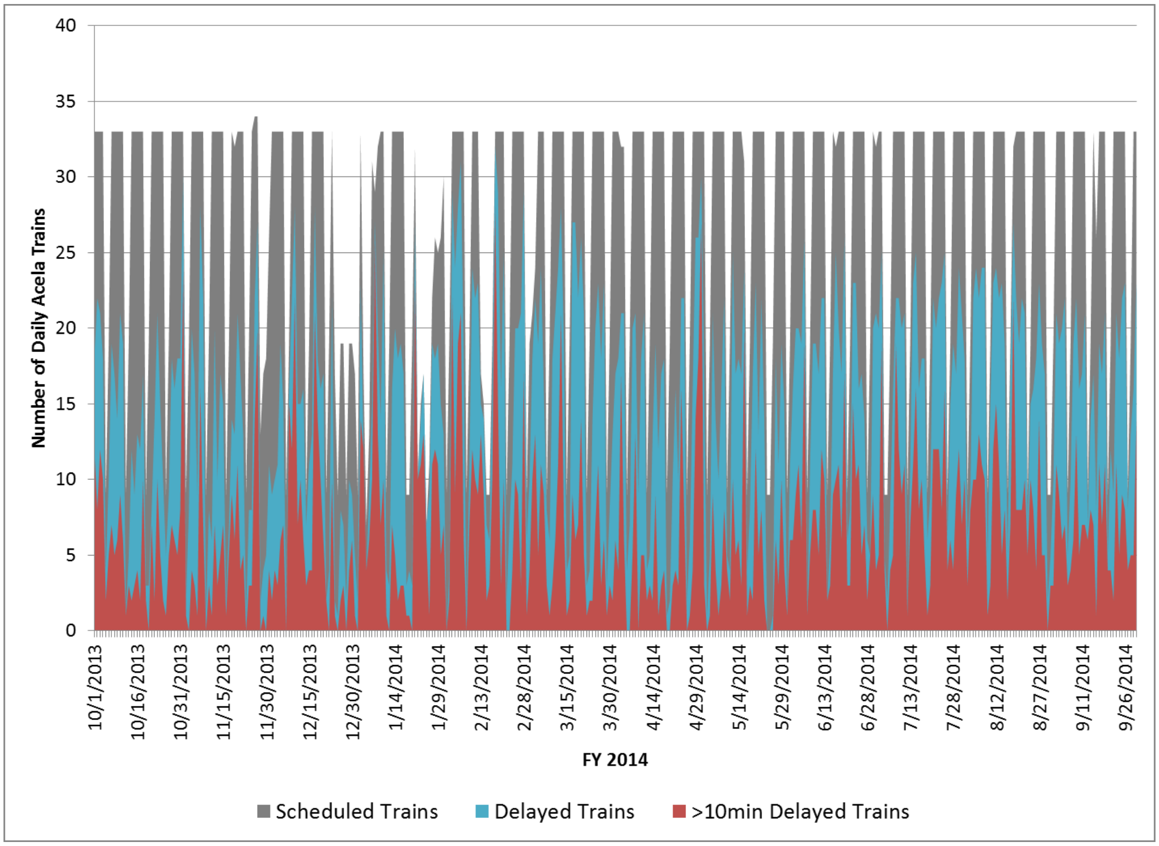

Figure 5.10: FY 2014 Scheduled and Delayed Acela Trains

5.3.2 FY 2012 and FY 2014 Daily Delays: Riders

Figure 5.11 and Figure 5.12 show the total number of daily and delayed Acela riders in FY 2012 and FY 2014, respectively. The gray area corresponds with the total number of daily riders. Firstly, the high weekday ridership trends versus the low weekend ridership are depicted as high peaks and the spaces between the high peaks. In both years, the lowest Acela ridership occurred on the days between Christmas and the New Year, which corresponds to the days with fewer scheduled Acela trains (as shown in Figure 5.9). Comparing Figure 5.11 and Figure 5.12, the gray regions also highlight the growth in ridership between FY 2012 and FY 2014. While in FY 2012, the daily ridership exceeded 12,000 on a few days, in FY 2014, it regularly exceeded 12,000, and even exceeded 14,000 occasionally.

In Figure 5.11 (FY 2012) and Figure 5.12 (FY 2014), the blue area shows the number of daily riders that arrived at their destination after the scheduled arrival time, and the red area shows the number of daily riders that arrived at their destination more than 10 minutes late. In FY 2012, 44% of the 3.4 million Acela passengers experienced delays, and 10% experienced delay greater than 10 minutes. In actual values, that corresponds to about 1.4 million delayed passengers and about 326,000 passengers experiencing delays greater than 10 minutes in FY 2012. In comparison, in FY 2014, the blue area almost overlaps entirely with the grey area suggesting that almost all Acela riders experienced delays. 2.3 million (66%) of the 3.55 million Acela riders arrived at their destination late, and 916,000 passenger (27%) arrived at their destination more than 10 minutes late.

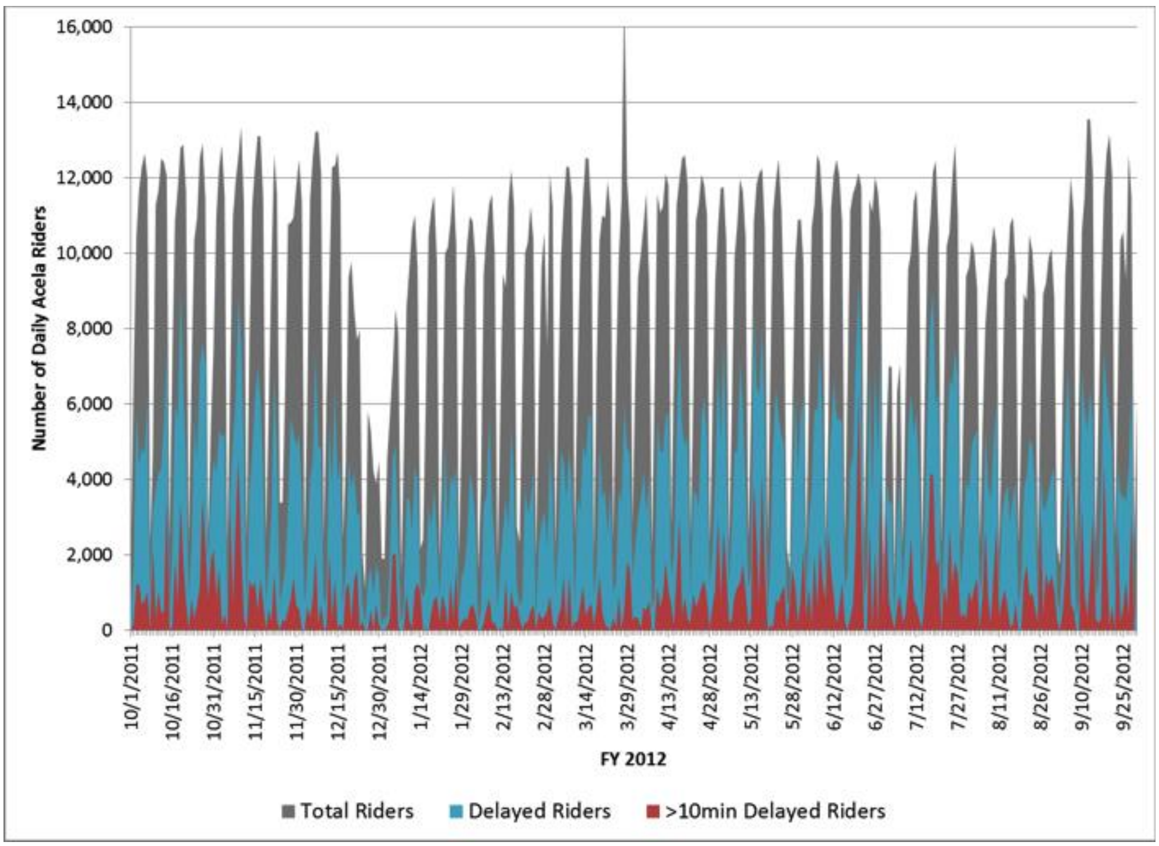

Figure 5.11: FY 2012 Scheduled and Delayed Acela Riders

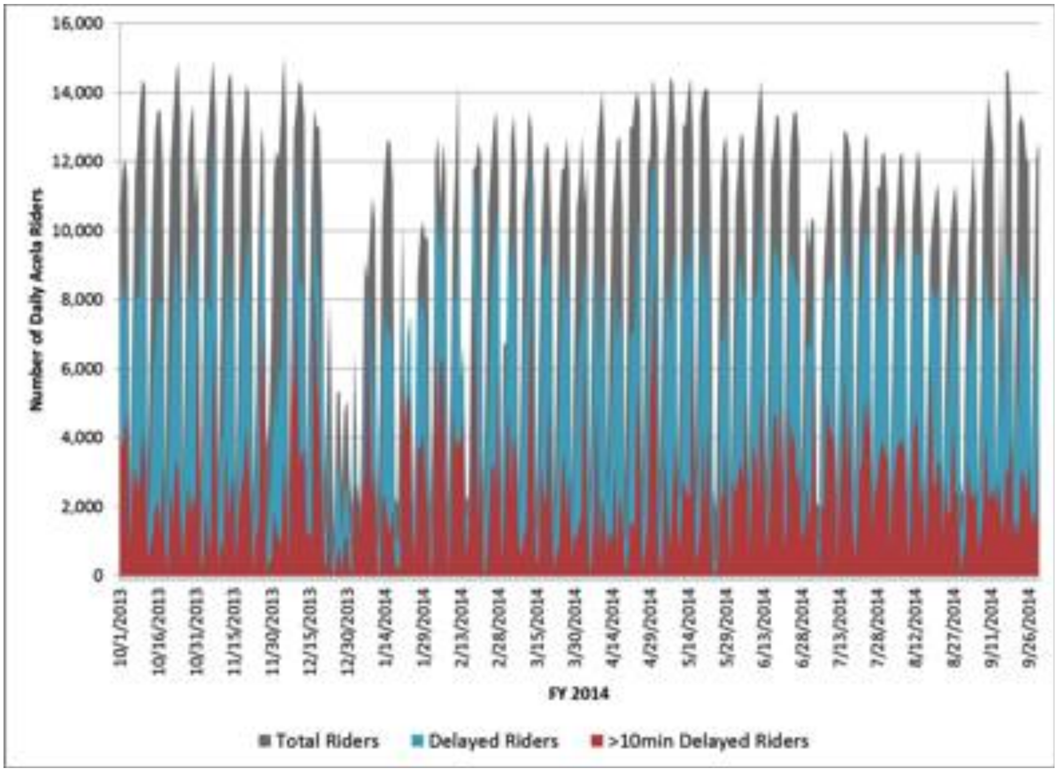

Figure 5.12: FY 2014 Scheduled and Delayed Acela Riders

In summary, even in the best performing year, FY 2012 as many as 35% of scheduled trains (11 of 32) and 44% of traveling passengers (1.4 million passengers) arrived at their final destination after the scheduled arrival time, and as many as 10% (3 of 32) of trains and 10% of passengers arrived late with delays greater than 10 minutes. By FY 2014, the numbers of late Acela trains and late Acela passengers had grown to about 56% of trains (18 of 32) and about (66%) of riders (2.3 million riders).

5.3.3 Day of Week Performance

Figure 5.13 shows the average daily ridership (dotted lines) and average daily delay per train (solid lines) on Acela trains by day of week for FY 2012 (in blue), FY 2014 (in red), and averages over FY 2005 to FY 2014 (in green). The averages over FY 2005 to FY 2014 were included in this analysis to ensure that random disruptions or calendar effects that might have affected Acela operations and service performance on a specific weekday did not bias the day of week patterns. Furthermore, the FY 2005 to FY 2014 values were likely more representative of true day of week performances since they reflect averages over many more days (there were 523 Mondays between FY 2005 and FY 2014 as opposed to only 53 Mondays in FY 2012 or FY 2014).

On the demand side, the average weekend ridership on Acela was significantly lower than the average weekday ridership in both FY 2012 and FY 2014, as well as over the 10-year period (FY 2005 – FY 2014). The average ridership was typically lowest on Saturdays. In FY 2012, the average daily ridership on Saturdays was 2,300 compared to 5,600 on Sundays, and 10,600 on weekdays. In FY 2014, the average daily ridership on Saturdays was 2,600 compared to 6,200 on Sundays, and 11,500 on weekdays. Of the weekdays, the ridership on Wednesdays and Thursdays were typically the highest, followed by Tuesdays, Friday, and lastly, Mondays.

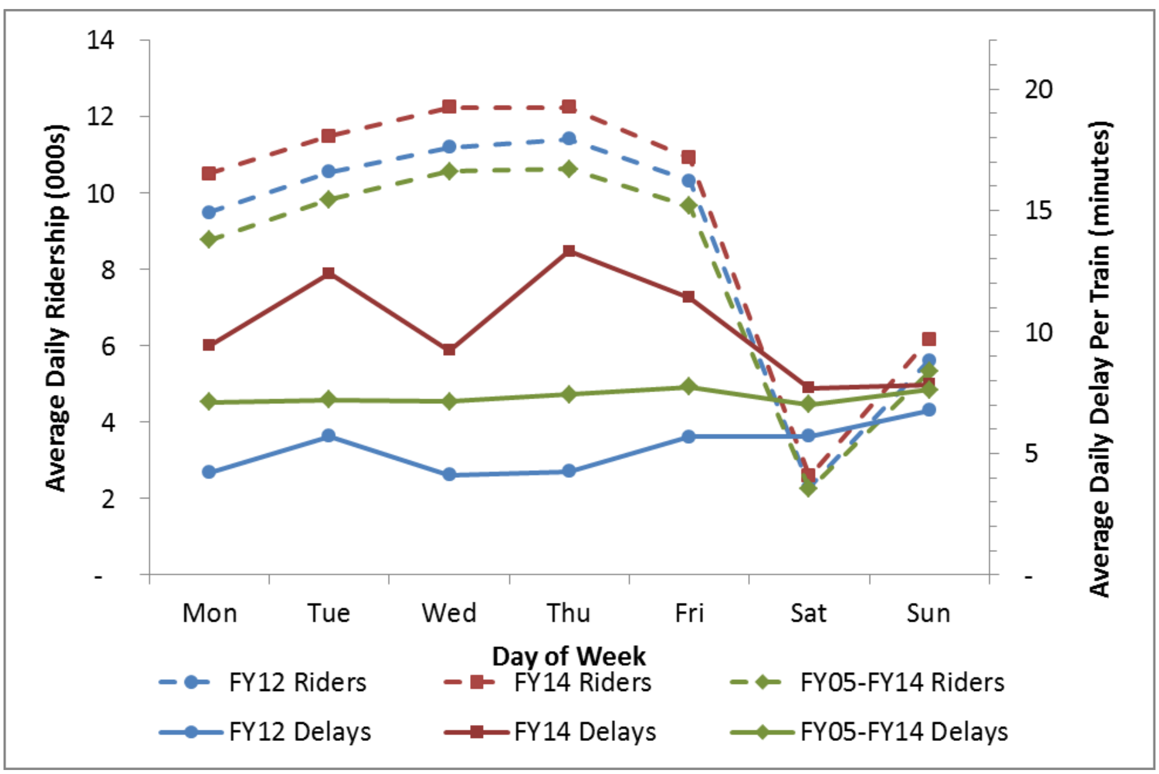

Figure 5.13: Average Ridership and Delay by Day of Week

On the delay side (solid lines), even though the average delay per train appeared to vary by day of week in FY 2012 and FY 2014, the averages over the 10-year period suggest that all weekdays and Sundays experience the same level of delays, while the delays on Saturdays were usually slightly lower. This implies that higher demand on certain days of the week did not lead to additional delays.

Figure 5.14 shows a similar chart (to Figure 5.13) but with average on-time performance instead of average delay per train by day of week. The dotted lines represent average daily ridership and the solid lines represent average on-time performance (OTP). Although the average OTP in FY 2014 (red) shows large variation ranging from 69% on Tuesdays to 81% on Saturday, it trended towards a flat line in both FY 2012 (blue) and over the 10-year period (FY 2005 – FY 2014 in green). Although the average OTP in FY 2012 and between FY 2005 and FY 2014 was slightly higher on Wednesdays and slightly lower on Fridays, the ranges were under 5% such that we can assume that weekday variations are trivial. However, similarly to the average delay, Acela OTP was significantly better on Saturdays, thus we can safely assume Acela service performance is best on Saturdays. This assumption is plausible since both Amtrak and commuter services usually have fewer trains scheduled on Saturdays.

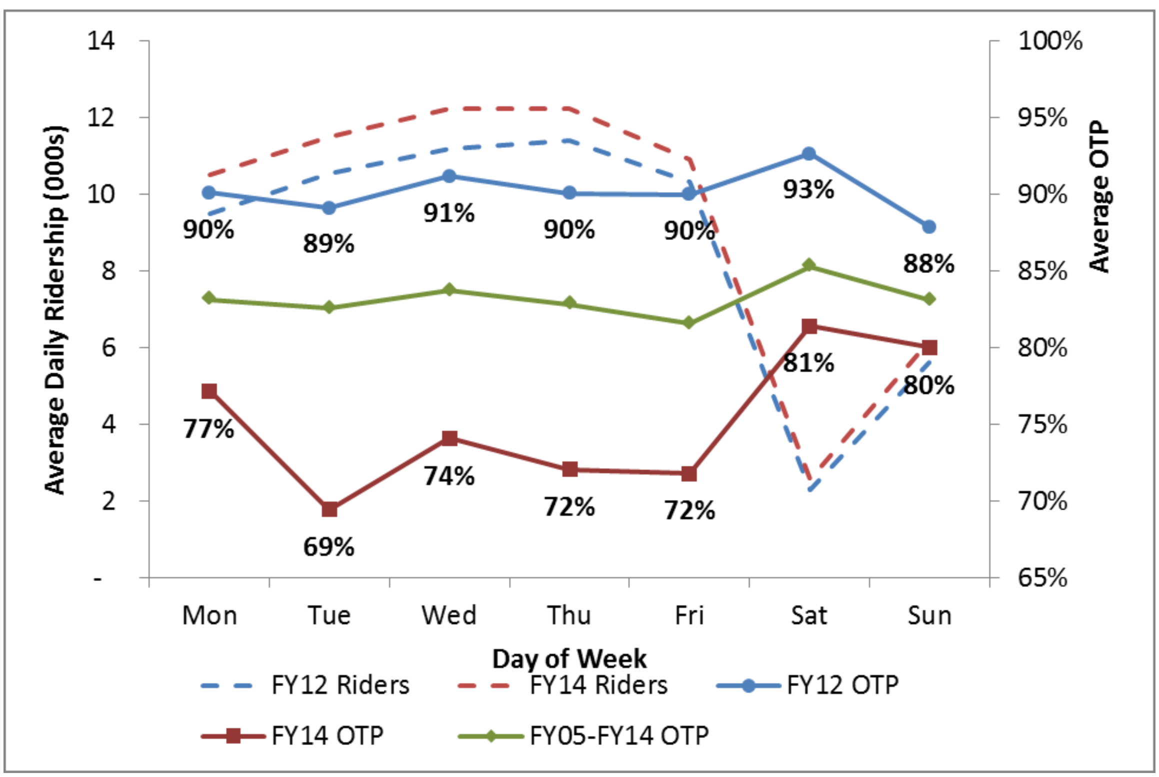

Figure 5.14: Average Ridership and OTP by Day of Week

In summary, Acela ridership volumes were lowest on Saturdays and highest on Wednesdays and Thursdays, likely an artifact of weekday business travel patterns. Additionally, of the weekdays, Mondays had the lowest ridership. In terms of service quality, performance appeared to be roughly the same on all weekdays and was usually slightly better on Saturdays. The Saturday performance improvement was likely because fewer Amtrak and Commuter services operate on weekends. Since days with higher ridership did not appear to have worse performance, it implies that higher demand on certain days of the week did not lead to additional delays.

5.3.4 Time of Day Performance

This section explores the performance of Acela trains by time of day. The Northeast Corridor spans 457 miles, and as such trains typically cross multiple time periods between departure at origin station and arrival at the terminating station. As a result, the time of day analysis in this section is based on train departure times by direction and originating station.

Table 5.1 shows the average Amtrak OTP (10-minute delay threshold) and average delay per train (no threshold) for Acela trains on weekdays in FY 2012 and FY 2014. The averages are over the 261 weekdays in both years. The first half of the table shows the Acela trains that travel southbound on the Northeast Corridor while the second half shows the northbound trains. The trains by direction are further categorized by originating-terminating station and departure times. In the southbound direction, the trains are grouped into BOS-WAS, through trains that operate between Boston South Station (BOS) and Washington Union Station (WAS), and NYP-WAS, south-end only trains that originate in New York Penn station (NYP) and terminate in WAS. Note that, the BOS-WAS trains also stop in NYP and as such serve the south-end (NYP-WAS) markets as well (see detailed explanation in Section 4.2). The BOS-WAS trains are scheduled to travel the 457-mile stretch in about 6hr 30min, including a roughly 15 minute dwell time for the train in NYP, while the NYP-WAS trains are scheduled to travel the 226-mile stretch in under 3 hours (about 2hr 50min).

Intuitively, the BOS-WAS through trains are likely to encounter more delays than the NYP-WAS south-end only trains since they longer travel times, travel double the distance, and stop at many more stations. The empirical data confirms this expectation showing that the SB BOS-WAS Acela trains had approximately 6% lower OTP on average in FY 2012, and 20% lower OTP on average in FY 2014. The BOS-WAS trains also encountered double the amount of delay than on the NYP-WAS trains in both years. This gives an impression that delays are accumulated along the length of the NEC, as opposed to being concentrated in certain segments. This will be further discussed in Section 5.4.

Regarding time of day performance, the performance of Acela SB trains deteriorated through the day; morning trains usually encountered fewer delays than afternoon trains. In addition, not surprisingly, trains scheduled to depart during the afternoon peak periods experienced the highest amount of delays.

Weekdays Only (261/365 days)					FY 2012		FY 2014	
Train No	Route	Direction	O-D	Departure Time	Amtrak OTP*	Avg. Delay per train (min)	Amtrak OTP*	Avg. Delay per train (min)
2151	Acela	SB	BOS-WAS	5:05:00 AM	92%	4.11	72%	11.09
2153	Acela	SB	BOS-WAS	6:05:00 AM	95%	2.42	77%	10.68
2155	Acela	SB	BOS-WAS	7:15:00 AM	93%	3.67	75%	10.12
2159	Acela	SB	BOS-WAS	9:15:00 AM	87%	5.16	67%	11.65
2163	Acela	SB	BOS-WAS	11:10:00 AM	86%	5.29	66%	14.88
2165	Acela	SB	BOS-WAS	12:10:00 PM	86%	5.47	65%	14.31
2167	Acela	SB	BOS-WAS	1:10:00 PM	84%	6.45	59%	18.58
2171	Acela	SB	BOS-WAS	3:10:00 PM	81%	12.33	61%	15.41
2173	Acela	SB	BOS-WAS	4:15:00 PM	90%	9.08	49%	17.59
2175	Acela	SB	BOS-WAS	5:20:00 PM			70%	17.22
2103	Acela	SB	NYP-WAS	6:00:00 AM	96%	2.23	89%	4.84
2107	Acela	SB	NYP-WAS	7:00:00 AM	96%	2.44	90%	5.68
2109	Acela	SB	NYP-WAS	8:00:00 AM	95%	3.62	78%	9.45
2117	Acela	SB	NYP-WAS	12:00:00 PM	94%	3.75	83%	6.02
2121	Acela	SB	NYP-WAS	2:00:00 PM	91%	3.76	89%	4.61
2119	Acela	SB	NYP-WAS	6:00:00 PM	93%	4.08	80%	9.41
2190	Acela	NB	NYP-BOS	6:20:00 AM	91%	3.96	87%	6.38
2100	Acela	NB	WAS-NYP	6:00:00 AM	87%	6.59	70%	10.96
2104	Acela	NB	WAS-NYP	8:00:00 AM	94%	2.63	79%	6.50
2110	Acela	NB	WAS-NYP	11:00:00 AM	98%	1.07	90%	3.96
2122	Acela	NB	WAS-NYP	5:00:00 PM	90%	5.08	87%	6.44
2124	Acela	NB	WAS-NYP	6:00:00 PM	89%	5.73	67%	12.58
2126	Acela	NB	WAS-NYP	7:00:00 PM	91%	5.29	83%	10.15
2128	Acela	NB	WAS-NYP	8:00:00 PM			79%	9.59
2150	Acela	NB	WAS-BOS	5:00:00 AM	81%	6.61	63%	16.00
2154	Acela	NB	WAS-BOS	7:00:00 AM	89%	4.22	63%	13.19
2158	Acela	NB	WAS-BOS	9:00:00 AM	91%	3.37	66%	12.70
2160	Acela	NB	WAS-BOS	10:00:00 AM	90%	3.71	66%	14.94
2164	Acela	NB	WAS-BOS	12:00:00 PM	93%	5.30	76%	8.97
2166	Acela	NB	WAS-BOS	1:00:00 PM	87%	6.16	81%	7.51
2168	Acela	NB	WAS-BOS	2:00:00 PM	90%	4.50	78%	9.31
2170	Acela	NB	WAS-BOS	3:00:00 PM	83%	7.21	55%	17.00
2172	Acela	NB	WAS-BOS	4:00:00 PM	81%	8.05	51%	17.96

*Amtrak OTP for the longest segment with passengers, which is not necessarily the end point station

Table 5.1: FY 12 and FY 14 Weekday OTP and Average Delay per Train

Continuing with the southbound discussion, in FY 2012, the 3:10PM BOS-NYP train (Train 2171) exhibited the worst performance with an average OTP of 81% and an average delay per train of 12 minutes. Likewise, in FY 2014, the trains departing BOS at 1:10PM (Train 2167), 3:10PM (Train 2171), 4:15PM (Train 2173), and 5:20PM (Train 2175) all exhibited the worst performance with average delays greater than 15 minutes and OTP less than 60% (except, Train 2175 which had an average OTP of 70%).

For the southbound trains departing NYP, in FY 2012, the 2:00PM train (Train 2121) exhibited the worst performance with an average OTP of 91% and average delay of 4 minutes. In FY 2014, the morning peak train departing NYP at 8:00AM (Train 2109) and the PM peak train departing NYP at 6:00PM (Train 2119) both experienced the worst performance with OTP less than 80% and average delays greater than 9 minutes.

Now focusing on the second half of Table 5.1, the northbound trains are also organized by O-D station and departure time of day. The trains are grouped into NYP-BOS trains (north-end), WAS-NYP trains (south-end), and WAS-BOS trains (through). Again, the WAS-BOS through trains serves both the north-end and south-end markets.

Similarly to the southbound trains, the longer through NB trains (WAS-BOS) performed worse than the south-end only trains (WAS-NYP) or the north-end only trains (NYP-BOS). In addition, trains that departed during the morning and afternoon peak periods had the worst performance, and experienced the highest amount of delays. In fact, the first northbound train departure at 5:00AM from WAS (Train 2150) appeared to have one of the worst performances in both years. And within the WAS-BOS trains, the PM peak trains departing from WAS at 3:00PM (Train 2170) and 4:00PM (Train 2172) also experienced higher delays on average in both years. In the WAS-NYP section, the AM peak train, Train 2100 departing WAS at 6:00AM and the PM peak train, Train 2124 departing WAS at 6:00PM exhibited the worst performance, in both years.

In summary, Acela trains that departed during AM peak periods (5:00AM to 8:00AM) or during the PM peak periods (3:00PM to 6:00PM) tended to have worse performance. Additionally, Acela trains exhibited distance-related deteriorations, suggesting that delays accumulate as trains served more stations along the length of the corridor. Furthermore, the first Acela train of the day was not able to achieve consistent on-time arrivals and encountered considerable amount of delays even though there were no other trains or at least fewer trains in the system to slow them down. Consequently, a detailed station-level analysis of the first Acela trains of the day is discussed in Section 5.4

5.4 First Train Analysis

This section examines the first train of the day in each direction within each market (north-end, south-end and through). In a system where trains interfere with one another, one would expect to see better performing trains in the morning when there were either no other trains or fewer trains in the system to slow each other down, and possibly performance deterioration through the day as more trains entered the system. However, Table 5.1 shows this is not the case in Amtrak's Acela system, and the first train of the day routinely encounters a significant amount of delays. Consequently, this section attempts to track the detailed station-to-station arrivals and departures of the first Acela trains over multiple days to identify causes of delay. The apriori assumption is that the findings in this section might serve as a proxy to quantify the effect of management and controls on service performance.

The discussion is divided into four subsections: i) northbound departures from New York Penn Station (NYP), ii) northbound departures from Washington Union Station (WAS), iii) southbound departures from New York Penn Station (NYP), and iv) southbound departures from Boston South Station (BOS). In each section, the average arrival and departure delays for the train at successive stations on the corridor are presented. The delays are calculated as differences between the actual and scheduled arrival and departure times of the train, and are averaged over the 261 weekdays of the year. In the delay calculations, Amtrak is not credited for 'negative' delays, and arrivals that occurred before the scheduled arrival time are treated as on-time arrivals with zero delays.

5.4.1 First Northbound Acela Train From NYP - Train 2190 (6:20AM)

Train 2190 is the first northbound Acela train scheduled to depart NYP at 6:20AM and arrive at BOS at 10:05AM on weekdays. In FY 2014, it had an on-time performance of 87% and average delay of 6 minutes. Figure 5.15 shows the average FY 2014 arrival and departure delays for the train at each successive station on the corridor. The light blue bars represent delays in arrivals while the dark blue bars represent departure delays.

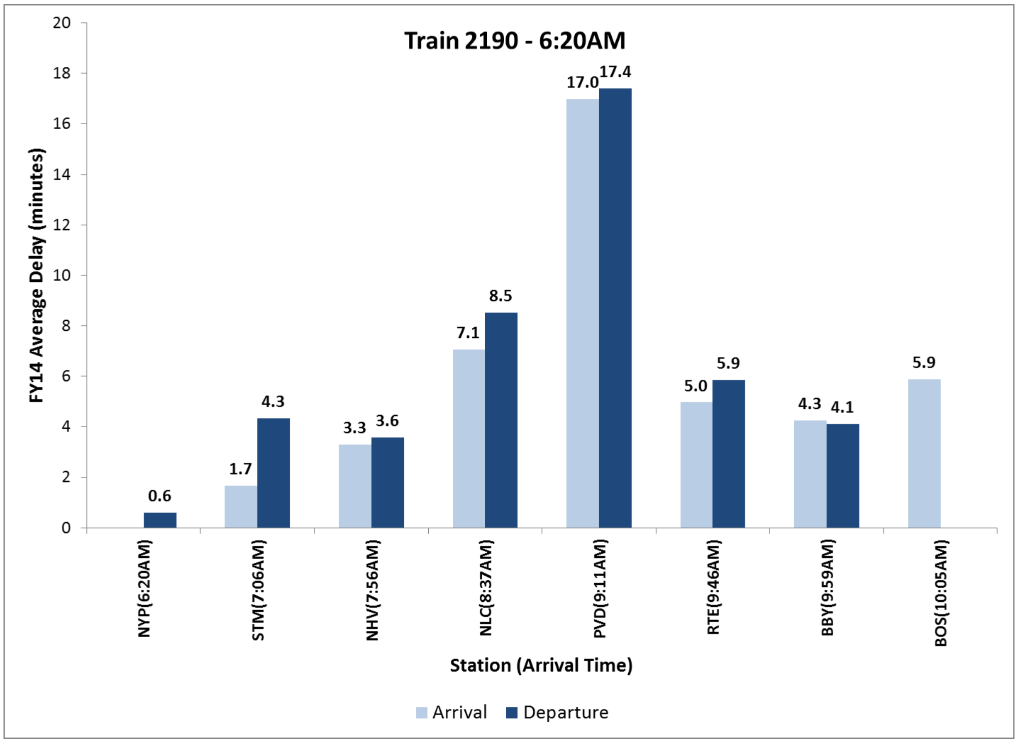

Figure 5.15: FY 2014 Average Station Delays for Train 2190

Overall, the dark blue bars are higher than the light blue bars, that is, trains typically accumulated additional delays between arrival at a station and departure from the same station. This is likely due to the fact that Amtrak does not schedule terminal time at all stations to account for the time it takes for passenger to get on and off the trains. There are no scheduled dwell times for Train 2190.

On average, Train 2190 departed NYP almost a minute later than scheduled, arrived at Stamford, CT (STM) about 2 minutes late, and had accumulated about 4 minutes of delay by the time it departed its second station (STM). The highest amount of delay seemed to accrue in the 62-mile segment between New London, CT (NLC) and Providence, RI (PVD) but the train seemed to recover from a substantial amount of the accrued delay in the 32-mile segment between PVD and Route 128, MA (RTE). On average, Train 2190 arrived at BOS 6 minutes later than the scheduled time.

Table 5.2 shows the first train analysis from a segment level and timetable point of view. A segment refers to the portion of the corridor between successive stations. It includes the segment distance, scheduled departure time from and arrival time at the stations in the segment, as well as total accumulated segment delays. The next set of columns in the table show the segment travel time (scheduled, average actual, and difference), and finally the last set of columns show segment travel speeds (scheduled, average actual, and difference). The data in each column are further clarified in the highlighted example below.

Focusing on the 62-mile NLC-PVD segment, Acela Train 2190 was scheduled to depart from NLC at 8:37AM and arrive at PVD at 9:11AM. The delay shown corresponds with the station arrival delays shown in light blue in Figure 5.15, which indicates that by the time Train 2190 arrived PVD, it had accumulated 17 minutes of delays. The next set of columns show that although the train was scheduled to travel the NLC-PVD segment in 34 minutes, on average, it actually took 42 minutes, 8 minutes slower than scheduled. Correspondingly, the scheduled travel speed in the NLC-PVD segment was 109 mph but on average, the train travelled at 88 mph, 22 mph slower than scheduled. It is interesting to notice that the scheduled travel speed in the NLC-PVD segment (109mph) is the fastest, 31 mph faster than the next highest (NHV-NLC: 98mph).

Train 2190		Scheduled		*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
NYP-STM	36	6:20 AM	7:06 AM	1.3	46	47	1	47	46	-1
STM-NHV	39	7:06 AM	7:56 AM	2.6	50	49	-1	47	48	1
NHV-NLC	51	7:58 AM	8:37 AM	6.8	39	43	4	78	72	-6
NLC-PVD	62	8:37 AM	9:11 AM	17.0	34	42	8	109	88	-22
PVD-RTE	32	9:11 AM	9:46 AM	2.2	35	23	-12	55	85	30
RTE-BBY	10	9:46 AM	9:59 AM	1.4	13	11	-2	46	53	6
BBY-BOS	1	9:59 AM	10:05 AM	1.6	6	8	2	10	8	-2

Table 5.2: Train 2190 Segment Level Performance

The reverse situation seems to occur in the PVD-RTE section, where the trains traveled 30 mph faster on average than scheduled, thus being able to traverse the PVD-RTE segment 12 minutes faster than scheduled, and recover from the delays accumulated in the NLC-PVD segment. This suggests that the Acela train timetables are not consistent with actual operations and further that the Acela timetables are padded to provide an opportunity for trains to “catch up”.

The next section focuses on Train 2150, which is the first train also traveling in the northbound direction between Washington and Boston.

5.4.2 First Northbound Acela Train From WAS - Train 2150 (5:00AM)

Train 2150 is the first weekday northbound Acela train scheduled to depart WAS at 5:00AM and arrive at BOS at 11:40AM with a 15-minute en-route dwell time at NYP. It is important to note that unlike Train 2190, Train 2150 is actually not the first Amtrak train on the corridor; it is the first Acela train on the corridor but there are four Northeast Regional trains preceding it. Also unlike Train 2190, Train 2150 does not have a scheduled stop at New London, CT (NLC) but travels directly from New Haven, CT (NHV) to Providence, RI (PVD). In FY 2014, Train 2150 had an on-time performance of 63% and average delay of 16 minutes. Figure 5.16 shows the average FY 2014 arrival and departure delays for the train at each successive station on the corridor.

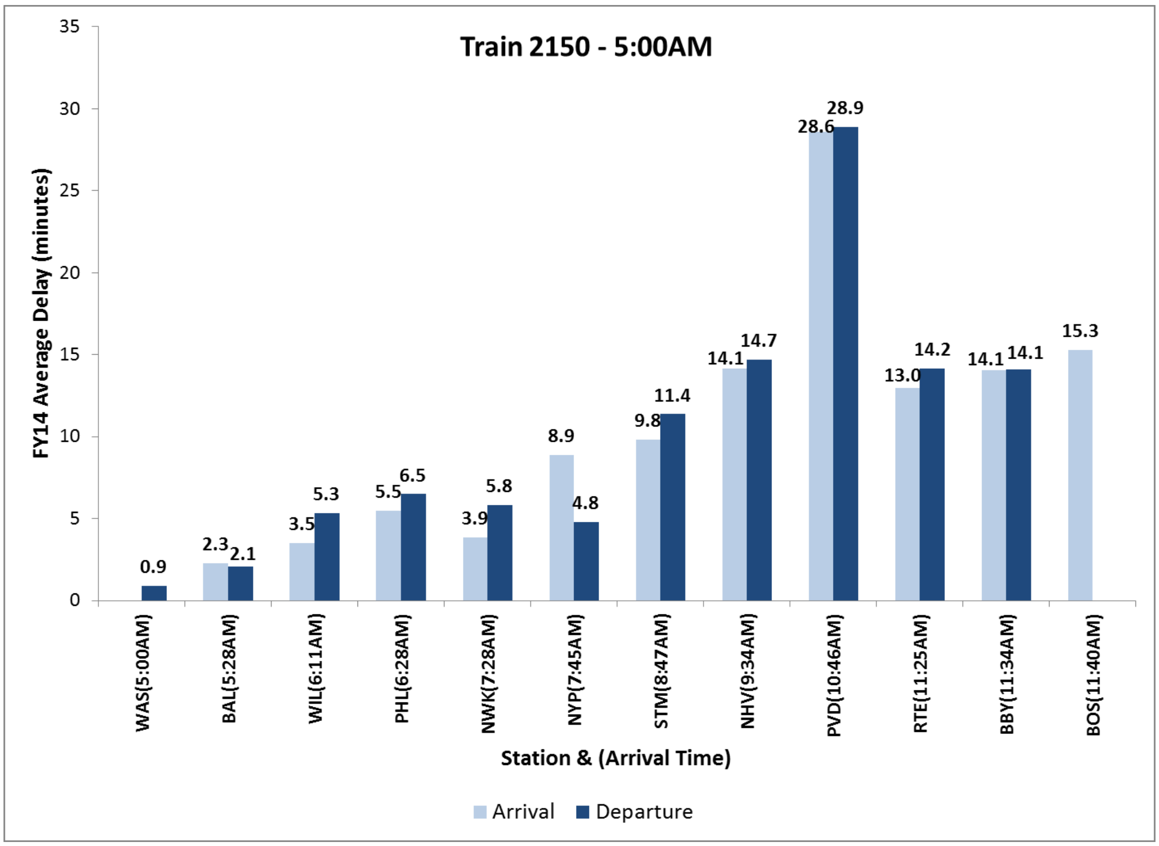

Figure 5.16: FY 2014 Average Station Delays for Train 2150

In FY 2014, the delay on Train 2150 grew incrementally between each segment along the corridor, starting with a one-minute on average late departure from WAS. The train typically accumulated additional delays between arrival at a station and departure from the same station, except at NYP, where the 15-minute scheduled dwell time also appeared to provide some buffer to recover from the upstream delays. The longest segment on Train 2150 is the 113-mile section between NHV and PVD, which also seemed to be the section where the highest amount of delay was accumulated. In

FY 2014, Train 2150 arrived and departed PVD on average, 29 minutes later than the scheduled time. However, the delays at the station immediately north of PVD – Route 128, MA (RTE) – were much lower (about 13 minutes), suggesting timetable paddings in the segment to provide an opportunity for trains to "catch up". Altogether, even though the delays were significantly lower south of PVD, some delays were still present and the train typically terminated at BOS with an average delay of 15 minutes.

Train 2150		Scheduled		*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
WAS-BAL	41	5:00 AM	5:28 AM	2.04	28	29	1	88	84	-4
BAL-WIL	69	5:30 AM	6:11 AM	3.05	41	42	1	101	98	-3
WIL-PHL	25	6:11 AM	6:28 AM	5.38	17	17	0	88	88	-1
PHL-NWK	81	6:30 AM	7:28 AM	2.85	58	55	-3	84	88	4
NWK-NYP	10	7:28 AM	7:45 AM	8.49	17	20	3	35	30	-5
NYP-STM	36	8:03 AM	8:47 AM	9.80	44	49	5	49	44	-5
STM-NHV	39	8:47 AM	9:34 AM	14.13	47	50	3	50	47	-3
NHV-PVD	113	9:36 AM	10:46 AM	28.56	70	84	14	97	81	-16
PVD-RTE	32	10:46 AM	11:25 AM	12.00	39	23	-16	49	83	34
RTE-BBY	10	11:25 AM	11:34 AM	13.56	9	9	0	67	67	1
BBY-BOS	1	11:34 AM	11:40 AM	14.43	6	7	1	10	8	-2

Table 5.3: Train 2150 Segment Level Performance

Table 5.3 shows the performance of Train 2150 from the segment level and timetable point of view. In the 113-mile NHV-PVD segment, although the train was scheduled to take 70 minutes, on average, it actually took 84 minutes, 14 minutes slower than scheduled. Correspondingly, the scheduled travel speed in the NHV-PVD segment was 97 mph but on average, the train travelled at 81 mph, 16 mph slower than scheduled. It is interesting to note that the scheduled travel speed in the BAL-WIL and NHV-PVD segments were the fastest, at 101mph and 97 mph, respectively. Although theoretically Acela is able to reach such high speed, in reality it usually did not. Again, the reverse situation seems to occur in the PVD-RTE section with the trains traveling 34 mph faster than scheduled, thus being able to traverse the segment 16 minutes faster than scheduled, and recover from the delays accumulated in the NHV-PVD segment. Once again, this suggests timetable padding and flawed timetables.

The first southbound trains are presented in the next sections.

5.4.3 First Southbound Acela Train From NYP - Train 2103 (6:00AM)

Train 2103 is the first southbound Acela train out of NYP. It is scheduled to depart NYP at 6:00AM and arrive WAS at 8:55AM. Although it is the first Acela train on the corridor, there are three Northeast Regional trains preceding it. In FY 2014, Train 2103 had an on-time performance of 89% and average delay of 5 minutes. There are no scheduled dwell times at en-route stations for Train 2103.

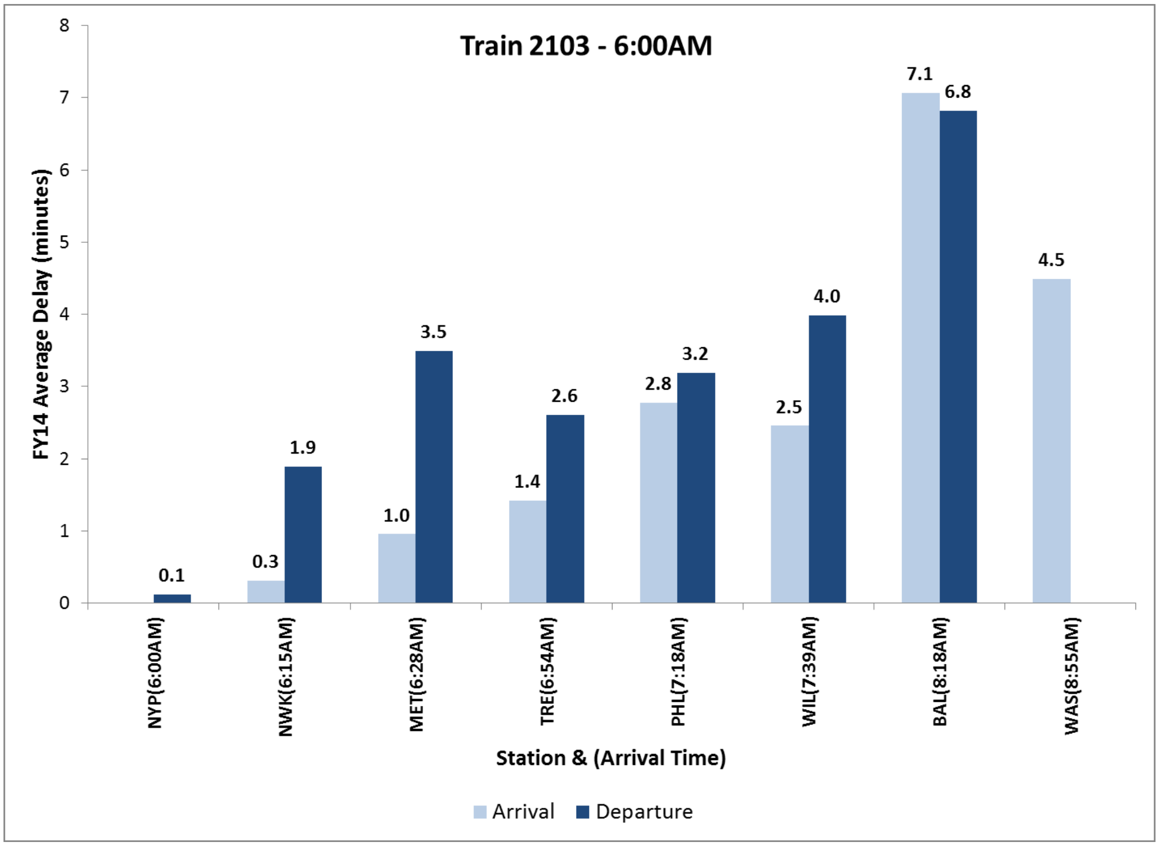

Figure 5.17: FY 2014 Average Station Delays for Train 2103

As shown in Figure 5.17, on average, the train departed NYP relatively on schedule but accumulated 2 minutes of delays as it departed Newark, NJ (NWK), and about 3.5 minutes as it departed Metropark, NJ (MET). Regarding terminal time, the train accumulated about 1.5 minutes of unscheduled time discharging and receiving passengers at NWK, and about 2.5 minutes at MET. The delays on the train typically continued to add up downstream, with the segment between Wilmington, DE Station (WIL) and Baltimore Penn Station (BAL) consistently experiencing the highest amount of delays (about 7 minutes).

Train 2103		Scheduled		*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
NYP-NWK	10	6:00 AM	6:15 AM	0.32	15	15	0	40	39	-1
NWK-MET	14	6:15 AM	6:28 AM	0.96	13	12	-1	65	70	5
MET-TRE	34	6:28 AM	6:54 AM	1.43	26	24	-2	78	85	7
TRE-PHL	33	6:54 AM	7:18 AM	2.78	24	24	0	83	82	-1
PHL-WIL	25	7:20 AM	7:39 AM	2.46	19	18	-1	79	82	3
WIL-BAL	69	7:39 AM	8:18 AM	7.07	39	42	3	106	98	-8
BAL-WAS	41	8:20 AM	8:55 AM	4.49	35	33	-2	70	75	5

Table 5.4: Train 2103 Segment Level Performance

Table 5.4 shows the performance of Train 2103 from the segment level and timetable point of view. In the 69-mile WIL-BAL segment, although the train was scheduled to take 39 minutes, it actually took 42 minutes on average, 3 minutes slower than scheduled. Correspondingly, the actual travel speed in the segment was 8 mph slower than scheduled. The scheduled speed in the segment was 106 mph but on average Train 2103 traveled at a speed of 98 mph in the WIL-BAL segment.

Table 5.4 also shows that on average, Train 2013 traveled in the NWK-MET segment about 5 mph (1 minute) faster than scheduled, 7mph (2 minutes) faster in the MET-TRE segment, and 5mph (2 minutes) fasters in the BAL-WAS segment.

5.4.4 First Southbound Train From BOS – Train 2151 (5:05AM)

Train 2151 is the first southbound Acela train scheduled to depart from BOS at 5:05AM and arrive at WAS at 11:53AM with a 15 minute en-route dwell time at NYP. Unlike Train 2103, Train 2151 does not have a scheduled stop at Metropark (MET) but travels directly from Newark, NJ(NWK) to Philadelphia, PA (PHL). Additionally, it is the first Acela train on the corridor, and there are no other Amtrak trains preceding it. In FY 2014, Train 2151 had an on-time performance of 72% and average delay of 11 minutes. Figure 5.18 shows the average FY 2014 arrival and departure delays for the train at each successive station on the corridor.

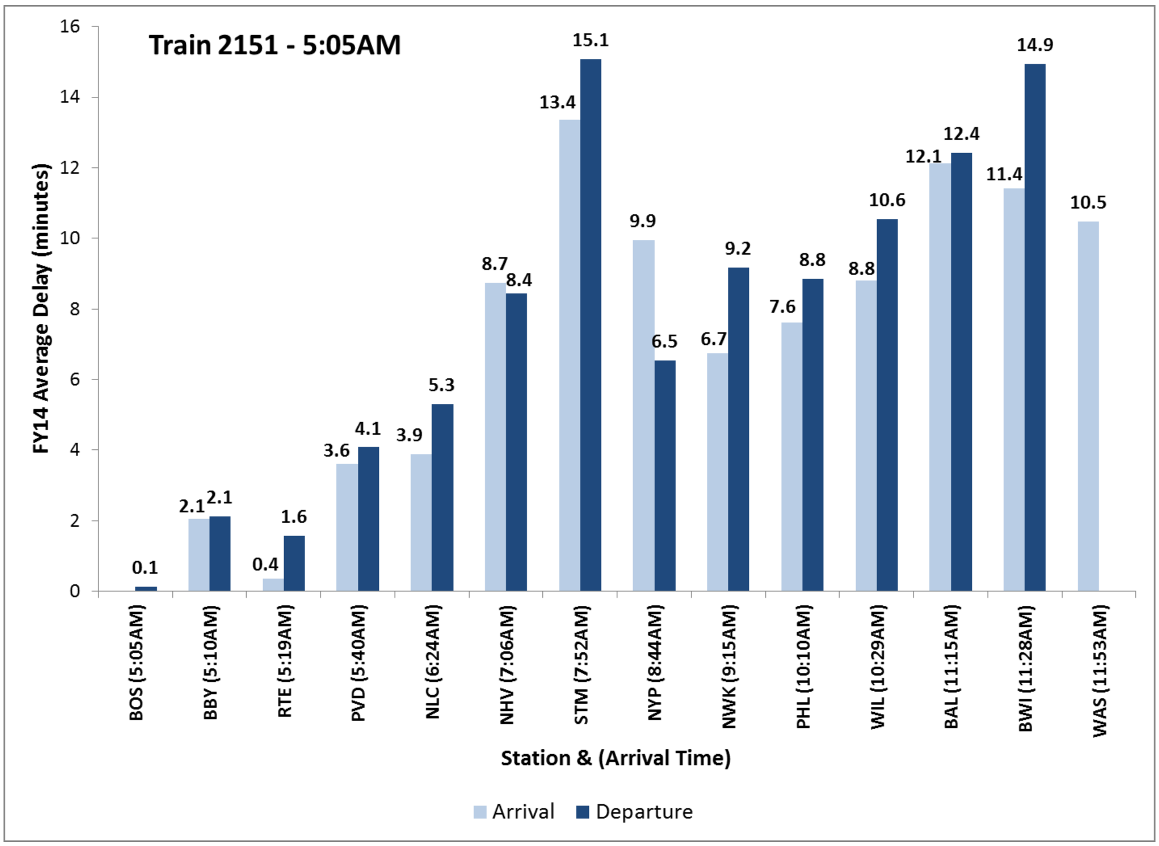

Figure 5.18: FY 2014 Average Station Delays for Train 2151

On average, in FY 2014, Train 2151 departed the originating station (BOS) relatively on time. Although scheduled to arrive at Boston Back Bay Station (BBY), 1 mile away at 5:10AM, Train 2151 didn't usually arrive until around 5:12AM. The train performance improved at RTE but after RTE, the delays on the train typically continued to grow, peaking in the New Haven - Stamford, CT segment (NHV-STM), where it usually arrived 13 minutes later and departed 15 minutes later than scheduled. Train 2151 often recovered from some of the built-up delays at NYP, likely an advantage of the scheduled 15-minute train dwell time. The delays typically continued to grow again downstream, with the train terminating at WAS on average, 11 minutes later than scheduled.

Table 5.5 shows the performance of Train 2151 from the segment level and timetable point of view. The train typically traveled about 3 minutes slower than scheduled in the NLC-NHV segment, and about 5 minutes slower than scheduled in the NHV-STM segment. The segments highlighted in green show segments where the train travelled faster than scheduled, which happened in the BBY-RTE segment, the STM-NYP segment, and the BWI-WAS segment.

Train 2151		Scheduled			Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time	*Delay (min)	Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
BOS-BBY	1	5:05	5:10	2	5	7	2	12	9	-3
BBY-RTE	10	5:10	5:19	0	9	7	-2	67	83	16
RTE-PVD	32	5:19	5:40	4	21	23	2	91	83	-8
PVD-NLC	62	5:40	6:24	4	44	44	0	85	85	0
NLC-NHV	51	6:24	7:04	9	40	43	3	77	70	-6
NHV-STM	39	7:06	7:52	13	46	51	5	51	46	-5
STM-NYP	36	7:52	8:44	10	52	47	-5	42	46	5
NYP-NWK	10	9:00	9:15	7	15	15	0	40	39	-1
NWK-PHL	81	9:15	10:08	8	53	51	-2	92	94	3
PHL-WIL	25	10:10	10:29	9	19	19	0	79	79	0
WIL-BAL	69	10:29	11:13	12	44	46	2	94	91	-3
BAL-BWI	11	11:15	11:28	11	13	12	-1	51	55	4
BWI-WAS	30	11:28	11:53	10	25	21	-4	72	88	16

Table 5.5: Train 2151 Segment Level Performance

To clarify that the station level performances observed so far are not unique to FY 2014, the next section shows the station level performance for Train 2151 in FY 2012.

5.4.5 First <u>Southbound</u> Acela Train From BOS - Train 2151 (FY 2012)

Fiscal Year 2012 was one of the best years in terms of service performance between FY 2005 and FY 2014. The Amtrak OTP for Train 2151 in FY 12 was 92% and the average delay per train was 4 minutes (compared to OTP of 72% and average delay of 11 minutes in FY 2014).

Figure 5.19 shows the FY 2012 station level average delay per train for Train 2151. Although the average delays at each station were lower in FY 2012 compared to FY 2014, the average delay trend looks very comparable. Similar to FY 2014, the delays on the train arriving at STM appeared to be the largest. The average delay peaked around STM, recovered in NYP but grew incrementally at each successive station on the corridor, and arrived WAS with 4 minutes of delay on average. The similarities between the FY 12 and FY 14 average delay for Train 2151 indicate that the delay trend on the first train is more of a regular occurrence than a unique or one-time event.

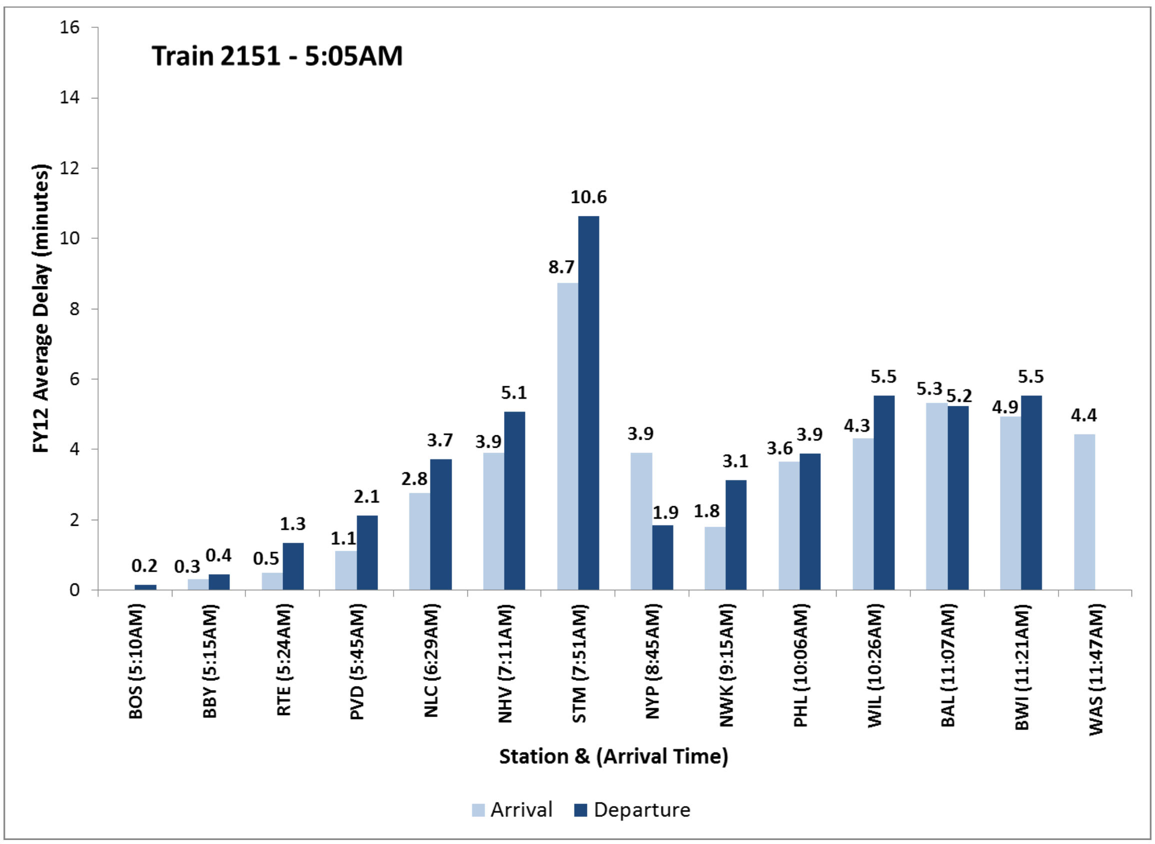

Figure 5.19: FY 2012 Average Station Delays for Train 2151

In summary, upstream delays on the Acela seemed to accumulate along the corridor as a result of unscheduled terminal time at many stations. In addition, flawed segment train speeds and travel times led to additional en-route delays on some segments, and catch-up on other segments.

5.5 Train Interference Analysis

Theoretically, delays on one Acela train could be large enough to spill over to the next scheduled train. This phenomenon is typically referred to as train interference, where one train interferes with smooth operations and performance of another train. This section investigates interference within the Amtrak system but does not include the effect of commuter or freight train interference.

Figure 5.20 shows the delay per mile for successive northbound Amtrak trains (including Acela and Regional). Assuming Amtrak trains interfered with one another, one would see an increasing trend in the delays on consecutive trains; however the delays between consecutive trains in Figure 5.20 appear to be random. This manifestation is not surprising because Amtrak usually spaces trains in intervals greater than 30 minutes, and Acela trains typically experience delays less than 20 minutes on an average day. Again, from the travel time distribution, we estimated that about 92% of Acela trains arrive within 30 minutes of the scheduled arrival time. This suggests that on an average day, delays do not propagate from one train to the next; however on a bad day, they likely do. Also, due to limited data on locomotives, the cascading effects of delay on round trips were not studied.

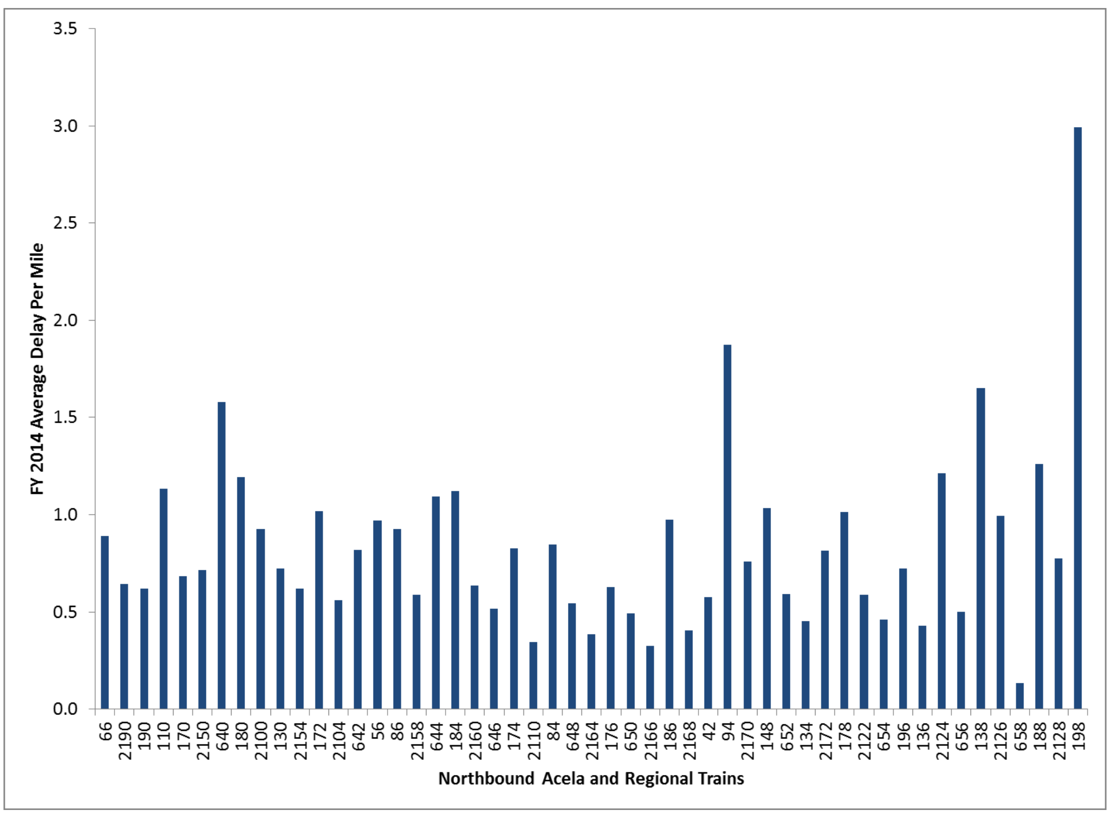

Figure 5.20: FY 2014 Average Delay Per Mile

5.6 Supply Fluctuations Due to Weather, Accidents and Other Incidents

In the Northeast Corridor, the performance of Acela service is occasionally affected by unanticipated changes in travel conditions such as bad/extreme weather, crashes and incidents, equipment failure or other unexpected infrastructure malfunctions. This section investigates supply fluctuations due to accidents and incidents (e.g. signal failures, weather related, track work, etc.), and includes their effects on travel delays and train cancellations.

Under PRIIA Section 207, Amtrak was required to report the total delay minutes apportioned into Amtrak-responsible, Host-responsible (Metro-North Railroad-responsible), and Third Party-responsible category (see Section 3.3.2 for additional details of PRIIA requirements regarding delays). However the author of this thesis did not have access to this data. Consequently, the inferences made in this section are based on observing the total daily delay minutes on the Acela services. The total daily delay minutes were calculated by aggregating end-point delays on all the Amtrak train that were operated each day. Following that, the author went through a manual process of searching through Amtrak's Twitter[iv] and Breaking News[v] feeds for reports of major accidents and incidents on days with significant delays.

FY 2012 Daily Delays

Figure 5.21 shows the total daily end-point delays in minutes experienced on Acela trains in FY 2012. There were four days of the year on which Acela experienced severe delays greater than 1,000 minutes. 1,000 minutes was chosen as an arbitrary boundary line separating 'regular' delays from severe delays. The Twitter and Breaking News feeds indicated Severe Storms as the main cause of the 1,939 minutes of delay on 6/29/2012 and 1,510 minutes of delay on 6/30/2012. In addition, the 2,566 minutes of delay on 9/18/2012 were attributed to service disruptions from Hurricane Sandy. The author was not able to identify the cause of the 1,346 minutes of delay on 6/1/2012. Not counting the severe delays (>1,000 minutes), there were 10 other days when total delays exceeded 500 minutes. Overall, the total daily delays on Acela trains in FY 2012 were fairly consistently around 100 minutes. To comprehend this value, divide 100 minutes by 32 trains on a given Monday, for example, which equates to Acela trains being on average 3 minutes late in arrivals at its final station.

5.6.1 Total Minutes of Delay

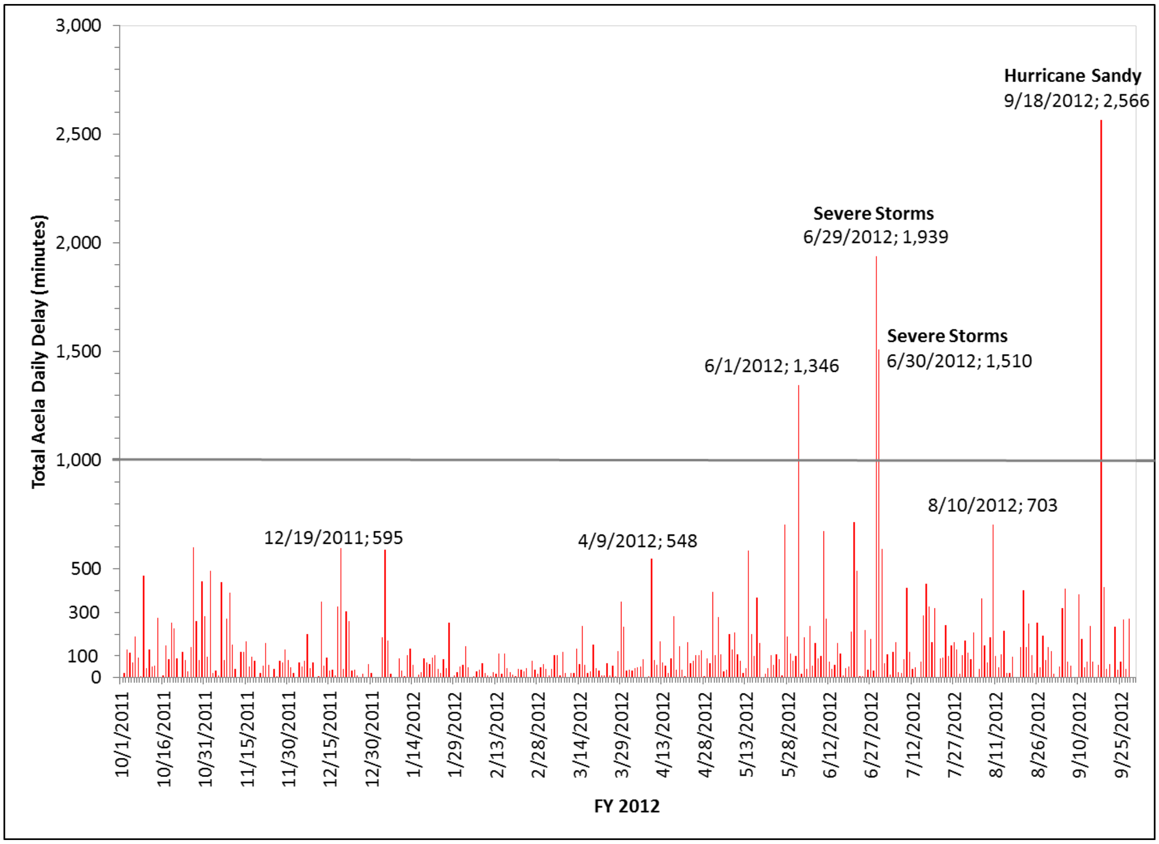

Figure 5.21: FY 2012 Acela Daily Delays

From this proxy analysis, the major delays in FY 2012 appear to be as a result of unanticipated weather disruptions, and accounted for 15% of FY 2012 total Acela delays.

FY 2014 Daily Delays

The same analysis process was undertaken for total daily delays in FY 2014. Figure 5.22 shows the total daily end-point delays in minutes experienced on Acela trains in FY 2014. There were 14 days of the year on which Acela experienced severe delays greater than 1,000 minutes.

The largest delay in FY 2014 was experienced on July 3rd, 2014 attributed to Hurricane Arthur. For example, Train 2124, which was scheduled to depart Washington Union station (WAS) at 6:00pm and arrive in New York Penn (NYP) at 8:45pm, did not pull into the terminal in New York until 2:47am with 150 passengers on board. Due to the severe weather condition, the train experienced a 6-hour delay, in addition to the scheduled 2hr 45min travel time. Amtrak's on-time performance metric for Acela trains on that day was 42%. In other words, 19 of the 33 scheduled Acela trains on July 3rd, 2014, arrived at their destination more than 10 minutes later than the scheduled arrival time.

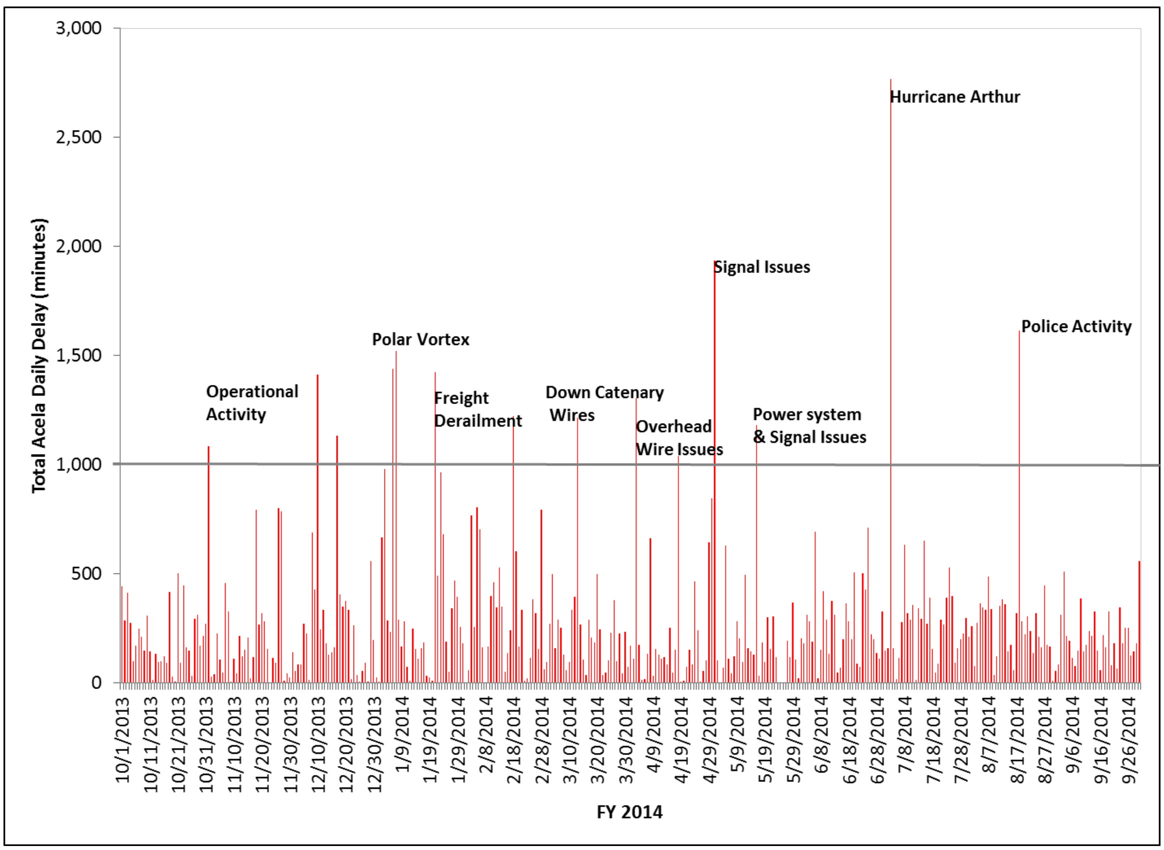

Figure 5.22: FY 2014 Acela Daily Delays

Signal issues on the section of track between Washington, DC and Baltimore, MA were responsible for the second most delayed day on Acela in FY 2014. The severe winter weather aka Polar Vortex in January 2014 also resulted in higher than average delays, especially on the 5th, 6th and 21st of the month. 7 of the 14 days in FY 2014 with significantly high delays were due to power system, signal issues, overhead wire issues, and operational issues. Compared to FY 2012, which did not experience any days with severe delays due to train or infrastructural malfunctions, this suggests that the track and equipment in the NEC corridor have deteriorated

Table 5.6 shows the 14 days in FY 2014, on which experienced total delay was greater than 1,000 minutes, including the date, day of week, reason for the delay, and the OTP achieved on that day. Although the total delay was abnormally high, the OTP on some days was still high (e.g. 4/18/2014), which suggests that the delay was concentrated at a specific section of the corridor and time of the day, and had minimal impact on most trains scheduled to operate on that day. Days with high delays and high OTP (e.g. 1/7/14) suggest that the delay propagated throughout the corridor and day, and affected majority of the scheduled trains.

Delay Reason	Date	Weekday	Total Delay Minutes	OTP
Hurricane Arthur	7/3/2014	Thu	2,767	42%
Signal issues WAS-BAL	5/1/2014	Thu	1,937	18%
Police activity PHL-TRE	8/18/2014	Mon	1,613	31%
Polar vortex	1/7/2014	Tue	1,523	10%
Polar vortex	1/6/2014	Mon	1,439	68%
Polar vortex	1/21/2014	Tue	1,424	28%
Operational activity	12/10/2013	Tue	1,412	33%
Overhead wire issues WAS-BAL	4/3/2014	Thu	1,306	47%
Freight derailment	2/18/2014	Tue	1,223	15%
Overhead wire Issues WIL-BAL	3/13/2014	Thu	1,214	36%
Power system issues NYP-STM; Police activity north of WAS	5/16/2014	Fri	1,182	35%
Disabled Amtrak train	12/17/2013	Tue	1,134	36%
Unknown	11/1/2013	Fri	1,086	27%
Overhead wire issues WAS-WIL	4/18/2014	Fri	1,040	88%

Table 5.6: Acela Daily Total Delay Greater Than 1,000 minutes

The severe delays were responsible for 24% of total FY 2014 Acela delays. Of the 24%, half were attributed to weather-related, police activity, or unknown sources while the other half were associated with equipment and infrastructural issues.

5.6.2 Cancelled Trains

It is important to investigate supply side fluctuations that result in train cancellations firstly because they pose huge difficulties to travelers, and secondly because they are currently not accounted for in the existing delay and OTP metrics.

Although Acela service performance was best in FY 2012 (of performance between FY 2005 and FY 2014), there were 14 days in the year on which Acela trains were cancelled, and 16 total cancelled trains. Figure 5.23 shows ten days on which one Acela train was cancelled, and two days with two Acela trains cancellations. Altogether, less than 1% (0.2%) of total FY 2012 scheduled trains was cancelled.

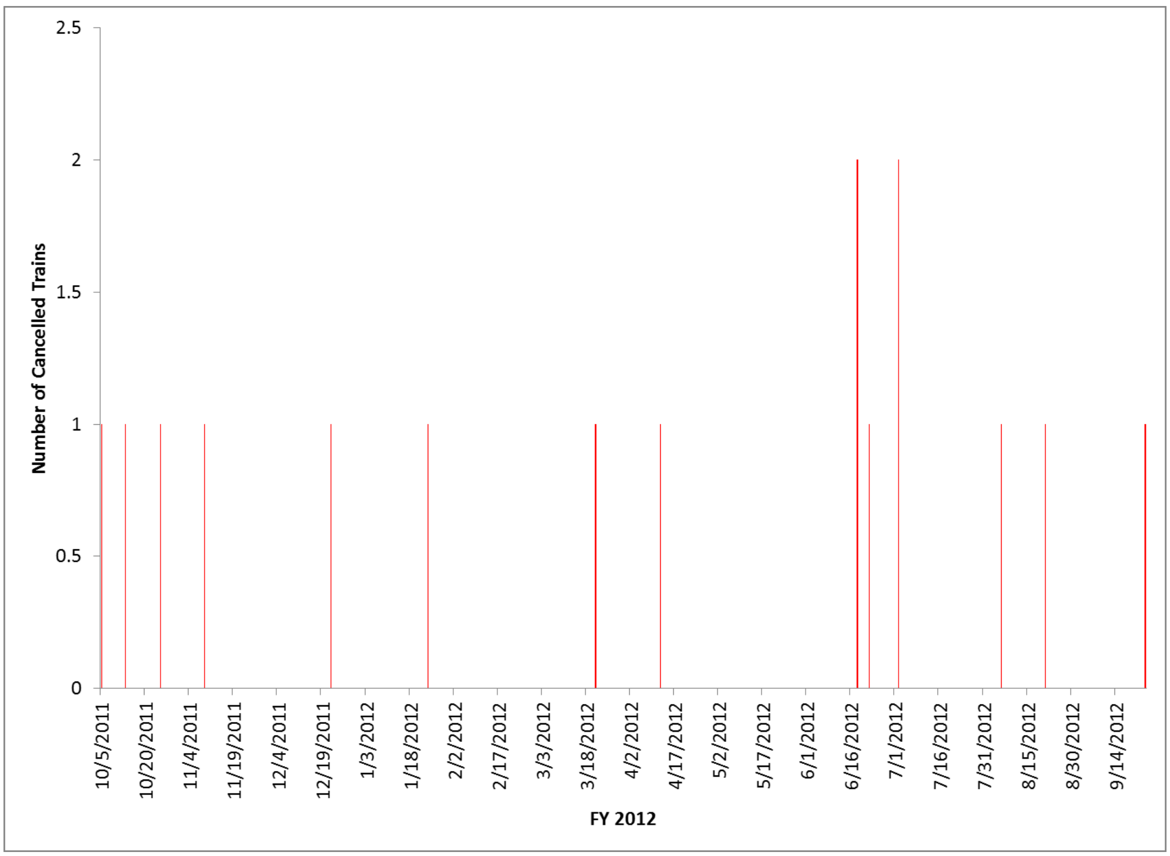

Figure 5.23: FY 2012 Number of Cancelled Acela Trains

In FY 2014, Figure 5.24 shows that there 28 days in the year on which Acela trains were cancelled, and a total of 187 cancelled trains. The data labels in Figure 5.24 are formatted as: date; # of cancelled trains (e.g. 1/22/2014; 23). The major train cancellations occurred in January and February. Altogether, 2% of total scheduled Acela Train in FY 2014 was cancelled.

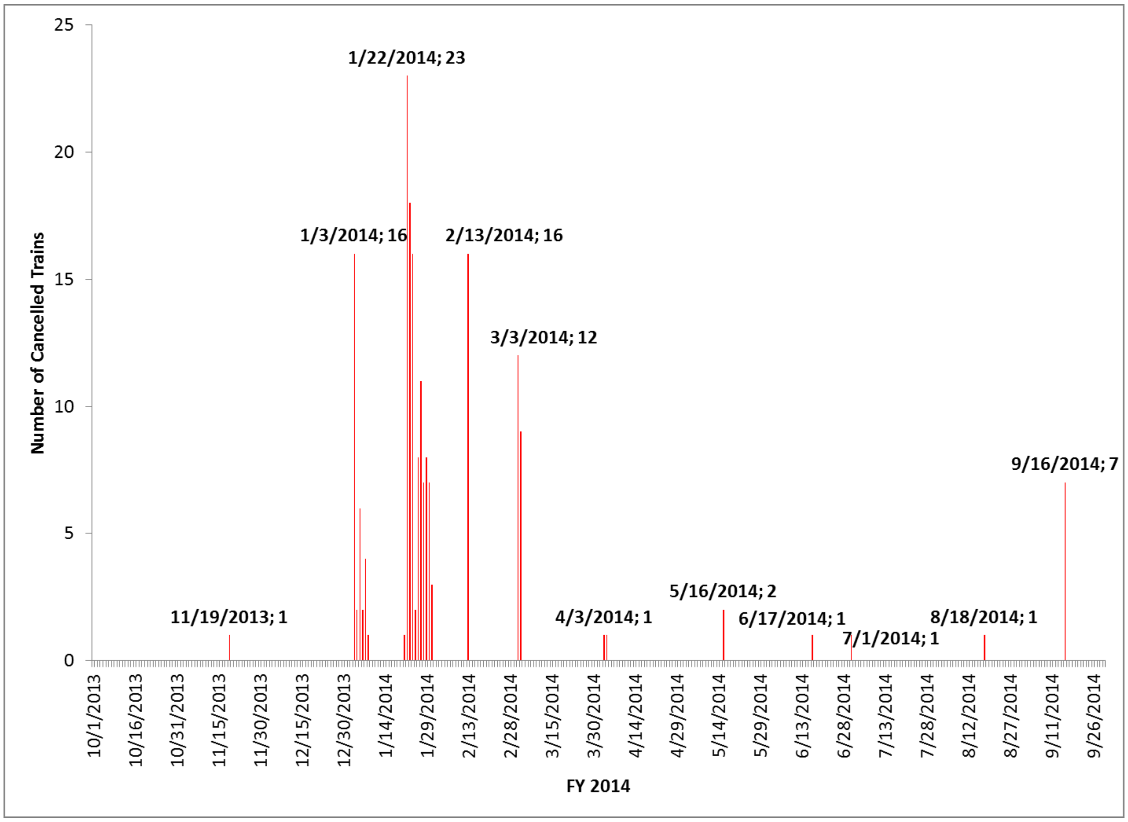

Figure 5.24: FY 2014 Number of Cancelled Acela Trains

Table 5.7 shows a list of the 28 days along with data on the number of scheduled trains, the number of cancelled trains, the total delay minutes on operated Acela trains, the Amtrak OTP, and the cause of the train delay/cancellations (from the authors manual process explained in Section 5.5.1). 84% of FY 2014 Acela train cancellations were attributed to weather-related issues, 7% to down catenary/overhead wires issues, 7% to Police Activity, and the last 2% to disabled Amtrak trains or unknown sources.

The days with high cancellations are also days with severe weather or other third-party-related issues. Furthermore, excluding the days with severe delays from external factors such as weather-related, infrastructure or police activity, Amtrak rarely cancels trains.

Date	Day of week	# Trains scheduled	# Trains Cancelled	Total Delay minutes	Amtrak OTP	Delay/Cancellation Reason
11/19/2013	Tue	33	1	269	81%	Disabled Amtrak train
1/3/2014	Fri	33	16	982	29%	Weather-Related
1/4/2014	Sat	9	2	286	43%	Weather-Related
1/5/2014	Sun	19	6	234	54%	Weather-Related
1/6/2014	Mon	33	2	1,439	68%	Weather-Related
1/7/2014	Tue	33	4	1,523	10%	Down Cantenary Wires
1/8/2014	Wed	33	1	290	59%	Down Cantenary Wires
1/21/2014	Tue	33	1	1,424	28%	Weather-Related
1/22/2014	Wed	33	23	492	0%	Weather-Related
1/23/2014	Thu	33	18	964	27%	Weather-Related
1/24/2014	Fri	33	16	682	24%	Weather-Related
1/25/2014	Sat	9	2	189	14%	Weather-Related
1/26/2014	Sun	19	8	51	91%	Weather-Related
1/27/2014	Mon	33	11	343	50%	Weather-Related
1/28/2014	Tue	33	7	470	54%	Weather-Related
1/29/2014	Wed	33	8	394	56%	Weather-Related
1/30/2014	Thu	33	7	255	81%	Weather-Related
1/31/2014	Fri	33	3	182	77%	Weather-Related
2/13/2014	Thu	33	16	530	24%	Weather-Related
3/3/2014	Mon	33	12	270	52%	Weather-Related
3/4/2014	Tue	33	9	498	46%	Police Activity
4/3/2014	Thu	33	1	1,306	47%	Down Cantenary Wires
4/4/2014	Fri	33	1	175	81%	Down Cantenary Wires
5/16/2014	Fri	33	2	1,182	35%	Police Activity
6/17/2014	Tue	33	1	366	69%	Unknown
7/1/2014	Tue	33	1	148	88%	Police Activity
8/18/2014	Mon	33	1	1,613	31%	Police Activity
9/16/2014	Tue	33	7	60	96%	Down Cantenary Wires

Table 5.7: FY 2014 Acela Train Cancellation Summary

In summary, although the train cancellations on the Acela service were not disturbingly high on an average day, cancellations cause a substantial amount of inconvenience and disutility to travelers and thus must be accounted for in service performance metrics. The need for a more precise cumulative service performance index is discussed in Section 8.4.

5.7 Capacity Analysis

This section analyzes the capacity on Acela trains between FY 2005 and FY 2014, which has the potential to influence variations both in demand and supply that impact the assessment of service performance.

The goal of the capacity analysis for this thesis is to provide a caveat to the analysis on the impact of Amtrak service performance on demand. Demand for Acela service is currently alleged to be above the capacity of Acela trains, which might dampen the actual effect of demand responses to service performance. For example, if a passenger on a train experienced major delays during an Acela trip and therefore decided to use a different mode of travel on their next trip, the demand data might not show the effect of the lost passenger because a traveler who was initially not able to purchase a ticket due to the capacity constraints, might replace the lost passenger. The section begins by showing the daily ridership profile and average weekday ridership on Acela trains between FY 2005 and FY 2014. Then it delves into the actual segment level volumes on each train for some chosen sample dates.

Amtrak ridership in the Northeast Corridor has continued to grow strongly, despite the effect of the economic recession that lessened ridership in FY 2009. Total Acela ridership grew from 2.3 million in FY 2005 to a record high of 3.5 million riders in FY 2014. The annual growth in passenger demand was reflected in daily ridership as well. The daily ridership volumes were used to pick the dates for which the Acela capacity analysis was done.

Figure 5.25 shows the number of Acela riders each day between FY 2005 and FY 2014. The top legend in the figure shows the number of days on which ridership exceeded the 14,000, 15,000 and 16,000 mark, respectively. Figure 5.25 also shows the day and month (format: day/month) each year with the highest ridership. In FY 2005, there was only one day where ridership exceeded 14,000 (and 15,000) on March 31, 2005 (3/31). However, by FY 2008, there were 13 days where ridership exceeded 14,000, 7 days where ridership exceeded 15,000 and 4 days with Acela ridership over 16,000. In FY 2008, April 30th (4/30) had the most riders (20,800). The daily ridership was significantly impacted in FY 2009 by the recession; in FY 2009, there were only 5 days with ridership above 14,000, 4 days with ridership above 15,000 and 1 day with ridership above 16,000, and May 29th 2009 (5/29) had the most riders (17,000). By FY 2014, there were 35 days on which the number of daily riders on Acela exceeded 14,000, compared to 14 times in FY 2013. In FY 2013, the day with highest demand was February 28 while in FY 2014, October 31ST and February 28th experienced the highest daily demand.

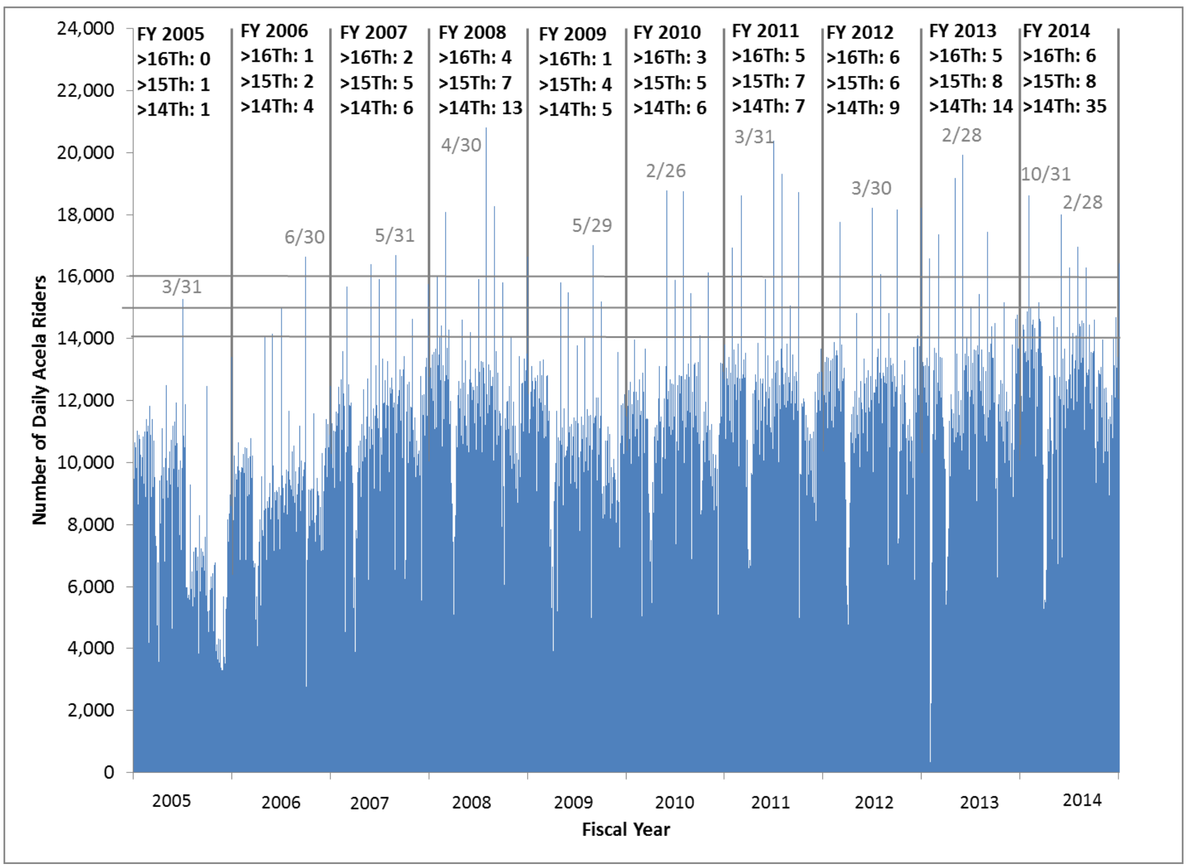

Figure 5.25: FY 2005 - FY 2014 Daily Acela Riders

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5.7.1 FY 2005

Since the growth in passenger demand between FY 2005 and FY 2014 has not been matched with a proportionate increase in infrastructure, some Acela trains have approached and other might have reached capacity in some segments of the Northeast Corridor. In FY 2005, the day with the highest ridership was March 31st (3/31) with a demand of 15,000 riders. The four figures in Figure 5.26 show segment level demand for each Acela train that was operated on March 31st 2005. The top plots show segment volumes on the northbound (NB) trains while the bottom plots show the volume on the southbound (SB) trains. The capacity of all Acela trains is 304, which corresponds to a load factor of 100%, that is, a segment level volume of 230 corresponds with a 75% load factor.

In the top left corner, the NB through trains (WAS-BOS) show peak loading in the segments between Newark, NK (NWK) and North Philadelphia, PA (PHN). Train 2168 (in red), which departed from WAS at 2:00PM had a load factor of 90% as it crossed the PHN - NWK section (between 3:30PM and 4:30PM). Train 2168, 2170 and 2172 are all PM peak trains, departing from WAS at 2:00PM, 3:00PM and 4:00PM, respectively. Train 2154 and 2158 are AM peak trains, departing from WAS at 7:00AM and 9:00AM, respectively. Train 2152 is also an AM peak train that departs from WAS at 6:00AM.

Similarly, in the bottom left figure, the through southbound trains show peak loading in the same section between NWK and PHN. Train 2167 (in red) departed from Boston (BOS) at 1:20PM, and had a peak loading of 90% as it crossed the section between NWK and PHN in the PM peak (between 5:00PM and 6:00PM). Train 2151 (in blue) which was the AM peak train departing from BOS at 5:00AM had the second highest segment load as it crossed the NWK - PHN section (between 9:00AM and 10:00AM). Train 2167 and 2171 are PM peak trains departing BOS at 1:00PM and 3:10PM, while Train 2151, 2163 are AM peak trains departing BOS at 5:00AM and 11:00AM, respectively.

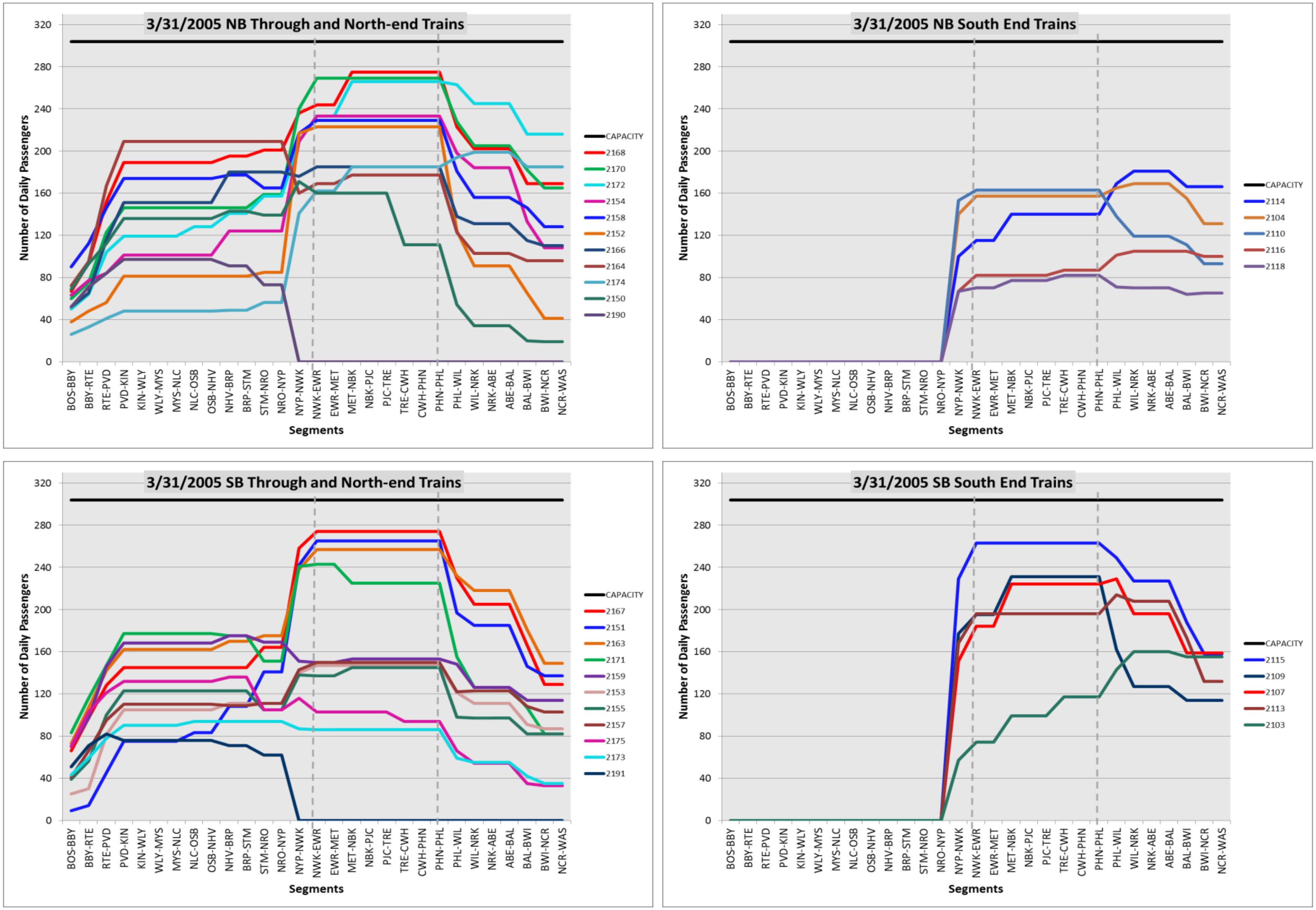

Figure 5.26: FY 2005 Segment Level Train Capacity

5.7.2 FY 2012

Figure 5.27 shows similar figures of segment loading for 3/30/2012, the day with peak ridership volume in FY 2012. Compared to the FY 2005 plots, all the trains show an upward shift suggesting more trains approaching capacity. Furthermore, by FY 2012, the segment loading in the north-end section of the Northeast Corridor between BOS and NYP saw a significant increase in ridership. In FY 2005, the peak volume in the North-end segments were about NB: 210 riders (70% load factor) and SB: 180 riders (60% load factor), however, by FY 2012, the peak volume in the north section of the NEC had increased to 220 riders (85% load factor) in both NB and SB.

In the top left figure, the through NB WAS-BOS trains show peak loading in the segments between Newark, NK (NWK) and North Philadelphia, PA (PHN). Train 2168 (in red), which departed from WAS at 2:00PM had a load factor of 96% as it crossed the PHN - NWK section (between 3:30PM and 4:30PM). Similarly, in the bottom left figure, the through southbound trains show peak loading in the same section between NWK and PHN. Train 2163 (in red) departed from Boston (BOS) at 11:00AM, and had a peak loading of 99% as it crossed the section between NWK and PHN in the PM peak (between 3:00PM and 4:30PM).

In the northbound direction for the through trains, Train 2168, 2170 and 2172 are all PM peak trains, departing from WAS at 2:00PM, 3:00PM and 4:00PM, respectively. Train 2160 and 2164 are late morning trains, departing from WAS at 10:00AM and 12:00PM, respectively, while for NB south-end only trains, Train 2124 and 2126 were scheduled to depart from WAS at 6:00PM and 7:00PM, respectively.

In the southbound direction for the through trains, Train 2163 is an AM peak train departing BOS at 11:00AM, Train 2171 is a PM peak train departing BOS at 3:00PM, and Train 2151 and 2153 are the early morning trains departing from BOS at 5:00AM and 6:00AM, respectively. For the SB south-end only trains, Train 2121 and 2119 were scheduled to depart NYP at 2:00PM and 6:00PM respectively.

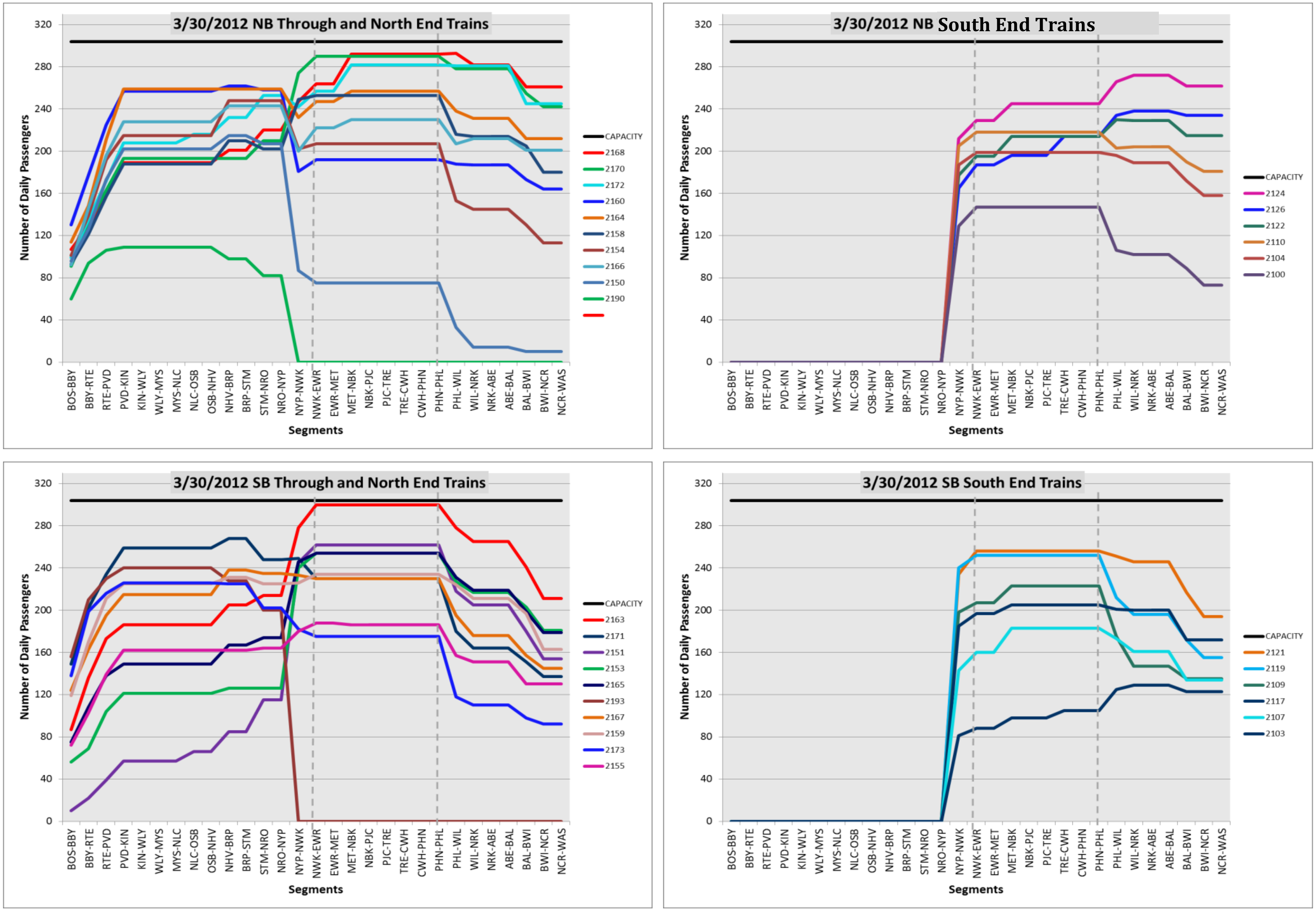

Figure 5.27: FY 2012 Segment Level Train Capacity

5.7.3 FY 2014

Figure 5.28 shows the segment volumes on February 28th 2014, the day with the highest daily ridership in FY 2014. In the top left figure, northbound Train 2168, 2170 and 2172 ran with a peak segment load factor of 100%, 98% and 95%, respectively. Train 2168, 2170 and 2172 are scheduled to depart WAS at 2:00PM, 3:00PM and 4:00PM, respectively. Train 2166, 2164 and 2160 are scheduled to depart from WAS but seem to have a higher loading in the north-end section after departing NYP at 1:00PM, 3:00PM and 4:00PM, respectively.

In the bottom left figure, the southbound through trains have a very interesting characteristic with the trains either loaded in the south-end or north-end sections. For example, Train 2165 scheduled to depart from BOS at 12:10PM was about 65% loaded in the north section; however the loading spiked up to 95% as the train departed from NYP at 4:00PM. Train 2167 (scheduled to depart from BOS at 1:10PM) and Train 2163 (scheduled to depart from BOS at 11:10AM) exhibited a similar pattern. On the other hand, Train 2171 exhibited the opposite pattern with a 94% loading in the north section and a 50% loading in the south section. Train 2171 departed from BOS at 3:10PM and from NYP at 7:00PM. The next train departures from BOS at 4:15PM (Train 2173) also exhibited a similar pattern.

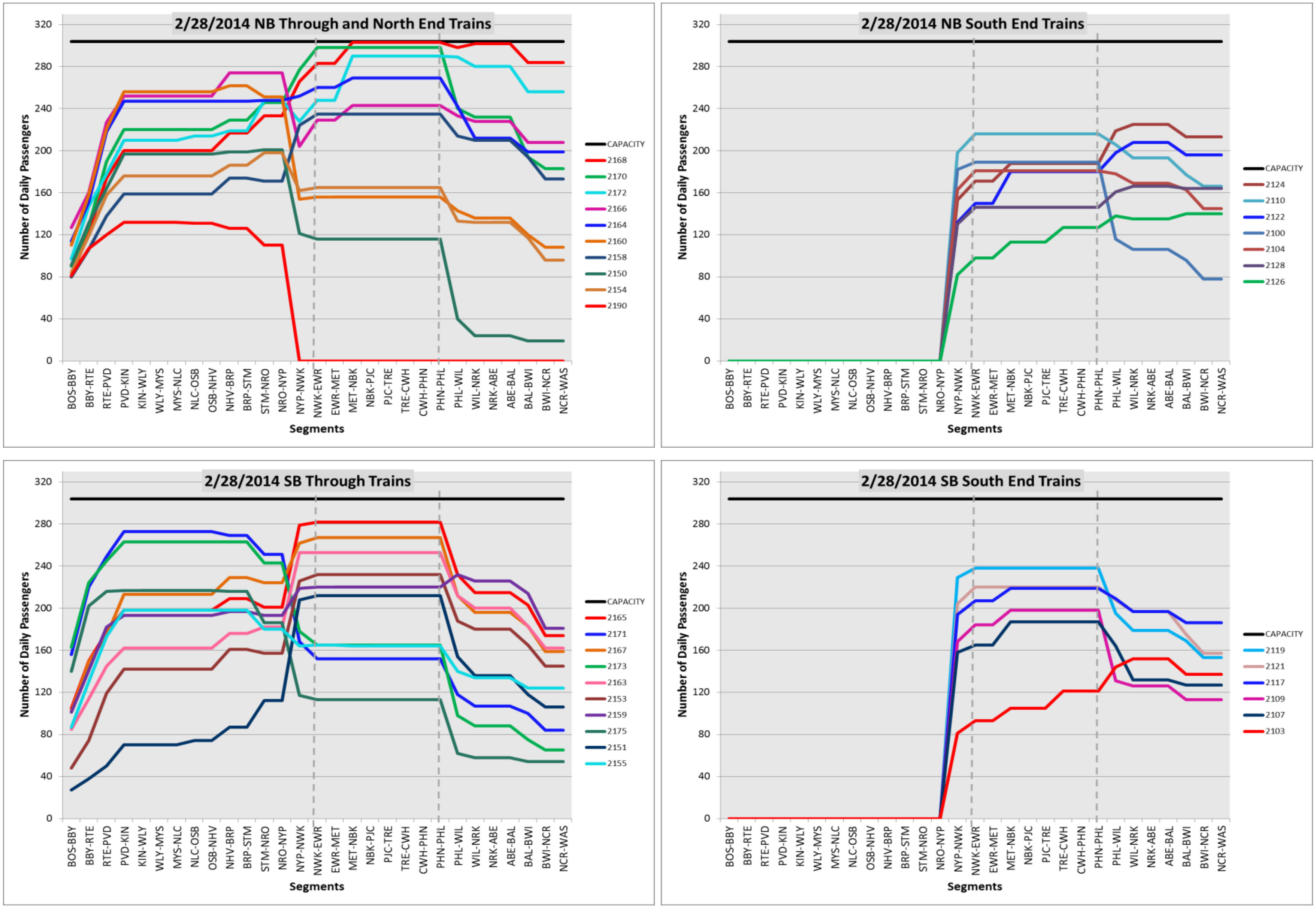

Figure 5.28: FY 2014 Segment Level Train Capacity

In summary, the capacity analysis shows that Acela peak hour trains were indeed at or near capacity, with load factors greater than 94%. This indicates that the full impact of service performance on demand might be dampened when using the historical data due to the capacity constraints. In other word, because demand on Acela trains appears to be more than the train capacity, if hypothetically Acela lost some demand due to poor performance, the full impact might not be evident as the demand backlog might replace the lost demand.

5.8 Demand Response to Acela Service Performance

The main question examined in this section is: Do Amtrak Acela passengers modify their future travel choices in response to past Acela performance that either they experienced or were informed about? As a practical constraint, there needs to be a period of time between when travelers experience or learn about performance information and when they make future travel decisions. This time is usually referred to as a lag period. Following this concept, a simple analysis was conducted to correlate total annual ridership each year with Acela train performance from the prior year, that is, assuming a lag of one year. In other words, the goal of the analysis was to test the assumption that a relationship exists between ridership in a given year and OTP or total delay from the prior year.

The correlation coefficient was used to measure the strength and direction of the relationship between annual ridership and performance. Correlation coefficients close to zero indicate a weak relationship between the ridership and performance from the prior year, while correlations coefficients equal to 1 represent a perfect relationship between both variables. Additionally, positive correlation values denote a direct relationship between the demand and performance, suggesting that years with high demand are associated with high prior year performances, and vice versa.

5.8.1 Annual Ridership to Annual Average OTP

Figure 5.29 shows the total annual Acela ridership (blue) between FY 2005 and FY 2014 and the annual average OTP (red) from the prior year. For example, the first data points show total FY 2006 ridership (2.6 million) and FY 2005 average OTP (71%). The relationship between OTP in two consecutive years is typically associated with a similar relationship between the ridership in the following year. For example, an upward trend in average OTP between FY 2005 and FY 2006 is followed by a similar upward trend between the annual ridership in FY 2006 and FY 2007. This relationship is observed between FY 2005 and FY 2010. However, in FY 2010, even though the performance deteriorated in the prior year, Acela ridership continued to grow. The relationship appeared the continue again between FY 2011 and FY 2013 but broke down again in FY 2014 with ridership increasing despite performance deteriorations in FY 2013. The correlation coefficient between the annual ridership and lagged annual on-time performance between FY 2005 and FY 2014 is 0.75. Although this correlation is not perfect (equal to 1), it is sufficiently high to propose that the ridership in a given year is associated with service performance from the prior year. Furthermore, as expected the correlation between FY 2005 and FY 2010 was much higher and equal to 0.97.

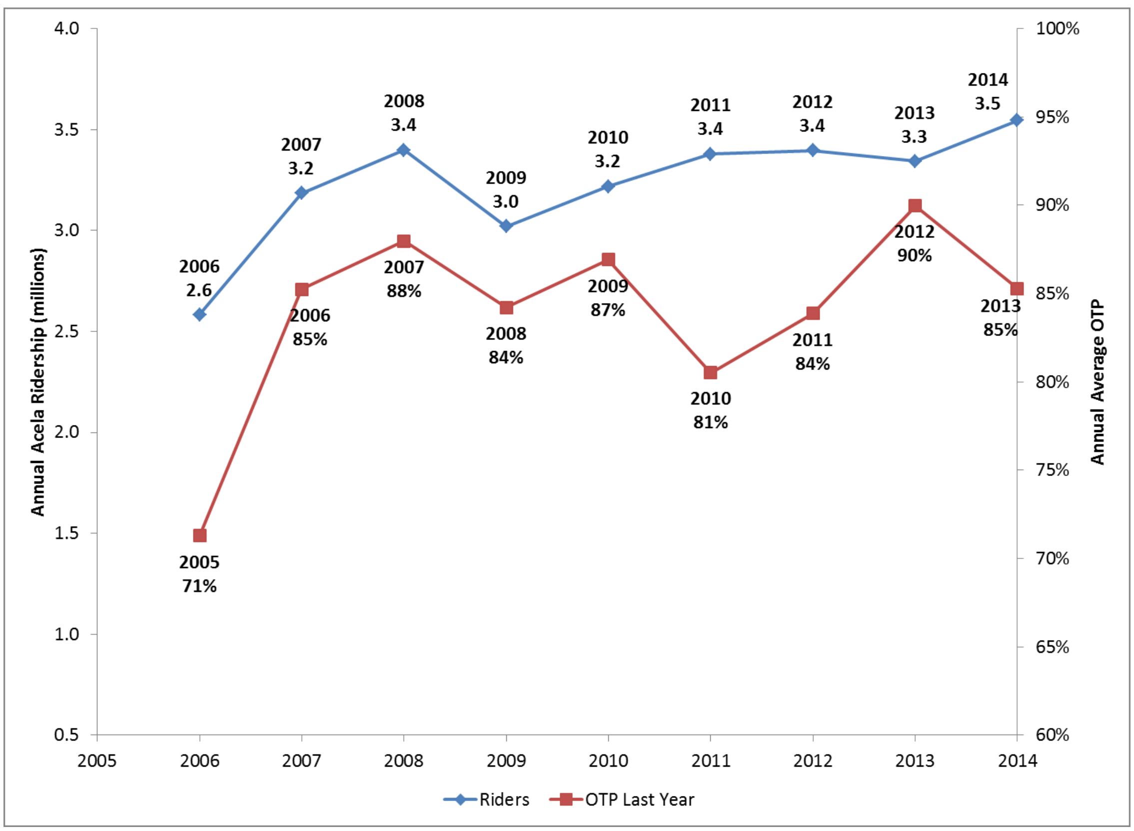

Figure 5.29: Lag Annual Ridership to OTP

5.8.2 Annual Ridership to Annual Delay

Figure 5.30 shows the total annual Acela ridership (blue) and the total annual delay (red) from the prior year. The annual ridership and annual delay exhibited a similar lagged relationship as the annual ridership and annual average OTP. Improvements in performance (that is reduction in total annual delay) appeared to be associated with ridership increase the following year. The correlation between the annual ridership and lagged annual total delay between FY 2005 and FY 2014 was 0.58. Although this correlation is not as high as the correlation coefficient for annual on-time performance, it suggests that Acela ridership in a given year is also associated with delays from the prior year. Furthermore, as expected the correlation between FY 2005 and FY 2010 was much higher and equal to 0.99.

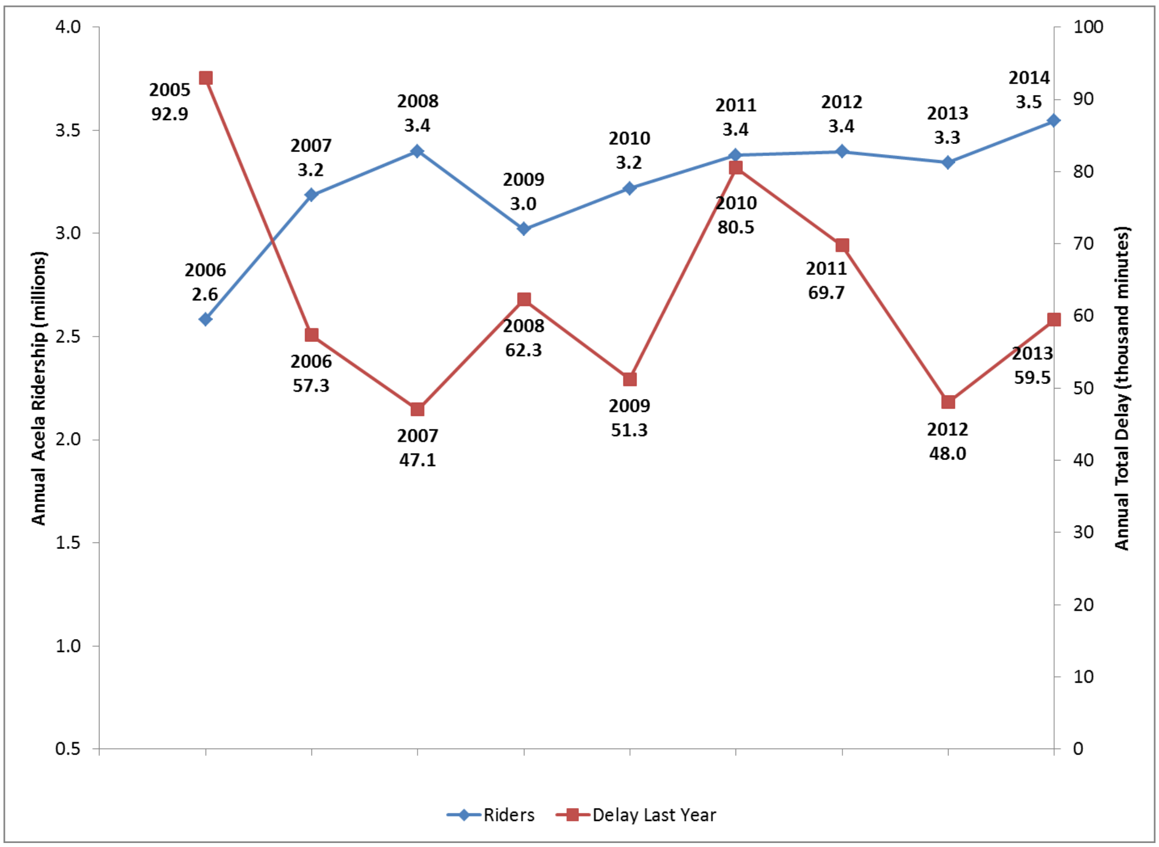

Figure 5.30: Lag Annual Ridership to Delay

It is unclear whether the one-year lagged associations exhibited between OTP or total delay and ridership are cause-effect relationships between service performance and demand. The correlation between Acela ridership and lagged service performance would be investigated further in the time series analysis in Chapter 7.

5.9 Acela Summary

This section summarizes the analysis in Chapter 5.

In FY 2014, 42% of Acela trains arrived on-time, 47% arrived late but within 30 minutes, and the remaining 11% experienced delays greater than 30 minutes. Altogether, 71% of trains arrived within 10 minutes and 89% within 30 minutes.

On-time performance and delay minutes are 70% correlated, and both are useful metrics in quantifying performance. However, neither of them includes the effect of cancelled trains, motivating the need for a cumulative service performance index.

Acela ridership and service performance exhibit seasonal variations. Acela ridership is usually highest in the fall months at the beginning of the fiscal year (October, November), and also during the spring months (April, May, June), and lowest in January and August. Acela performance is usually worst in January (especially during extreme winters) and in the summer (July, August), and best in October, April and May.

Both Acela ridership and service performance vary by day of week. Ridership was typically higher on the weekdays and service performance was typically better during the weekend. However, during the week (Monday – Friday), while Acela ridership exhibited weekday variations, Acela service performance appears to be independent of the day.

In terms of time of day performance variations, AM and PM peak trains were usually more prone to delays than trains during other off-peak times of the day.

The first train analysis revealed that a major portion of Acela delays appeared to be attributable to late departures from originating station, which accumulated and propagated at each consecutive station downstream. In addition, unscheduled dwell time at many stations and poorly estimated segment train speeds and travel times lead to additional en-route delays. On an average day, delays attributed to interference from other Amtrak trains were limited because of the scheduled spacing between trains throughout the day.

The performance of Acela service was occasionally affected by unanticipated changes in travel conditions such as bad/extreme weather, crashes and incidents, equipment failure or other unexpected infrastructure malfunctions. Unanticipated weather-related and third-party events were responsible for about 12% of Amtrak train delays (based on FY 2012 and FY 2014 analysis). Furthermore, in FY 2012, there were no major delays caused by equipment failure, however, in FY 2014, 12% of delays were associated with equipment and infrastructural issues, suggesting rolling-stock and infrastructure deterioration. Lastly, not including days with severe weather issues, Amtrak rarely cancels Acela trains.

The capacity analysis revealed that Amtrak peak hour trains were indeed at or near capacity, with load factors greater than 94% in either the north-end or south-end section of the Northeast Corridor. In addition, a few peak period trains were capacity constrained throughout the entire corridor.

Finally, Acela ridership appeared to exhibit a one-year lagged correlation with service performance. However, it is unclear whether the one-year lags exhibited between OTP or total delay and ridership were due to cause-effect relationships between service performance and demand or just correlations.

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6 NORTHEAST REGIONAL RIDERSHIP AND SERVICE PERFORMANCE

Figure 5.1 used to describe the variability in travel times on the Acela service is repeated here because of its equal applicability in describing travel time variability on the Northeast Regional service. Figure 6.1 shows different factors that cause fluctuations of Regional demand and service performance, which subsequently lead to variability in travel times on the Regional service. The factors discussed here are those that influence variability in the number of Regional passengers, on the demand side, as well as those that influence variability in the service performance on Regional trains.

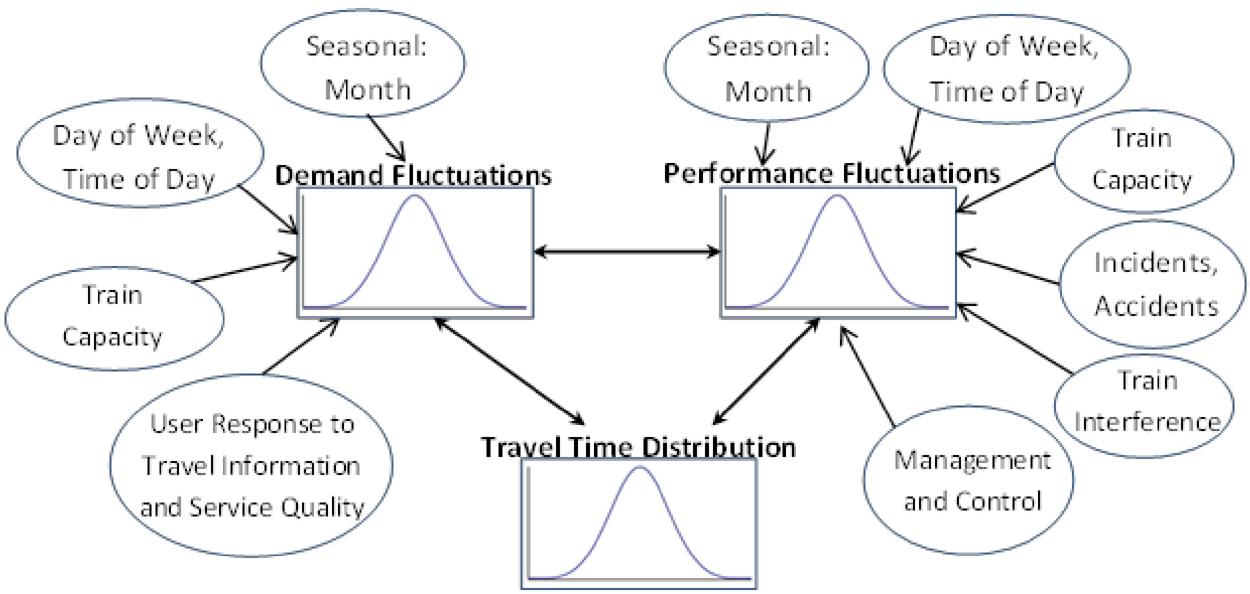

Figure 6.1: Factors affecting Travel Time Distribution on the Regional Service

In this chapter, the factors that cause fluctuations of both Regional ridership and service performance area captured under three main categories:

i) Seasonality and month of year,

ii) Day of week, and time of day, and

iii) Capacity levels on the trains.

Other factors considered in this chapter causing either ridership or performance fluctuations are:

i) Performance disruptions due to accidents and incidents (e.g. signal failures, weather-related, track work, etc.),

ii) Performance interruptions as a result of train interferences,

iii) Performance variations due to administration, management and control elements, and

iv) Demand responses to travel information and service quality.

Each of these factors will be individually investigated in the different sections of this chapter. Firstly, **Section 6.1** shows the distribution of actual delays on Regional trains, and examines the relationship between delays and on-time performance. **Section 6.2** presents the annual, seasonal and month of year fluctuations in the ridership (demand) and performance of Amtrak's Regional service (supply) between FY 2005 to FY 2014. **Section 6.3** drills further down into day-of-week and time-of-day variations in both ridership and service performance, and highlights any relationships between them. This section will directly answer the question about whether poor performance leads to even poorer performance. **Section 6.4** is on the First Train Analysis, which examines the en-route delays on the first trains of the day, comparing the scheduled performance to the average actual performance at each station on Regional trains. **Section 6.5** focuses on service performance disruptions caused by accidents and incidents (e.g. signal failures, weather related, track work, etc.), including their effects on delays and train cancellations. **Section 6.6** analyzes the capacity on Regional trains between FY 2005 and FY 2014, which on the demand side, affects the number of people able to ride Regional trains, and on the supply side, affects the overall performance of operated Regional trains. **Section 6.7** presents a preview of the relationship between the service quality and demand of the Regional service. Finally, **Section 6.8** concludes the chapter with a summary of the prior sections.

6.1 Regional Travel Time Variability

As discussed in the context of Acela trains, travel time variability is a measure of service performance, and is often measured by on-time performance (OTP) or minutes of delay. However both metrics capture different aspects of performance; while the minutes of delay reveals the **magnitude** of delay, the OTP shows the **frequency** of good performance. Both metrics are discussed and compared in this section.

6.1.1 Distribution of Delay

Figure 6.2 shows the distribution of end-to-end delays encountered on all Regional trains operated in FY 2014. The performances on the ~22,000 Regional trains operated in FY 2014 are reflected in the delay distribution. On time arrivals at the terminating station are represented as trains with negative (<0) and zero delays; late trains have positive delay values (>0). The distribution of the delays on Regional trains in FY 2014 is very similar to that of Acela trains. In both, 42% of trains arrived earlier than or at the scheduled arrival time, and 58% of all scheduled trains arrived at the terminating station later than scheduled. In addition, on both the Acela and Regional services, 29% of trains arrived within 10 minutes of the scheduled arrival time. However, compared to Acela, more Regional trains arrived with a delay greater than 30 minutes. Altogether, 71% of Regional trains arrived within 10 minutes of the scheduled arrival time, and 29% arrived more than 10 minutes late.

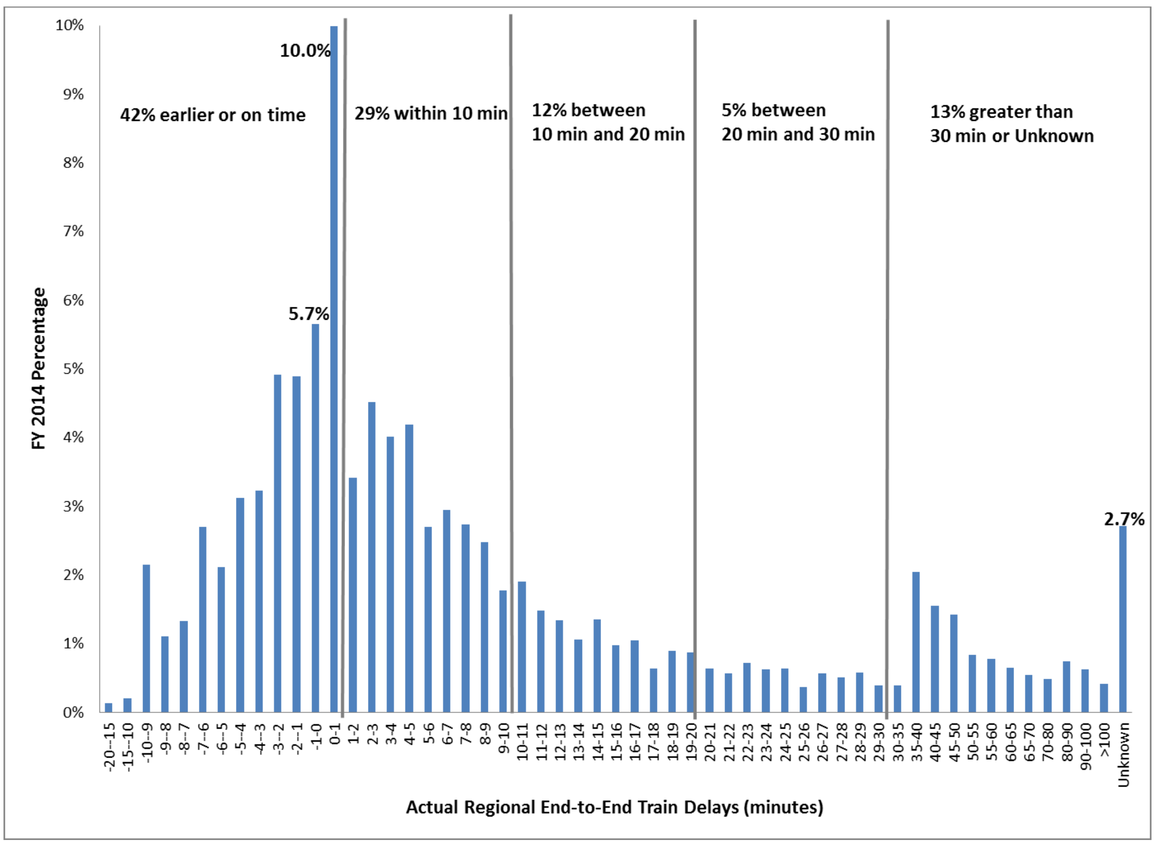

Figure 6.2: Distribution of Actual FY 2014 End-to-End Regional Train Delays

6.1.2 On-Time Performance versus Average Delay

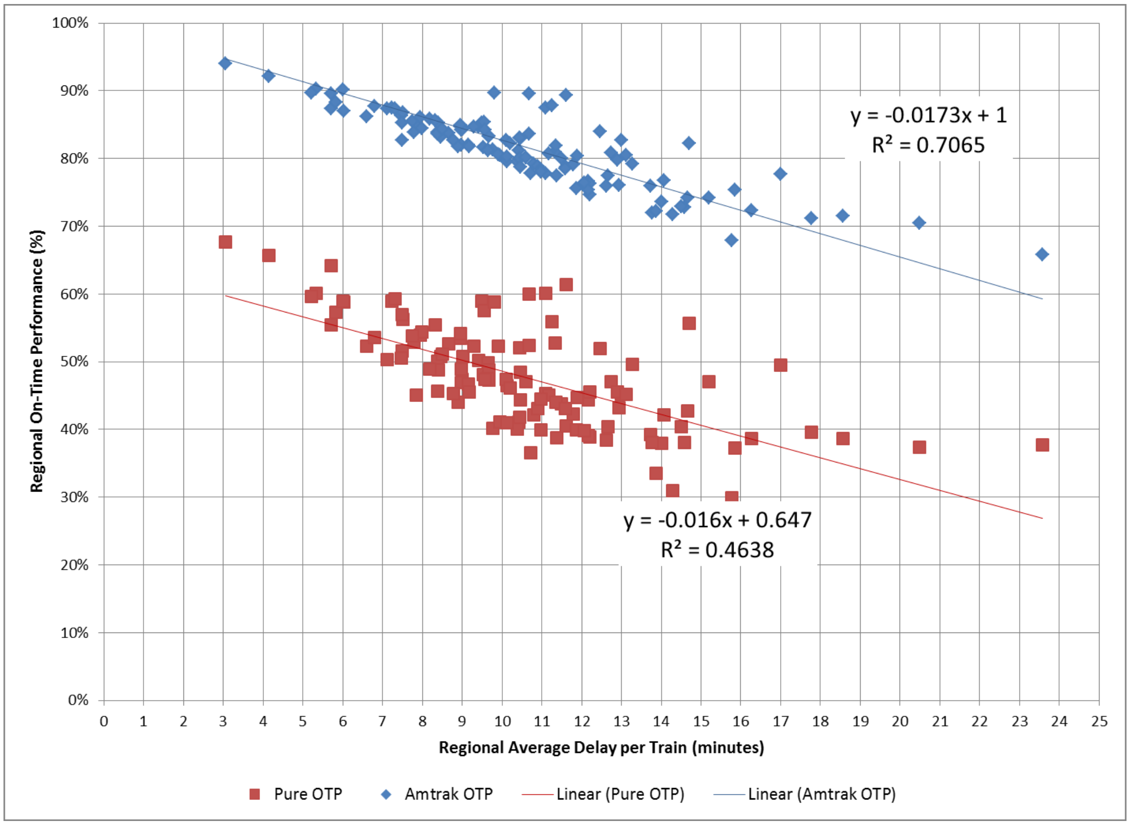

Figure 6.3: Regional On-Time Performance versus Average Delay/Train

Figure 6.3 shows the relationship between the monthly on-time performance and average delay per train on the Regional trains operated between FY 2005 and FY 2014. Currently, Amtrak's on-time threshold for Regional trains is 10 minutes for trains under 250 miles, and 20 minutes for trains over 250 miles. The blue data points represent Amtrak OTP (assuming a 10-20 minute delay tolerance) while the red data points represent Pure OTP (assuming a zero-delay tolerance). The simple regression shows a linear relationship between OTP and average delay per train, including the linear trend line equation and correlation factor (R^2). Unlike the Acela, some of the data points for Regional do not fall close to the linear function, which suggests that the monthly average delay per train and monthly OTP are not highly correlated. This is likely due to the fact unlike the Acela service, the on-time threshold on the Regional service varies by distance, and the number of scheduled Regional services also varies by day of week. That said, the R^2 between the monthly average delay per train and monthly Amtrak OTP is about 70% (compared to 87% on the Acela), which suggests that although the correlation is not perfect (equal to 1), the metrics are still sufficiently correlated and can be substituted for one another if needed.

6.2 Regional Annual and Monthly Riders, On-Time Performance and Delays

This section investigates the annual, seasonal and month of year fluctuations in the ridership and performance of Amtrak's Regional service between FY 2005 to FY 2014.

6.2.1 Annual Regional Riders

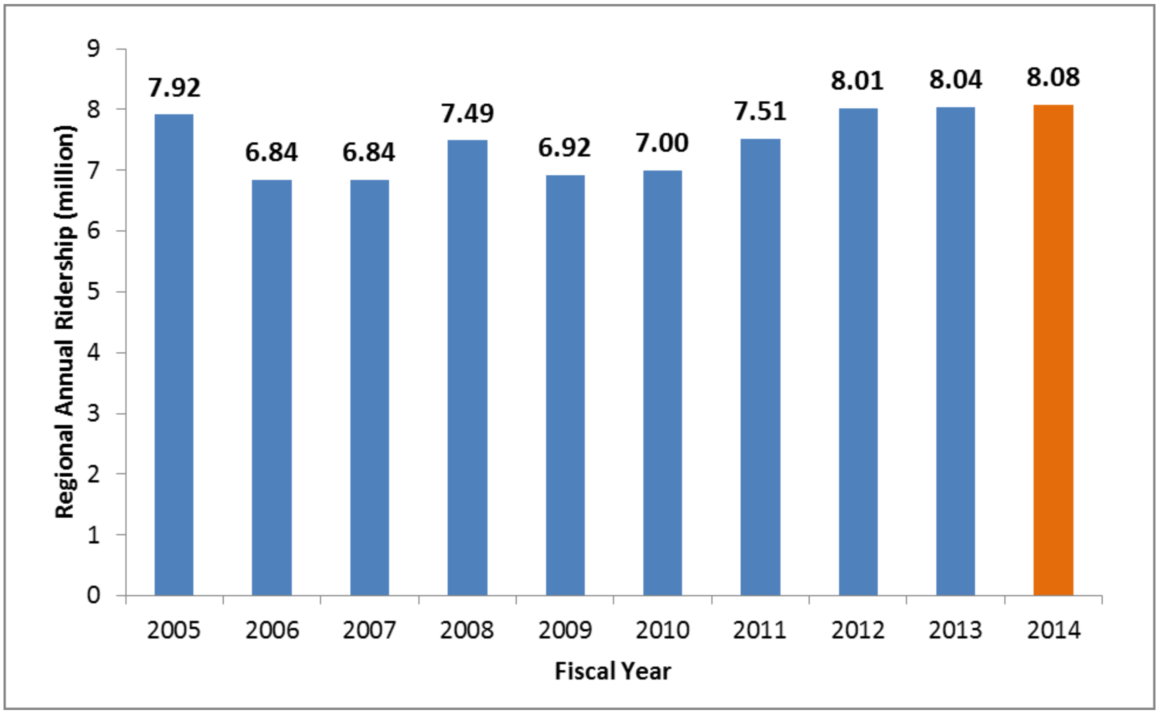

Figure 6.4: Regional Annual Ridership

Figure 6.4 shows the total Regional ridership between FY 2005 and FY 2014, highlighting the year-to-year variations. Unlike Acela that saw a 13% increase in ridership between FY 2005 and FY 2006, the Regional service experienced a 14% ridership decrease between FY 2005 and FY 2006. This was likely due to cannibalization of Regional demand by Acela service as it continued to grow in popularity around FY 2006. Regional ridership remained steady at 6.8 million in FY 2006 and FY 2007, and increased by 10% in FY 2008. Similar to the Acela service, Regional demand was greatly impacted by the recession that lasted through late 2008 and 2009, which led to an 8% drop in FY 2009 ridership. Following the recession, Regional ridership grew by 7% in both FY 2011 and FY 2012, but seems to have plateaued in the last three years. However, in FY 2014 Regional service experienced a record high of 8.1 million riders, which compared to pre-recession in FY 2008 was an 8% growth. The seasonal and month of year variations are explored in the next section.

6.2.2 Riders by Month

Regional demand exhibits fairly consistent patterns within the months of each year. The seasons and holidays largely influence travel patterns and in turn, the demand and ridership on Regional trains. Figure 6.5 shows the total ridership by month on the Regional service from FY 2005 to FY 2014. Typically, the months with the lowest travel on the Regional are in January and February, coinciding with the end of the winter holiday and vacation, while the ridership at the beginning of each fiscal year (October, November and December), and through the spring and summer months are usually much higher. Excluding January and February, the monthly demand for Regional does not appear to vary very much. For example, the total demand in FY 2014 was roughly 700,000 each month (except in January and February). This suggests that Regional passengers might be regular riders, who have similar travel patterns throughout the year.

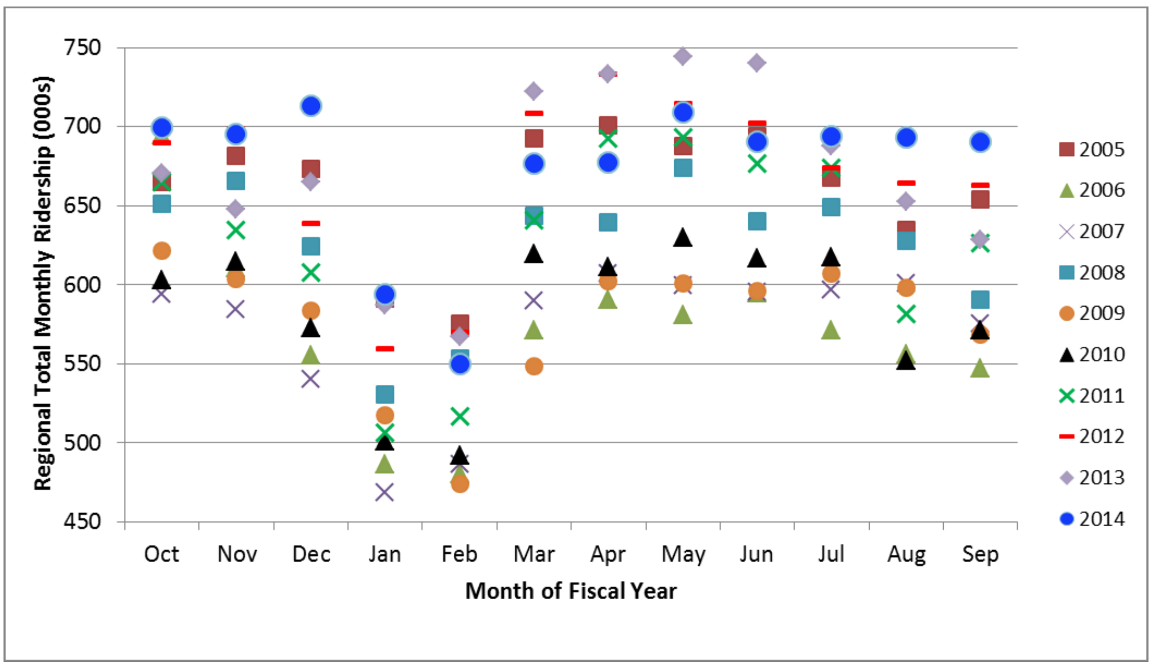

Figure 6.5: Regional Monthly Ridership

6.2.3 On-Time Performance by Month

Figure 6.6 shows Regional on-time performance by month for FY 2005 to FY 2014. Unlike Regional ridership, the on-time performance appears to vary between months. The winter months (November, December, January and February) experienced a wide variation in OTP. For example, the Regional OTP for the month of <u>January</u> was as low as 66% in 2014 but was as high as 89% in 2012. <u>February</u> also experienced a large variation, with an OTP range from 72% to 94% between FY

2005 and FY 2014. Unsurprisingly, the years with severe winters (e.g. 2005, 2010 and 2014) experienced worse performance. Essentially, the service performance in the winter months is largely dependent on the severity of the weather. Although the winter months suffered the worst performance, compared to other months, they also experienced the best service performance in years with less severe winters, while the summer months usually experienced worse performance. In other words, if the severe winter outliers are excluded in each fiscal year, the months with the highest OTP are usually in December, January, February or March, while the months with lowest OTP are usually June, July or August. This is likely because heat restrictions are usually imposed in the summer when the temperature of the track exceeds 120 degrees. The heat restrictions require trains to run at a slower speed, which leads to delays. Furthermore, the absence of constant tension catenary in the Northeast Corridor means that on hot days the overhead power lines droop, which is a safety hazard and also causes additional delays in summer months.

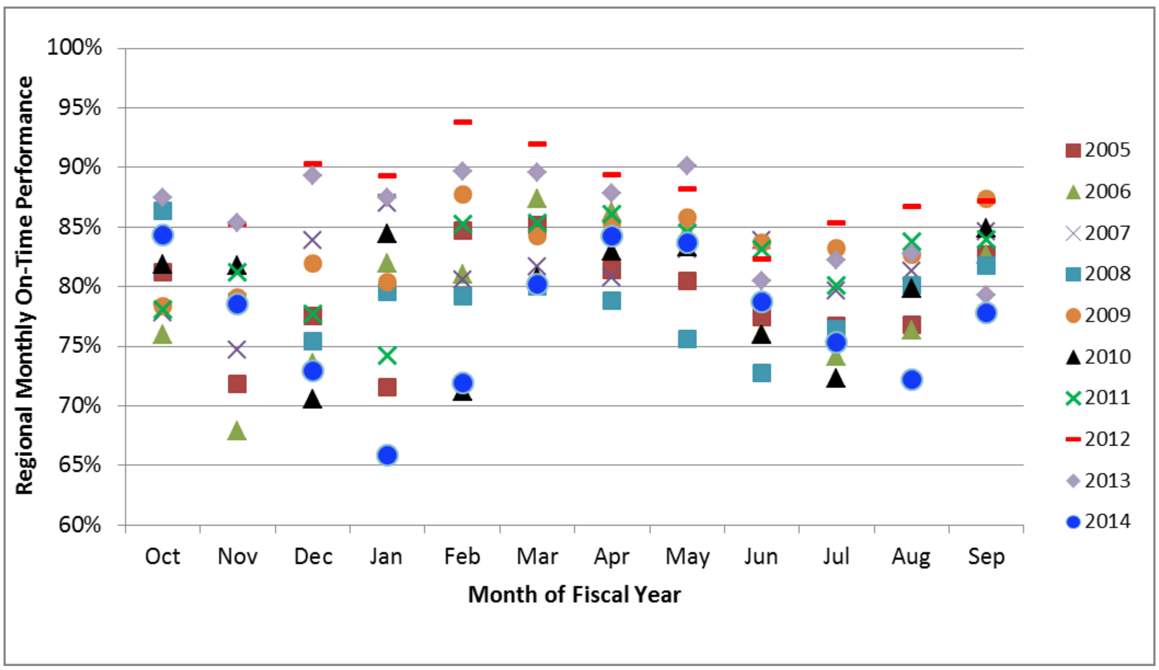

Figure 6.6: Monthly Regional On-Time Performance

Collectively, the Regional OTP in FY 2012 (red dashes) and FY 2013 (purple diamonds) were the highest, while the OTP in FY 2008 (blue squares) and FY 2014 (blue dots), were the lowest. Furthermore, comparing over all years, the Regional OTP in all months in FY 2014 was one of the worst, even after excluding the effect of the harsh winter weather – the Regional OTP was below 85% in all months of FY 2014.

6.2.4 Total Minutes of Delay by Month

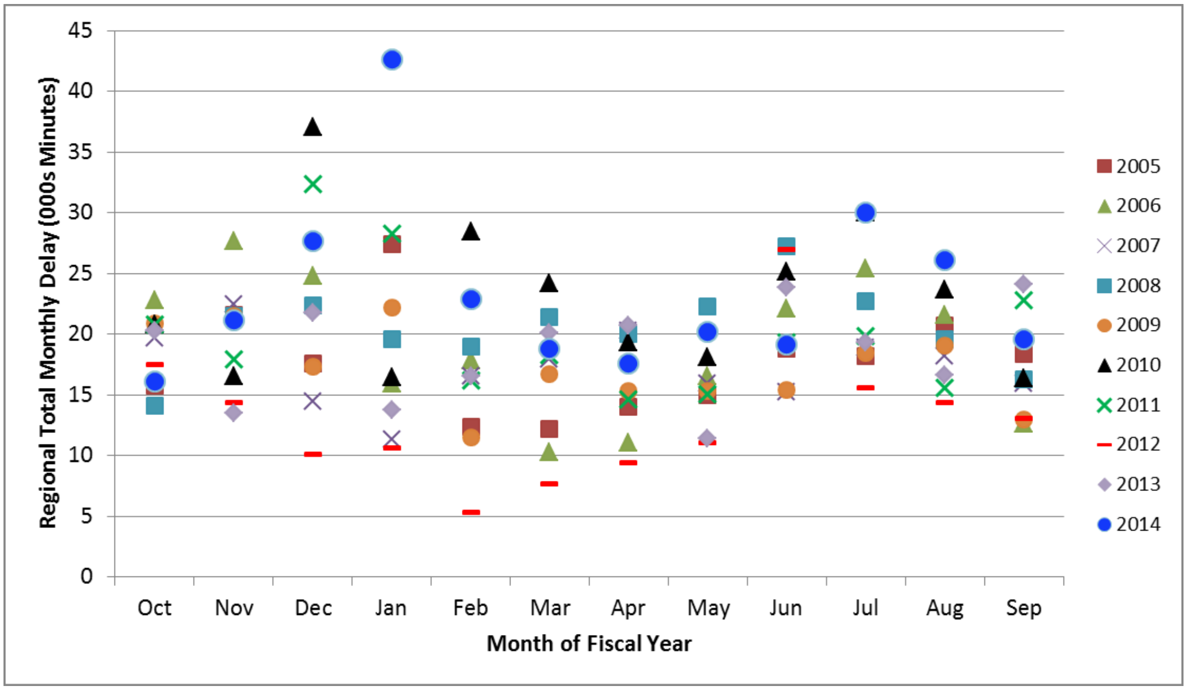

Figure 6.7: Regional Total Monthly Delay

The second supply side performance indicator that was used to investigate seasonal and day of month trends was the delay minutes incurred on operated trains. Figure 6.7 shows total Regional service delay by month for FY 2005 to FY 2014. Similar to the OTP trends, the winter months - December, January and February exhibited a wide variance in the total delay while the summer months exhibited less variance. For example, comparing across January, Regional trains incurred about 42,700 minutes of total delay in January 2014 but only a total of 10,600 delay minutes in January 2012, which is roughly equivalent to 23 minutes per train in January FY 2014 and only 6 minutes per train in January FY 2012. Similar to the observations from the OTP, although the winter months suffered the worst delays, compared to other months, they also experienced the least delays in years with less severe winters, while the summer months typically experienced higher delays. Furthermore, even though the performance in July was generally not the worst, the amount of delay incurred was usually relatively high (>15,000) compared to other months, likely due to summer track work.

Collectively, the total monthly Regional delay in FY 2012 (red dashes) and FY 2006 (green triangles) were the lowest (best), while the total monthly delay in FY 2010 (black triangles) and FY 2014 (blue dots) were the highest (worst).

In summary,

vii. In FY 2014 Regional service experienced a record high of 8.1 million riders

viii. Excluding January and February, Regional ridership exhibited minimal variation between the months of the year, which suggests that Regional riders have similar travel patterns throughout the year.

ix. Unlike the ridership, the performance on the Regional service varied within the same month in different years. Compared to summer months, the winter months exhibited a large variance due to the effects of mild and severe winter seasons on performance. Nonetheless, the best on-time performances were usually in the winter months.

x. Additionally, the performance on the Regional service varied across different months in the same fiscal year. Although the summer months exhibited less year-to-year variance, on a month-to-month comparison (excluding the severe winter months), the amount of delays were usually higher in the summer due to routinely scheduled track works, heat restrictions and infrastructures issues (catenary wire drooping).

xi. Between FY 2005 and FY 2014, the best Regional performance was in FY 2012 while the worst performance was in FY 2014.

xii. Compared to the Acela service, Regional service had almost 2.5 more riders in FY 2014. Additionally, Regional trains experienced more delays, probably because the Regional is a more local service with more frequent stops along the corridor.

6.3 Daily Variations in Performance and Ridership

This section begins with an overview of the impacts of service performance on daily train operations and daily ridership, and then focuses on the day-of-week and time-of-day variations on both Regional ridership and service performance. Except for the day of week analysis, the daily variations are presented only for the years where Regional service experienced the best performance (FY 2012) and the worst performance (FY 2014). The reasoning behind this is that the systematic portion of the day-of-week and time-of-day fluctuations in the other years not shown are likely similar to either FY 2012 or FY 2014, thus presenting the redundant information might not add additional value to the discussion.

6.3.1 FY 2012 and FY 2014 Daily Delays: Trains

In both FY 2012 and FY 2014, Amtrak scheduled 64 Regional trains on Mondays, Tuesdays and Wednesdays, 65 trains on Thursdays, 67 trains on Fridays, 51 trains on Saturdays, and 53 trains on Sundays, except on holidays. Figure 6.8 shows the daily total and delayed Regional trains in FY 2012, with the gray area representing the total number of scheduled trains. The spike in the chart occurs on the days before Thanksgiving on which Amtrak scheduled 9 additional Regional trains.

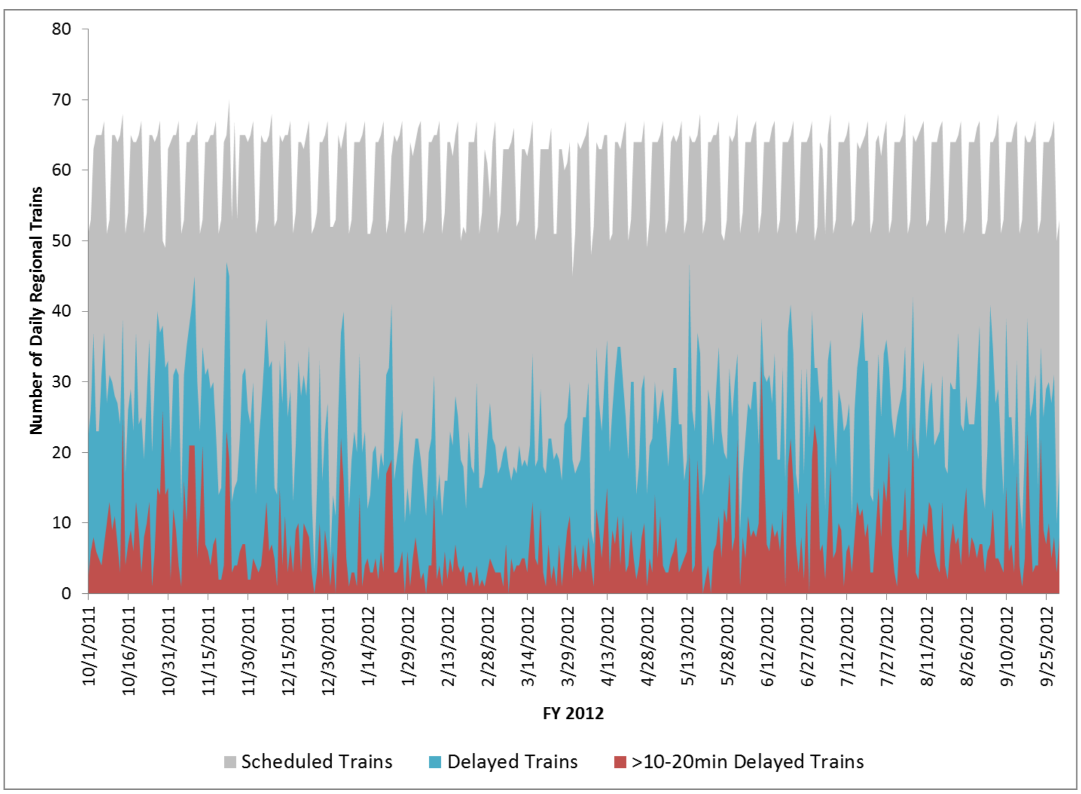

Figure 6.8: FY 2012 Total and Delayed Regional Trains

The blue bars represent the total number of trains in FY 14 that arrived at their final destination after the scheduled arrival time, while the red bars represent those that arrived late under Amtrak's PRIIA standards with a delay greater than 10 minutes for Regional trips under 250 miles and greater than 20 minutes for Regional trips over 250 miles.

In FY 2012, about 41% of all scheduled Regional trains (e.g. 26 of 64 trains on a given Monday) arrived at their final destination after the scheduled arrival time, and about 12% (e.g. 8 of 64 trains on a given Monday) arrived with a delay greater than the PRIIA standards (10 to 20 minutes depending on trip distance). Compared to Acela trains in FY 2012, about 6% more Regional trains were late.

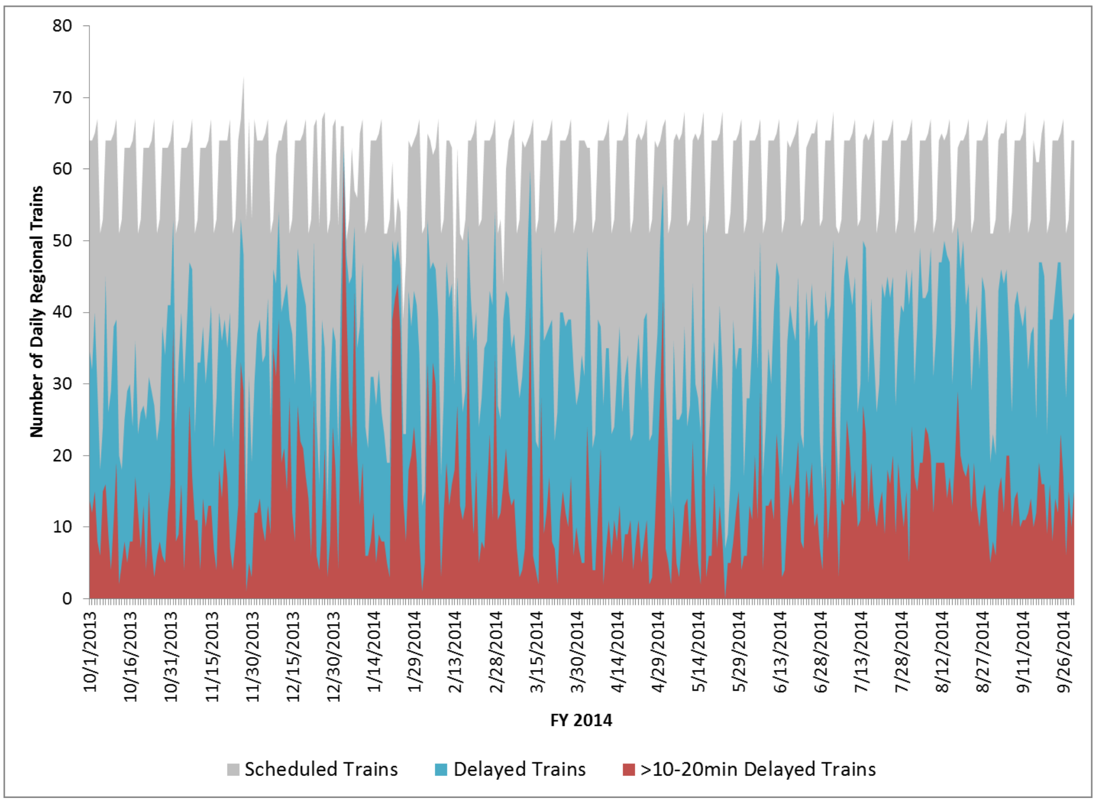

Figure 6.9: FY 2014 Total and Delayed Regional Trains

Figure 6.9 shows the blue and red bars in FY 2014 are much longer than in FY 2012, indicating a higher number of delayed trains compared to schedule. In FY 2014, 58% of all scheduled Regional trains (e.g. 37 of 64 trains on a given Monday) arrived at their final destination after the scheduled arrival time (blue bars), and roughly 23% of Regional trains (15 of 64) arrived more than 10 or 20 minutes later than the scheduled arrival time.

6.3.2 FY 2012 and FY 2014 Daily Delays: Riders

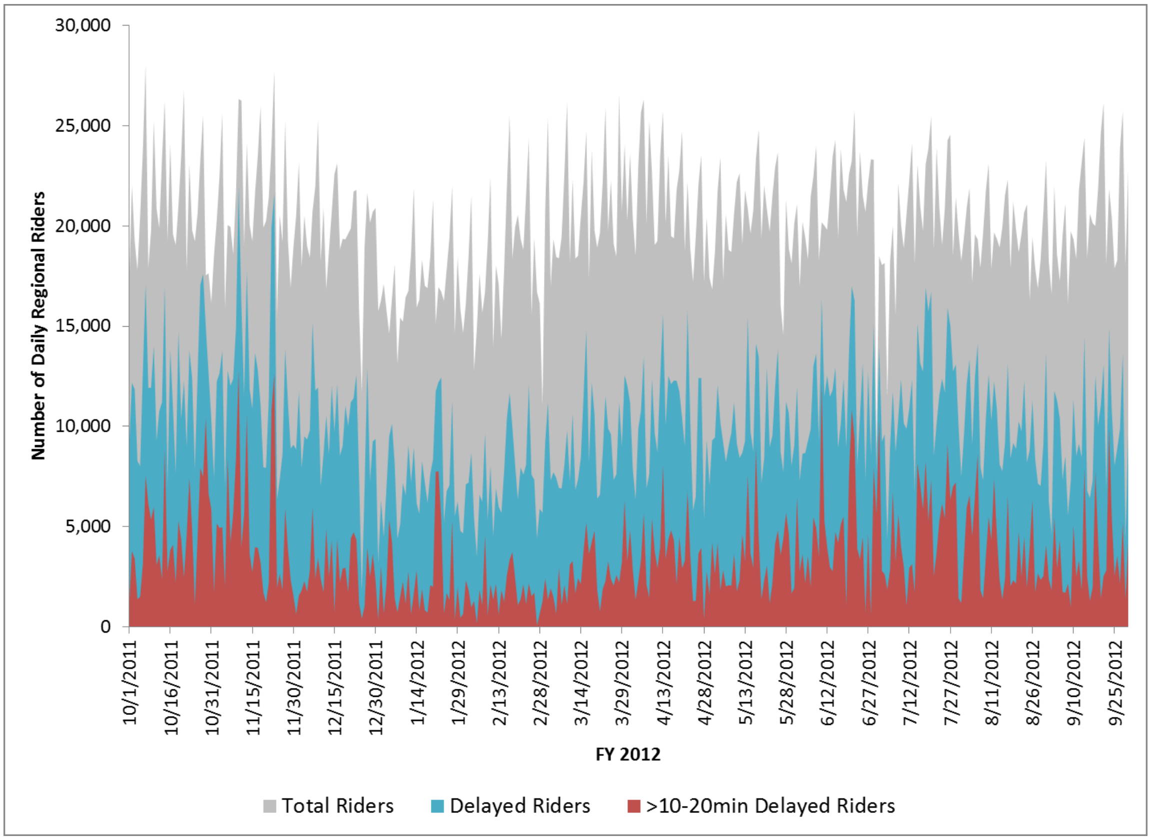

Figure 6.10: FY 2012 Total and Delayed Regional Riders

In Figure 6.10 the gray bars corresponds with the total number of daily Regional riders In FY 2012, the blue bars corresponds with the number of daily riders that arrived at their destination after the scheduled arrival time, and the red bars show the number of daily Regional riders that experienced delays greater than the PRIIA threshold, that is, 10 minutes for trips under 250 miles and greater than 20 minutes for trips over 250 miles.

The gray area shows low daily ridership between 12/15/2013 and 2/13/2014, and peak daily ridership around the 10/13/2014 and 11/30/2012 over the Columbus and Thanksgiving holidays. In FY 2012, half of all Amtrak Regional riders, that is about 4 million riders arrived at their destination after the scheduled arrival time, and 18% of Amtrak Regional passengers, that is about 1.5 million riders arrived at their destination on a train that was more than 10 or 20 minutes late. Compared to Acela riders in FY 2012, about 6% more Regional riders experienced delays.

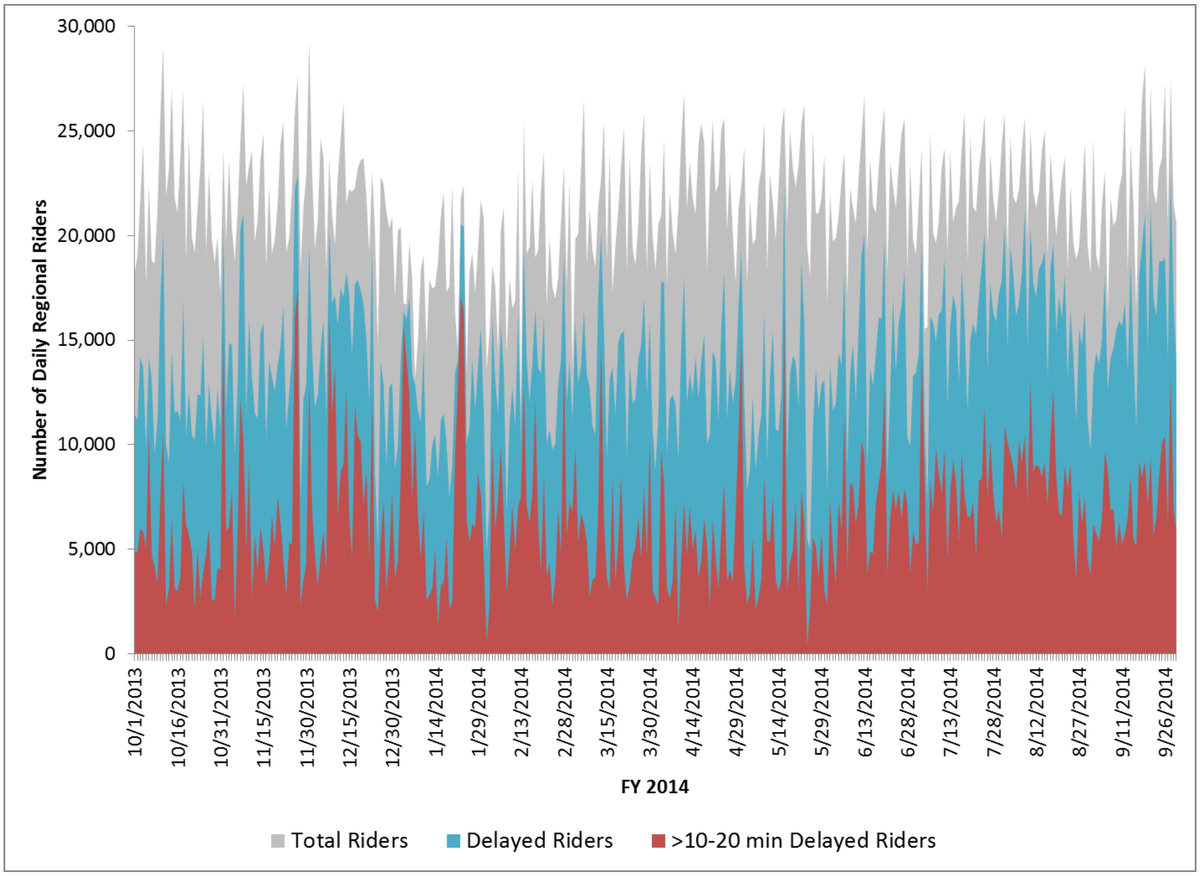

Figure 6.11: FY 2014 Total and Delayed Regional Riders

Figure 6.11 shows the FY 2014 total and delayed Regional riders. Similar to the earlier observation, the gray area shows low ridership over the winter holiday, and peak ridership around the Columbus and Thanksgiving holidays. In FY 2014, 66% of all Amtrak Regional riders, that is about 5.3 million riders arrived at their destination after the scheduled arrival time, and 31% of Amtrak Regional passengers, that is about 2.5 million passengers arrived at their destination on a train that was more than 10 to 20 minutes late. Compared to the Acela riders in FY 2014, roughly the same proportion of Regional riders experienced delays. Furthermore on the Regional, some days in January (red spikes between 12/30/2014 and 1/29/2014) impacted by the Polar Vortex had more than 90% of Regional passengers experiencing some delay, and more than 70% experienced delays above the 10 to 20 minute PRIIA threshold.

In summary, even in the best performing year, FY 2012 as many as 41% of scheduled trains (26 of 64) and 50% of traveling passengers arrived at their final destination after the scheduled arrival time, and as many as 12% (8 of 64) of trains and 18% of passengers arrived late with delays greater than 10-20 minutes. By FY2014, the numbers of late trains and late passengers had almost doubled.

6.3.3 Day of Week Performance

Figure 6.12 shows the average daily ridership (dotted lines) and average daily delay per mile (solid lines) on Regional trains by day of week for FY 2014 (in red), FY 2012 (in blue), and averages over FY 2005 to FY 2014 (in green). The averages over FY 2005 to FY 2014 were included in this analysis to ensure that random disruptions or calendar effects that might have affected Regional operations and service performance on a specific weekday did not bias the day of week patterns. In other words, the FY 2005-FY 2014 values reflect averages over many more days.

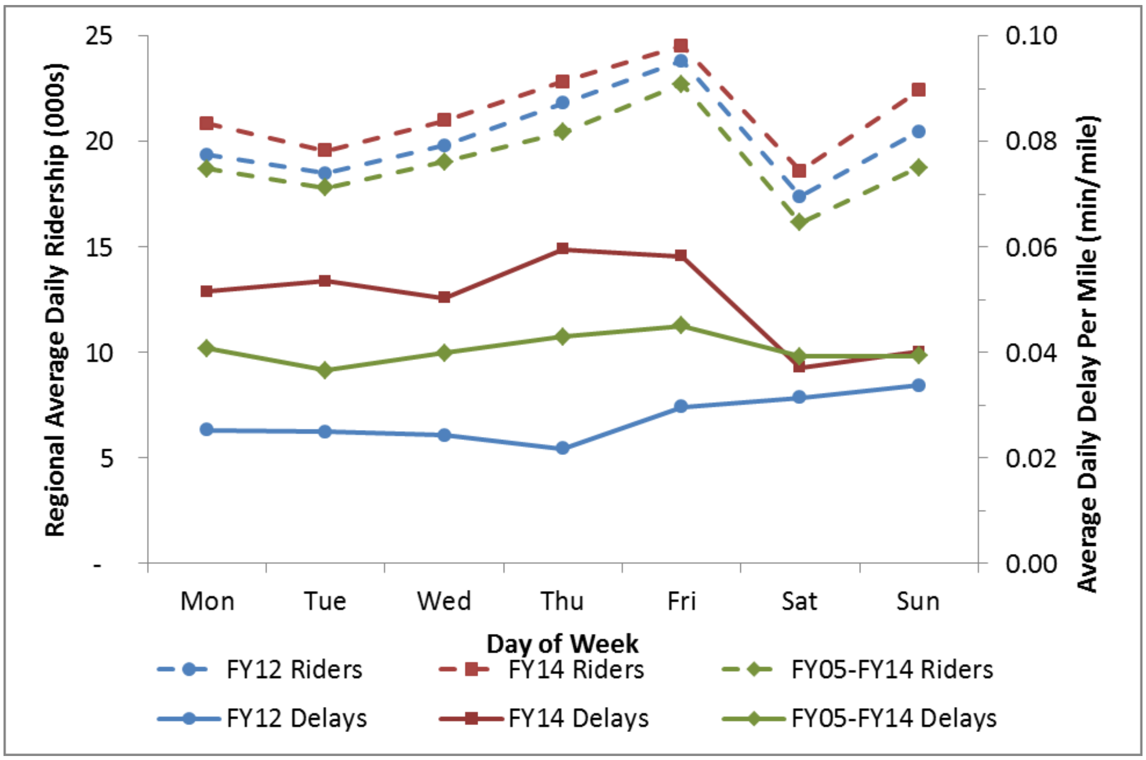

Figure 6.12: Regional Average Ridership and Delay by Day of Week

Firstly, focusing on the ridership (dotted lines), the Regional trend by day of week exhibited the same pattern in FY 2012, FY 2014, as well as over the 10-year period (FY 2005 – FY 2014). The average ridership on Regional was typically lowest on Saturdays compared to the average weekday and Sunday ridership. Unlike the Acela, which had low ridership volumes on both Saturdays and Sundays, the Regional ridership level on Sundays was comparable to weekday ridership. This is likely due to the fact that Acela riders are mainly business passengers traveling during the week while Regional riders are more leisure passengers with majority of trips at the end of the week on Fridays and as the week begins on Sundays. Of the weekdays, the ridership on Tuesdays was typically the lowest, followed by similar ridership levels on Mondays and Wednesdays, higher ridership on Thursdays, and peak ridership on Fridays. In FY 2012, the average daily ridership on Saturdays was 17,400 compared to 20,500 on Sundays, and on average 20,700 on weekdays. In FY 2014, the average daily ridership on Saturdays was 18,600 compared to 22,400 on Sundays, and on average 21,800 on weekdays.

The average delay per mile (solid lines in Figure 6.12) exhibited different day of week patterns in FY 2012 and FY 2014. This emphasized the value of presenting the averages over the 10-year period (FY 2005 to FY 2014), which might reflect patterns closer to the true day of week proportions since they represent averages over many more days. For example, in FY 2012 and FY 2014, there were only 53 Mondays; however, there were 523 Mondays between FY 2005 to FY 2014. From the FY 2005 to FY 2014 averages (solid green line), although the delays on the Regional service were similar for all days of the week, Regional trains appeared to encounter slightly more delays on Mondays and Fridays and slightly fewer delays on Tuesdays and Saturdays. The OTP by day of week on the Regional service were explored to see if they exhibited a day of week pattern similar to average delay.

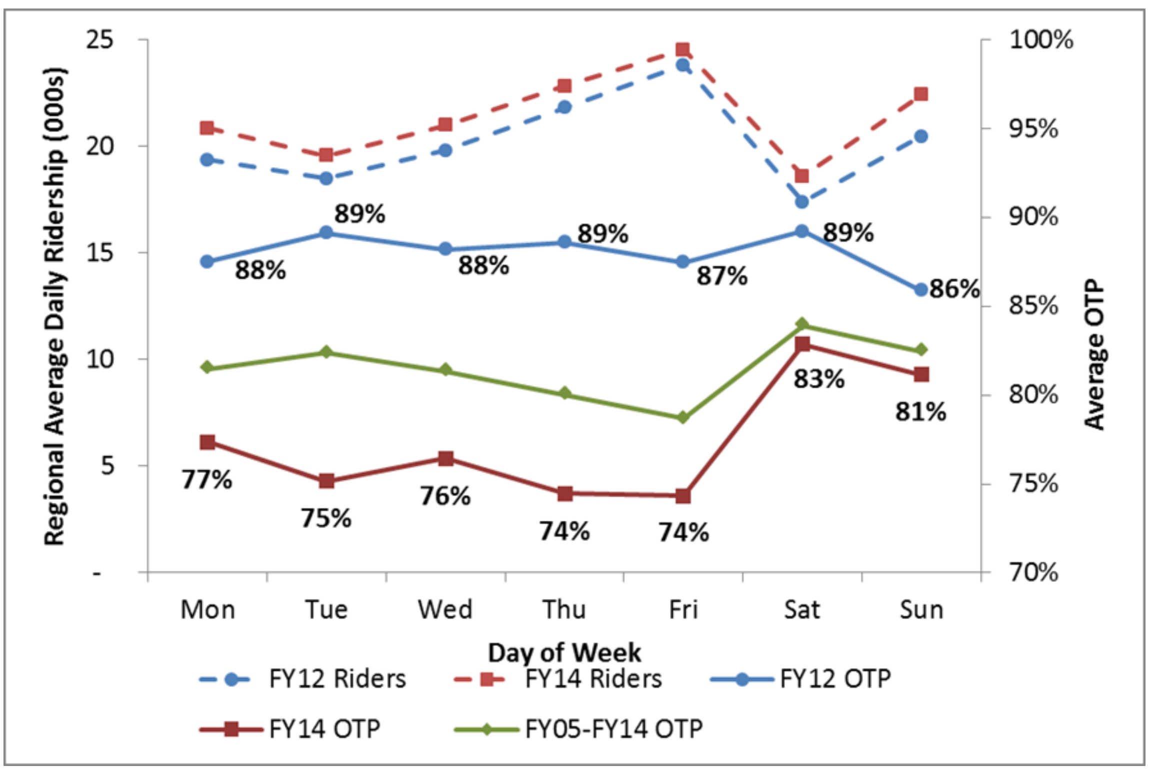

Figure 6.13: Average Ridership and OTP by Day of Week

Figure 6.13 shows a similar chart (to Figure 6.12) but with average on-time performance instead of average delay by day of week. The dotted lines represent ridership and the solid lines represent on-time performance (OTP). In FY 2012 the average OTP (solid blue line) was roughly the similar on all days of the week, while in FY 2014 the average OTP (solid red line) varied considerably by day of week. In comparison, over the 10-year averages (FY 2005 – FY 2014 in green), which theoretically provide a more accurate representation of actual day of week performances, Regional performance appeared to be the best on Saturday and Sundays, and worst on Fridays. This seems reasonable since the number of scheduled Amtrak trains is lower and commuter services usually also have fewer trains in operation on weekends.

Furthermore, the performance on the Regional service looked like the reverse of the Regional ridership. This suggests that higher Regional demand on certain days of the week might be associated with poorer performance.

In summary, Regional ridership volumes were lowest on Saturdays and highest on Fridays. Additionally, unlike Acela, Regional ridership on Sundays was relatively high. The high ridership volumes are likely because Regional riders are more leisure passengers with majority of trips at the end of the week on Fridays and as the week begins on Sundays. Finally, of the weekdays, Tuesdays had the lowest ridership. In terms of performance, overall, performance appeared to be roughly the same on all days of the week; however, it was usually slightly better on Tuesdays, Saturdays and Sundays, and slightly worse on Fridays. The weekend improvements were likely because fewer Amtrak and Commuter services operate on weekends.

6.3.4 Time of Day Performance

This section explores the performance of Regional trains by time of day. However the Northeast Corridor is very long and each train crosses multiple time periods between departure at originating station and arrival at the terminating station. Consequently, the time of day analysis in this section is based on the departure times of train by direction and originating station. A more comprehensive time of day analysis might include train departure and arrival times at each station on the NEC.

In the time of day analysis, each Regional train is categorized by market and further classified into origin-destination routes as: NYP-WAS, NYP-PHL (Keystone trains that serve NYP and PHL but terminate in the Keystone segment west of PHL), BOS-NYP, and BOS-WAS. Table 6.1 summarizes the level of service characteristics of the Regional train routes. The scheduled travel times are provided as ranges to indicate that trains are sometimes scheduled with different end-to-end travel times based on the actual stopping patterns of the train.

Service	Route	Market	Distance (miles)	Scheduled Travel Time (hr:min)
Regional	New York – Washington (NYP–WAS)	South End	226	3:12 to 3:39
	New York – Philadelphia (NYP–PHL)	South End	91	1:20 to 1:25
	Boston - New York (BOS-NYP)	North End	231	4:00 to 4:20
	Boston – Washington (BOS-WAS)	Through	457	7:40 to 8:05

Table 6.1: Level of Service for Regional Train Route Groups

Table 6.2 shows the average Amtrak OTP (10-minute delay threshold) and average delay per train (no threshold) for southbound (SB) Regional trains on weekdays in FY 2012 and FY 2014. The averages are over the 261 weekdays each year. The southbound trains are further classified into origin-destination routes (as summarized in Table 6.1). Intuitively, the NYP-PHL trains are likely to have the best performance due to the short trip length and fewer stops, and the BOS-WAS trains are likely to encounter the most delays since they travel the longest distances and have more stops. This speculation is confirmed in Table 6.2, which shows that the southbound NYP-PHL trains had the best performance in both FY 2012 and FY 2014, and the BOS-WAS trains had approximately 10% lower OTP than the NYP-WAS trains, and also roughly double the amount of average delay per train on the NYP-WAS trains. This suggests that delays accumulate along the length of the corridor.

Weekdays Only (261 of 365 days)					FY 2012		FY 2014	
Train No	Route	Direction	O-D	Departure Time	Amtrak OTP*	Avg. Delay per train (min)	Amtrak OTP*	Avg. Delay per train (min)
151	Regional	SB	NYP-WAS	4:40:00 AM	96%	1.73	86%	6.14
111	Regional	SB	NYP-WAS	5:30:00 AM	94%	2.68	85%	7.21
181	Regional	SB	NYP-WAS	6:10:00 AM	81%	5.95	78%	7.98
79	Regional	SB	NYP-WAS	7:05:00 AM	77%	8.41	66%	13.69
183	Regional	SB	NYP-WAS	7:17:00 AM	91%	4.67	72%	10.72
185	Regional	SB	NYP-WAS	8:10:00 AM	88%	4.64	69%	14.67
125	Regional	SB	NYP-WAS	11:35:00 AM	85%	5.76	63%	15.86
133	Regional	SB	NYP-WAS	1:09:00 PM	63%	12.01	53%	17.02
85	Regional	SB	NYP-WAS	3:05:00 PM	78%	8.42	67%	15.32
127	Regional	SB	NYP-WAS	4:05:00 PM	88%	4.77	76%	11.86
129	Regional	SB	NYP-WAS	4:42:00 PM	80%	7.77	69%	18.58
193	Regional	SB	NYP-WAS	5:39:00 PM	85%	7.52	68%	16.89
187	Regional	SB	NYP-WAS	9:20:00 PM	85%	9.29	75%	13.21
641	Regional	SB	NYP-PHL	7:25:00 AM	93%	3.84	87%	6.65
643	Regional	SB	NYP-PHL	9:30:00 AM	94%	2.49	88%	5.88
43	Regional	SB	NYP-PHL	10:52:00 AM	92%	3.40	72%	10.65
645	Regional	SB	NYP-PHL	12:05:00 PM	94%	2.61	85%	6.09
647	Regional	SB	NYP-PHL	2:11:00 PM	92%	3.65	89%	5.05
649	Regional	SB	NYP-PHL	2:44:00 PM	90%	3.50	89%	3.94
651	Regional	SB	NYP-PHL	4:03:00 PM	93%	1.80	95%	2.39
653	Regional	SB	NYP-PHL	5:10:00 PM	92%	5.24	83%	8.31
655	Regional	SB	NYP-PHL	6:35:00 PM	84%	6.48	69%	11.96
639	Regional	SB	NYP-PHL	11:15:00 PM	92%	3.73	87%	6.54
95	Regional	SB	BOS-WAS	6:10:00 AM	87%	10.40	65%	27.79
195	Regional	SB	BOS-WAS	6:40:00 AM	90%	10.04	64%	25.30
171	Regional	SB	BOS-WAS	8:15:00 AM	90%	7.98	71%	24.28
93	Regional	SB	BOS-WAS	9:30:00 AM	86%	9.00	57%	29.63
83	Regional	SB	BOS-WAS	9:30:00 AM	56%	24.89	48%	29.86
173	Regional	SB	BOS-WAS	11:15:00 AM	89%	9.28	64%	25.73
137	Regional	SB	BOS-WAS	1:40:00 PM	86%	12.31	76%	17.33
175	Regional	SB	BOS-WAS	3:20:00 PM	89%	8.67	69%	22.90
177	Regional	SB	BOS-WAS	5:35:00 PM	85%	12.95	77%	23.84
179	Regional	SB	BOS-NYP	6:45:00 PM	76%	10.15	67%	9.72
67	Regional	SB	BOS-WAS	9:30:00 PM	96%	2.80	92%	8.36
55	Regional	SB	SAB-WAS	8:58:00 AM	88%	14.07	59%	30.23
141	Regional	SB	SPG-WAS	5:55:00 AM	86%	8.54	69%	18.74

*Amtrak OTP for the longest segment with passengers, which is not necessarily the end point station

Table 6.2: Regional SB FY 12 and FY 14 Weekday OTP and Average Delay per Train

In the NYP-WAS group, Train 151 departing NYP at 4:40AM exhibited the best performance, while Train 133 departing at 1:09PM exhibited the worst performance in both FY 2012 and FY 2014.
In the NYP-PHL group, Train 651 departing NYP at 4:03PM exhibited the best performance while Train 655 departing at 6:35PM exhibited the worst performance in both years.

In the BOS-WAS group, the 9:30PM departure from BOS, Train 67 exhibited the best performance while the 9:30AM departure from BOS, Train 83 exhibited the worst performance in both years.
Firstly, it is interesting that even though the overall performance of Regional trains in FY 2012 was much better than in FY 2014, the best and worst performing trains were the same. This suggests that there are systematic disturbances that disrupt the trains on a regular basis. Furthermore, the best and worst performing trains were not time-of-day consistent across the different groups. For example, the first train of the day at 4:40AM was the best in the NYP-WAS group but one of the last trains of the day at 9:30PM performed the best in the BOS-WAS group. The fact that some of the morning trains exhibited bad performance while some of the afternoon and end of day trains exhibited better performance suggests that the cascading effects from trains interfering with each other might not be present in the data.

Table 6.7 shows the Regional trains that travel northbound (NB) on the Northeast Corridor. Although similar to the SB trains, the NB trains exhibited worse performance as trip length increased; collectively, the NB trains performed better than the SB trains. In addition, comparisons between the best and worst performing trains in FY 2012 and FY 2014 show similar relative performances, again suggesting systematic disturbances on the NEC. Lastly, likewise the best and worst performing trains in each segment were not time-of-day consistent, which suggest that trains are not necessarily interfering with one another

In summary, similar to the Acela service, the Regional trains exhibited distance-related deteriorations, suggesting that delays accumulate as trains stopped to serve more stations along the corridor. Furthermore, just like the Acela, the first Regional train of the day was not able to achieve consistent on-time arrivals even though there was no other train or at least fewer trains in the system to slow them down. Consequently, a detailed station-level analysis of the first Regional trains of the day was done and discussed in Section 6.4

Weekdays Only (261 of 365 days)					FY 2012		FY 2014	
Train No	Route	Direction	O-D	Departure Time	Amtrak OTP*	Avg. Delay per train (min)	Amtrak OTP*	Avg. Delay per train (min)
190	Regional	NB	WAS-BOS	3:15:00 AM	91%	8.36	83%	14.14
170	Regional	NB	WAS-BOS	4:52:00 AM	87%	9.23	76%	15.71
172	Regional	NB	WAS-BOS	7:25:00 AM	87%	9.62	68%	21.97
56	Regional	NB	WAS-SPG	8:10:00 AM	84%	8.61	69%	16.88
86	Regional-RVR	NB	WAS-BOS	8:40:00 AM	90%	6.52	73%	18.34
174	Regional-NFK	NB	WAS-BOS	10:20:00 AM	91%	9.59	75%	18.36
176	Regional-LYH	NB	WAS-BOS	12:02:00 PM	87%	12.71	83%	13.70
94	Regional-NPN	NB	WAS-BOS	2:02:00 PM	86%	10.42	46%	38.93
148	Regional	NB	WAS-SPG	3:02:00 PM	82%	11.01	65%	17.98
178	Regional	NB	WAS-BOS	4:02:00 PM	91%	5.87	81%	20.95
136	Regional	NB	WAS-SPG	5:05:00 PM	88%	11.96	79%	27.38
66	Regional-NPN	NB	WAS-BOS	10:10:00 PM	91%	7.24	87%	11.42
110	Regional	NB	WAS-NYP	4:00:00 AM	84%	6.76	67%	12.58
180	Regional	NB	WAS-NYP	5:30:00 AM	85%	7.58	66%	13.47
130	Regional	NB	WAS-NYP	6:30:00 AM	86%	5.28	77%	8.31
184	Regional	NB	WAS-NYP	9:20:00 AM	81%	8.25	68%	11.37
84	Regional-RVR	NB	WAS-NYP	11:02:00 AM	90%	3.78	75%	9.45
186	Regional	NB	WAS-NYP	1:02:00 PM	90%	4.26	68%	10.64
134	Regional	NB	WAS-NYP	3:30:00 PM	80%	5.89	77%	9.12
80	Carolinian	NB	WAS-NYP	4:06:00 PM	79%	17.32	33%	49.30
196	Regional	NB	WAS-NYP	5:05:00 PM	89%	5.40	79%	9.61
138	Regional	NB	WAS-NYP	6:05:00 PM	79%	9.50	73%	15.99
188	Regional	NB	WAS-NYP	7:10:00 PM	92%	4.57	76%	13.45
198	Regional	NB	WAS-NYP	9:05:00 PM	85%	23.03	70%	22.13
640	Keystone	NB	PHL-NYP	7:00:00 AM	82%	7.89	59%	15.17
642	Keystone	NB	PHL-NYP	9:45:00 AM	90%	4.30	79%	7.65
644	Keystone	NB	PHL-NYP	10:55:00 AM	93%	3.16	74%	10.68
646	Keystone	NB	PHL-NYP	11:45:00 AM	93%	2.36	89%	5.05
648	Keystone	NB	PHL-NYP	1:00:00 PM	97%	1.01	86%	5.41
650	Keystone	NB	PHL-NYP	2:05:00 PM	92%	2.80	89%	4.47
42	Pennsylvanian	NB	PHL-NYP	3:25:00 PM	91%	4.19	81%	8.36
652	Keystone	NB	PHL-NYP	5:18:00 PM	84%	7.92	81%	5.69
654	Keystone	NB	PHL-NYP	6:50:00 PM	96%	2.23	91%	4.56
656	Keystone	NB	PHL-NYP	7:40:00 PM	97%	1.25	88%	4.70
658	Keystone	NB	PHL-NYP	8:35:00 PM	91%	2.78	89%	5.26

Table 6.3: Regional NB FY 12 and FY 14 Weekday OTP and Average Delay Per Train

6.4 First Train Analysis

This section examines the first train of the day in each direction within each market (north-end, south-end and through). In a system where trains interfere with one another, one would expect to see better performing trains in the morning when there are either no other trains or fewer trains in the system to slow each other down. However, the discussion in Section 6.3 showed that this is not the case in Amtrak's Regional system, and the first train of the day routinely encounters considerable amounts of delay. Consequently, this section attempts to track the detailed station-to-station arrivals and departures of the first Regional trains over multiple days to identify causes of delay.

The discussion is divided into three subsections: i) northbound departures from Washington, DC (WAS), (since the first NB Regional train of the day is a through train which serves both the north and south segment, it was not necessary to analyze other NB trains), ii) southbound departures from New York Penn Station (NYP), and iii) southbound departures from Boston South Station (BOS). In each subsection, the average arrival and departure delays for the train at successive stations on the corridor are presented. The delays are calculated as differences between the actual and scheduled arrival and departure times, and are averaged over the 261 weekdays of the year. In the delay calculations, Amtrak was not credited for 'negative delays', that is, arrivals that occurred before the scheduled arrival time are treated as on-time arrivals with zero delays.

6.4.1 First Northbound Regional Train From WAS - Train 190 (3:15AM)

Train 190 is the first northbound Regional train scheduled to depart WAS at 3:15AM and arrive BOS at 11:05AM on weekdays. In FY 2014, it had an on-time performance of 83% and average delay of 14 minutes. Amtrak's scheduled dwell times for Train 190 are – 2 minutes in BAL, 5 minutes in PHL, and 15 minutes in NYP. Figure 6.14 shows the average FY 2014 arrival (light blue) and departure (dark blue) delays for the train at each successive station in the corridor. Firstly, overall the dark blue departure bars are higher than the light blue arrival bars, likely because Amtrak does not schedule terminal time at all stations. Secondly, as assumed in Section 6.3, the delays appear to accumulate along the length of the corridor. Regarding delay accumulation, two unusual delay reductions occur en-route and are highlighted in the chart. The first is at NYP, which shows a 2-minute drop between NWK and NYP, and the second is at RTE, which shows an 8-minute drop between PVD and RTE, suggesting that the timetables are padded to provide an opportunity for the train to "catch up". It was also unusual that despite the dwell time at NYP, the amount of delay jumped by about 4 minutes immediately north of NYP in the segment entering Stamford, CT (STM).

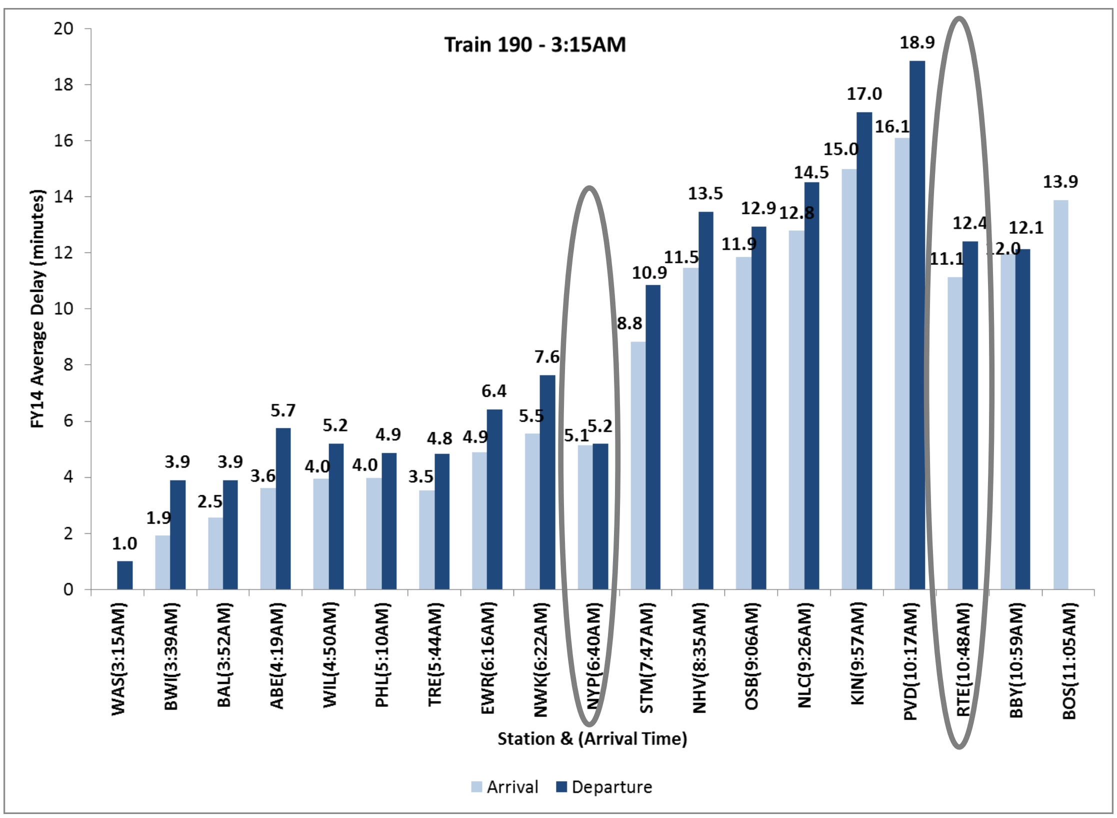

Figure 6.14: FY 2014 Average Station Delays for Train 190

Table 6.4 shows the performance of Train 190 from the segment level and timetable point of view. It shows that in the 32 mile PVD-RTE segment, although the train was scheduled to travel at 62mph, on average it traveled 21mph faster and thus was able to traverse the segment about 8 minutes faster. A similar effect was observed between the scheduled and actual performance on Acela trains in the PVD-RTE segment. This explains the 8-minute delay reduction at RTE that was observed in Figure 6.14. Additionally, although the discrepancy is not as much, Table 6.4 also shows that the train on average travelled about 5mph (1 to 2 minutes) faster than scheduled in some of the south-end segments, including the NWK-NYP segment where the other 2-minute travel delay reduction was observed (at NYP). This further supported the timetable-padding idea that provided an opportunity for trains to "catch up".

Train 190		Scheduled		*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
WAS-BWI	30	3:15 AM	3:39 AM	1.9	24	25	1	75	72	-3
BWI-BAL	11	3:39 AM	3:52 AM	2.5	13	12	-1	51	57	6
BAL-ABE	30	3:54 AM	4:19 AM	3.6	25	25	0	72	73	1
ABE-WIL	39	4:19 AM	4:50 AM	4.0	31	29	-2	75	80	5
WIL-PHL	25	4:50 AM	5:10 AM	4.0	20	19	-1	75	80	5
PHL-TRE	33	5:15 AM	5:44 AM	3.5	29	28	-1	68	72	3
TRE-EWR	45	5:44 AM	6:16 AM	4.9	32	32	0	84	84	0
EWR-NWK	3	6:16 AM	6:22 AM	5.5	6	5	-1	30	35	5
NWK-NYP	10	6:22 AM	6:40 AM	5.1	18	16	-2	33	39	5
NYP-STM	36	6:55 AM	7:47 AM	8.8	52	56	4	42	39	-3
STM-NHV	39	7:47 AM	8:35 AM	11.5	48	49	1	49	48	-1
NHV-OSB	33	8:37 AM	9:06 AM	11.9	29	27	-2	68	72	4
OSB-NLC	18	9:06 AM	9:26 AM	12.8	20	20	0	54	54	0
NLC-KIN	35	9:26 AM	9:57 AM	15.0	31	31	0	68	67	-1
KIN-PVD	27	9:57 AM	10:17 AM	16.1	20	19	-1	81	85	4
PVD-RTE	32	10:17 AM	10:48 AM	11.1	31	23	-8	62	82	21
RTE-BBY	10	10:48 AM	10:59 AM	12.0	11	11	0	55	57	2
BBY-BOS	1	10:59 AM	11:05 AM	13.9	6	8	2	10	8	-2

Table 6.4: Train 190 Segment Level Performance

6.4.2 First Southbound Regional Train From NYP - Train 151 (4:40AM)

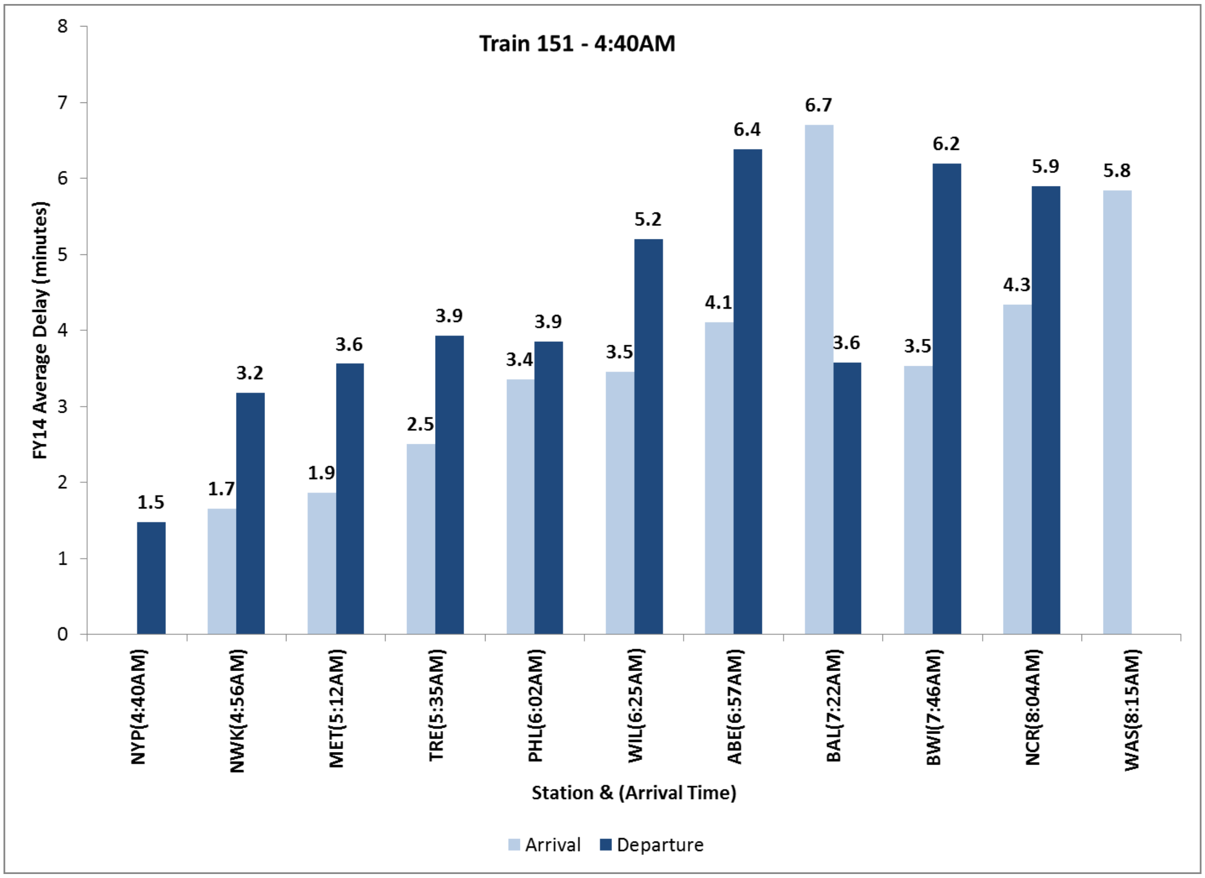

Figure 6.15: 2014 FY 2014 Average Station Delays for Train 151

Train 151 is the first southbound Regional train scheduled to depart from NYP at 4:40AM and arrive at WAS at 8:15AM. There are no Amtrak trains scheduled to operate ahead of this train (The overnight Regional train, Train 67 is scheduled to arrive NYP at 2:15AM and depart NYP at 3:00AM, an hour and 40 minutes before Train 151). Amtrak's scheduled dwell time for Train 151 is 10 minutes at BAL. Figure 6.15 shows the average FY 2014 arrival and departure delays for Train 151. In FY 2014, two of every five trains arrived the end-point terminal later than the scheduled time. On average the actual departure time for the train was almost two minutes later than scheduled. In FY 2014, the delays on Train 151 grew incrementally between each segment along the corridor, peaking around BAL, where it also recovered from some of the upstream delays, likely an advantage of the 10-minute scheduled train dwell time. Nonetheless, the train typically accumulated additional delays south of BAL, and terminated at Washington Union Station (WAS) with an average delay of about 6 minutes.

The Regional trains travelled about 8 mph (2 minutes) faster than scheduled in the BWI-NCR segment as shown in Table 6.5. Like the Acela trains, on average it also travelled faster than scheduled in the NWK-MET segment as well as the MET-TRE segment.

Train 151		Scheduled		*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
NYP-NWK	10	4:40 AM	4:56	1.7	16	16	0	37	37	0
NWK-MET	14	4:56 AM	5:12	1.9	16	15	-1	53	57	5
MET-TRE	34	5:12 AM	5:35	2.5	23	22	-1	89	93	4
TRE-PHL	33	5:35 AM	6:02	3.4	27	26	-1	73	75	2
PHL-WIL	25	6:05 AM	6:25	3.5	20	20	0	75	77	2
WIL-ABE	39	6:25 AM	6:57	4.1	32	31	-1	73	76	3
ABE-BAL	30	6:57 AM	7:22	6.7	25	25	0	72	71	-1
BAL-BWI	11	7:32 AM	7:46	3.5	14	14	0	47	47	0
BWI-NCR	21	7:46 AM	8:04	4.3	18	16	-2	70	78	8
NCR-WAS	9	8:04 AM	8:15	5.8	11	11	0	49	49	0

Table 6.5: Train 151 Segment Level Performance

6.4.3 First <u>Southbound</u> Regional Train From BOS - Train 95 (6:10AM)

Train 95 is the first southbound Regional through-train departure from BOS scheduled to depart from BOS at 6:10AM and arrive at WAS at 2:00PM. Amtrak's scheduled dwell times for the train are – 2 minutes in NHV, 15 minutes in NYP, 3 minutes in PHL, and 8 minutes in BAL. In FY 2014, Train 95 had an on-time performance of 65% and an average delay of 28 minutes.

Figure 6.16 shows that the train usually departed from BOS on average almost a minute later than scheduled, and usually arrived at WAS on average about 28 minutes later than the scheduled time. Overall, the dwell times did not seem to provide enough buffer for the train to recover from upstream delays. The upstream delays appeared to propagate and heighten along the length of the corridor. The delays are typically almost as high as 15 minutes in the first half of the trip, north of NYP, and almost doubles in the south end segments, south of NYP.

Table 6.6 shows the segment level performance for Train 95, which shows that on average, the train travelled about 7minutes faster than scheduled in the OSB-NHV segment, and about 4 minutes faster in the BWI-NCR segment. The Acela trains also appeared to travel faster than schedule in the BWI-WAS segment.

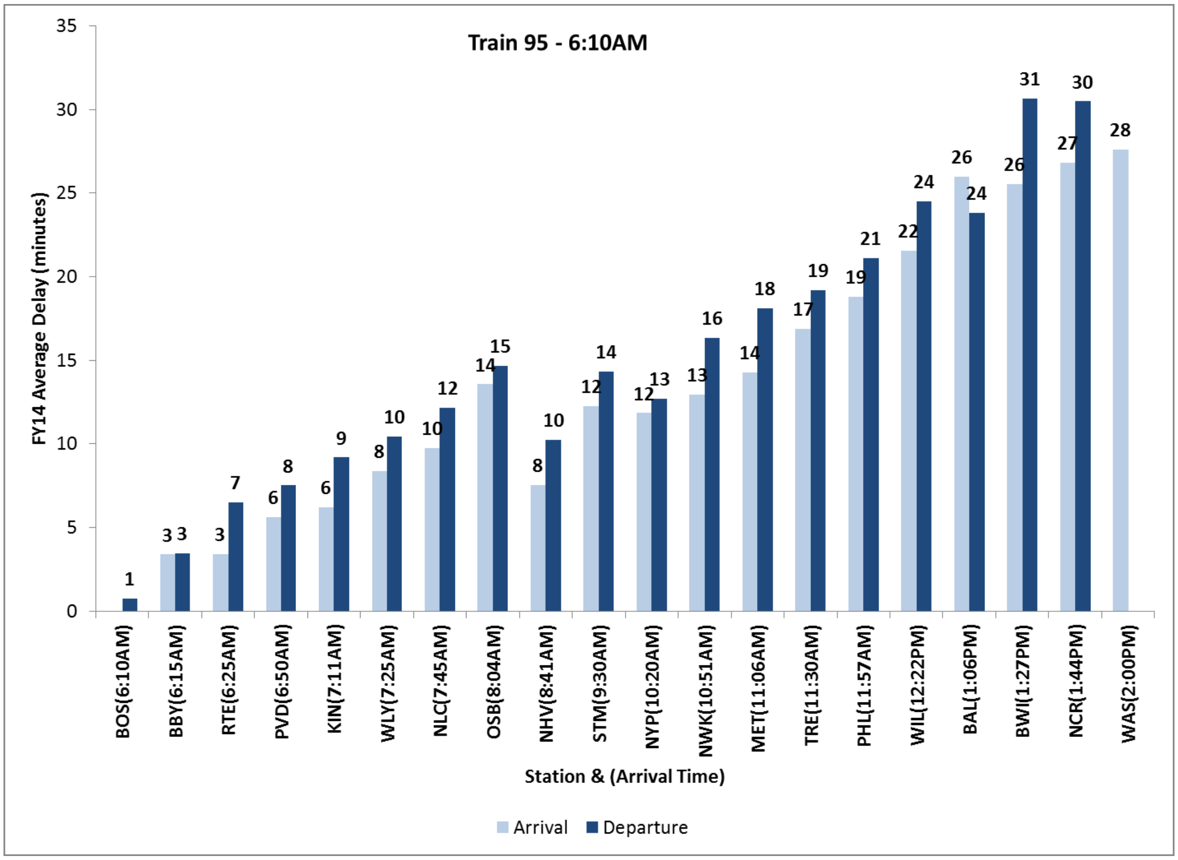

Figure 6.16: FY 2014 Average Station Delays for Train 95

Train 95	Scheduled			*Delay (min)	Segment Travel Time (min)			Segment Travel Speed (mph)		
Segment	Distance (miles)	Departure Time	Arrival Time		Scheduled	Avg. Actual	Actual-Scheduled	Scheduled	Avg. Actual	Actual-Scheduled
BOS-BBY	1	6:10 AM	6:15 AM	0.0	5	8	3	12	8	-4
BBY-RTE	10	6:15 AM	6:25 AM	3.4	10	10	0	60	60	0
RTE-PVD	32	6:25 AM	6:50 AM	3.4	25	24	-1	77	80	3
PVD-KIN	27	6:50 AM	7:11 AM	5.6	21	20	-1	77	82	5
KIN-WLY	17	7:11 AM	7:25 AM	6.2	14	13	-1	73	77	4
WLY-NLC	18	7:25 AM	7:45 AM	8.4	20	19	-1	54	56	2
NLC-OSB	18	7:45 AM	8:04 AM	9.7	19	20	1	57	53	-4
OSB-NHV	33	8:04 AM	8:41 AM	13.6	37	30	-7	54	66	13
NHV-STM	39	8:43 AM	9:30 AM	7.6	47	49	2	50	48	-2
STM-NYP	36	9:30 AM	10:20 AM	12.3	50	48	-2	43	45	2
NYP-NWK	10	10:35 AM	10:51 AM	11.8	16	16	0	38	37	-1
NWK-MET	14	10:51 AM	11:06 AM	13.0	15	13	-2	56	65	9
MET-TRE	34	11:06 AM	11:30 AM	14.3	24	23	-1	85	90	5
TRE-PHL	33	11:30 AM	11:57 AM	16.9	27	27	0	73	74	1
PHL-WIL	25	12:00 PM	12:22 PM	18.8	22	22	0	68	67	-1
WIL-BAL	69	12:22 PM	1:06 PM	21.6	44	45	1	94	91	-3
BAL-BWI	11	1:14 PM	1:27 PM	26.0	13	15	2	51	45	-6
BWI-NCR	21	1:27 PM	1:44 PM	25.6	17	13	-4	74	96	22
NCR-WAS	9	1:44 PM	2:00 PM	26.8	16	13	-3	34	41	7

Table 6.6: Train 95 Segment Level Performance

In summary, the first train of the day routinely encountered considerable amounts of delays because:

i. The trains departed from the originating station late, and upstream delays propagated downstream and in addition, accumulated along segments in the corridor, as well as at each station on the corridor

ii. Amtrak does not schedule dwell time at many of the stations, thus delays add up between arrival at and departure from each station in the corridor.

iii. Overall, the trains usually ran behind schedule though on occasion, some trains were able to recover from some of the built-up upstream delays by traveling faster than scheduled in certain segments.
    a. Northbound: on occasion, the trains traveled on average 1 to 2 minutes faster in some of the south-end segments, including the NWK-NYP segment, and on average 8 minutes faster than scheduled in the PVD-RTE segment
    b. Southbound: on occasion, the trains traveled on average 2 minutes faster than scheduled in the NWK-MET segment and MET-TRE segments, as well as on average 5 to 7 minutes in the OSB-NHV segment and the BWI-WAS segment.

iv. Altogether, late departures, terminal time not accounted for at stations, and poorly estimated segment train speeds and travel times led to significant en-route delays.

6.5 Fluctuations Due to Weather, Accidents and Other Incidents

In the Northeast Corridor, the performance of Regional service is occasionally affected by random variations including delays caused by incidents/accidents, engine failure, injuries, signal failures, broken rails, construction, crew-related, or weather-related issues. This section investigates supply fluctuations due to these random, generally one-time disruptions.

Under PRIIA Section 207, Amtrak was required to report the total delay minutes apportioned into Amtrak-responsible, Host-responsible (Metro-North Railroad-responsible), and Third Party-responsible category (see Section 3.3.2 for additional details of PRIIA requirements regarding delays). However the author of this thesis did not have access to this data. Consequently, the inferences made in this section are based on observing the total daily delay minutes on the Regional services. The total daily delay minutes were calculated by aggregating end-point delays on all the Amtrak train that were operated each day. Following that, the author went through a manual process of searching through Amtrak's Twitter[vi] and Breaking News[vii] feeds for reports of major accidents and incidents on days with significant delays.

6.5.1 Total Minutes of Delay

FY 2012 Daily Delays

Figure 6.17 shows the total daily end-point delays in minutes experienced on Regional trains in FY 2012. There were seven days of the year on which Regional experienced severe delays greater than 2,000 minutes. 2,000 minutes was chosen as an arbitrary boundary line separating 'regular' delays from severe delays. The Twitter and Breaking News feeds indicated Severe Storms as the main cause of the delays in June. In addition, the 2661 minutes of delay on 9/18/2012 were attributed to service disruptions from Hurricane Sandy. The author was not able to identify the cause of the 1,346 minutes of delay on 6/1/2012. Overall, the total daily delays on Regional trains in FY 2012 were consistently around 400 minutes. To comprehend this value, divide 400 minutes by 64 trains on a given Monday, for example, which is equivalent to Regional trains being on average 6 minute delayed in arriving at their final stations. From this proxy analysis, overall the major delays in FY 2012 appeared to be as a result of unanticipated weather disruptions, and on one occasion as a result of operational issues.

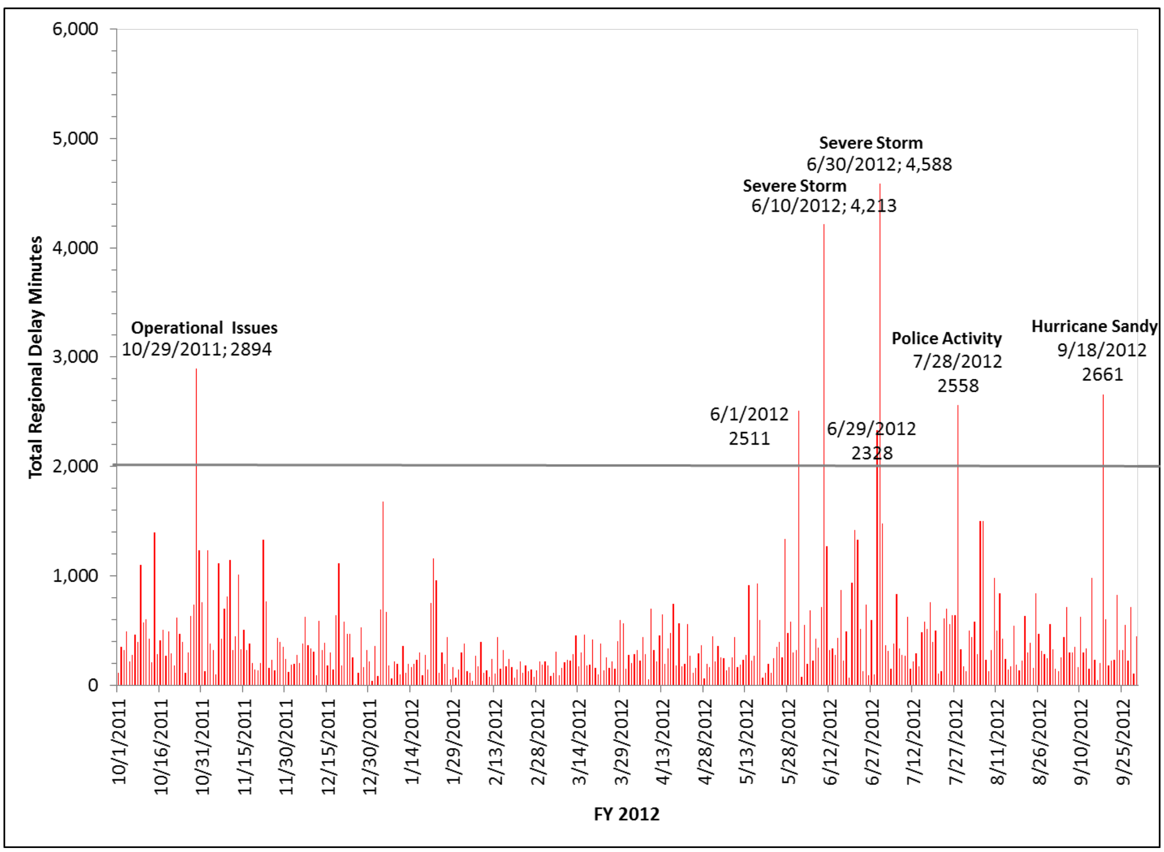

Figure 6.17: FY 2012 Regional Daily Delays

FY 2014 Daily Delays

Figure 6.18 shows the total amount of daily delays in minutes experienced by all Regional trains in FY 2014. The most significant Regional delays were due to the Polar Vortex and sub-zero weather conditions in the Northeast Corridor on multiple days in January 2014. Hurricane Arthur on July 3rd, 2014 also caused major disruption and delays on the Regional service. Due to these severe weather conditions, some trains experienced delays as high as 3hours, and Amtrak's on-time performance metric for Regional trains on some of those days were as low as 8%. For example, 64 of the 65 scheduled Acela trains on July 3rd, 2014, arrived at their destination more than 10 to 20 minutes later than the scheduled arrival time. The other major causes of Regional delay were operational issues, down catenary wires, signal issues and power issues. These operational and infrastructure issues led to 9 of the 16 major delays.

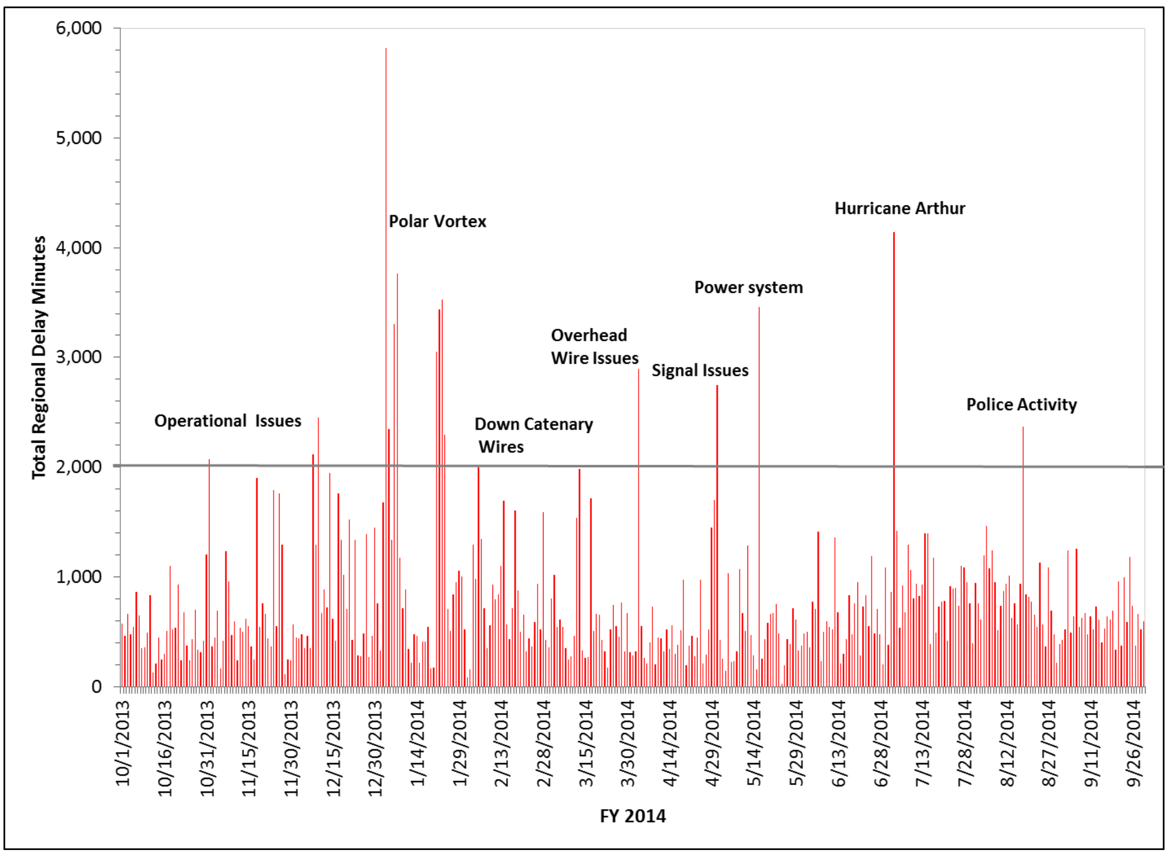

Figure 6.18: FY 2014 Regional Daily Delays

Table 6.7 shows all the days, which experienced total delays greater than 2,000 minutes, including the date, day of week, reason for the delay, and the OTP achieved on that day. Although the total delay was abnormally high on 1/4/2014 and 1/24/2014, the OTP on these days were still greater than 60%, which suggests that the delay was concentrated in specific sections of the corridor and times of the day, and affected a select few of the trains scheduled to operate on that day. Days with high delays and low OTP (e.g. 1/7/14 Polar Vortex) suggest that the delay expanded throughout the corridor and day, and affected majority of the scheduled trains.

Delay Reason	Date	Weekday	Total Delay Minutes	OTP
Operational Issues	11/1/2013	Fri	2,073	43%
Operational Issues	12/8/2013	Sun	2,114	34%
Operational Issues	12/10/2013	Tue	2,452	39%
Polar Vortex	1/3/2014	Fri	5,820	8%
Polar Vortex	1/4/2014	Sat	2,346	18%
Polar Vortex	1/6/2014	Mon	3,307	67%
Polar Vortex	1/7/2014	Tue	3,766	25%
Polar Vortex	1/21/2014	Tue	3,053	36%
Polar Vortex	1/22/2014	Wed	3,437	18%
Polar Vortex	1/23/2014	Thu	3,525	21%
Polar Vortex	1/24/2014	Fri	2,298	31%
Catenary/Power Issues	4/3/2014	Thu	2,894	62%
Signal Issues WAS-BAL	5/1/2014	Thu	2,746	36%
Power system issues NYP-STM; Police activity north of WAS	5/16/2014	Fri	3,456	49%
Hurricane Arthur	7/3/2014	Thu	4,142	50%
Police Activity	8/18/2014	Mon	2,368	54%

Table 6.7: Regional Daily Total Delay Greater Than 2,000 minutes

In summary, the major disruptions on Regional service in both FY 2012 and FY 2014 were caused by weather related factors (severe winter weathers and hurricanes). However, in FY 2014, in addition to the weather related issues, there were significantly more delays attributed to infrastructural issues compared to FY 2012. This suggests the state of infrastructures and equipment in the Northeast Corridor has deteriorated in recent years.

6.5.2 Cancelled Trains

The existing performance metrics do not account for train cancellations, even though they pose huge inconveniences to travelers. In this section, Regional train cancellation in FY 2012 and FY 2014 are presented.

Although Regional service performance in FY 2012 was relatively high (compared to other fiscal years), there were 54 days in the year on which Regional trains were cancelled, and a total of 73 cancelled trains. Figure 6.19 shows that only one train was cancelled on most days, and at most 3 trains cancelations happened once. Altogether, less than 1% of total FY 2012 scheduled Regional trains were cancelled.

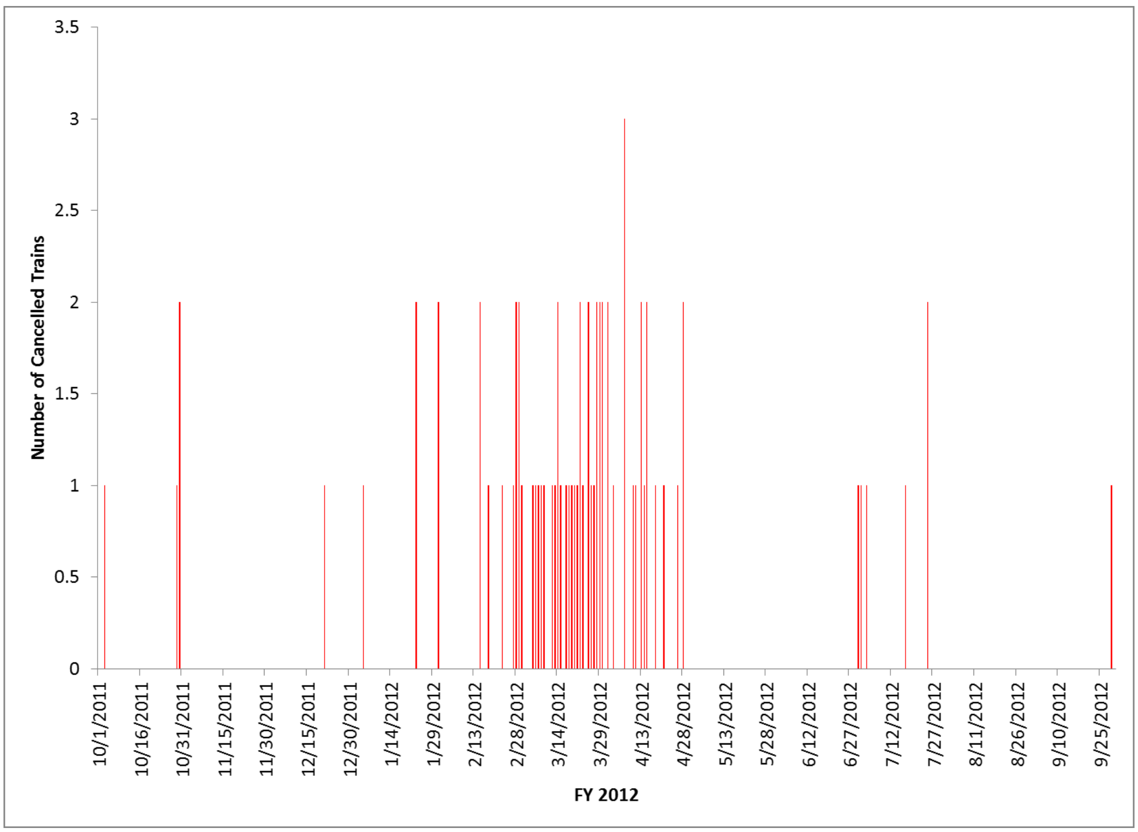

Figure 6.19: FY 2012 Number of Cancelled Regional Trains

Figure 6.20 shows that in FY 2014, there were 48 days in the year on which Regional trains were cancelled, and there were a total of 167 cancelled trains. The major train cancellations occurred in January and February due to the severe winter weather attributed to the Polar Vortex[viii]. 51% of FY 2014 Regional train cancellations were attributed to weather-related issues, 6% to down catenary/overhead wires issues, 2% to Police Activity, and 40% to unknown sources. Altogether, 1% of total scheduled Regional trains in FY 2014 were cancelled.

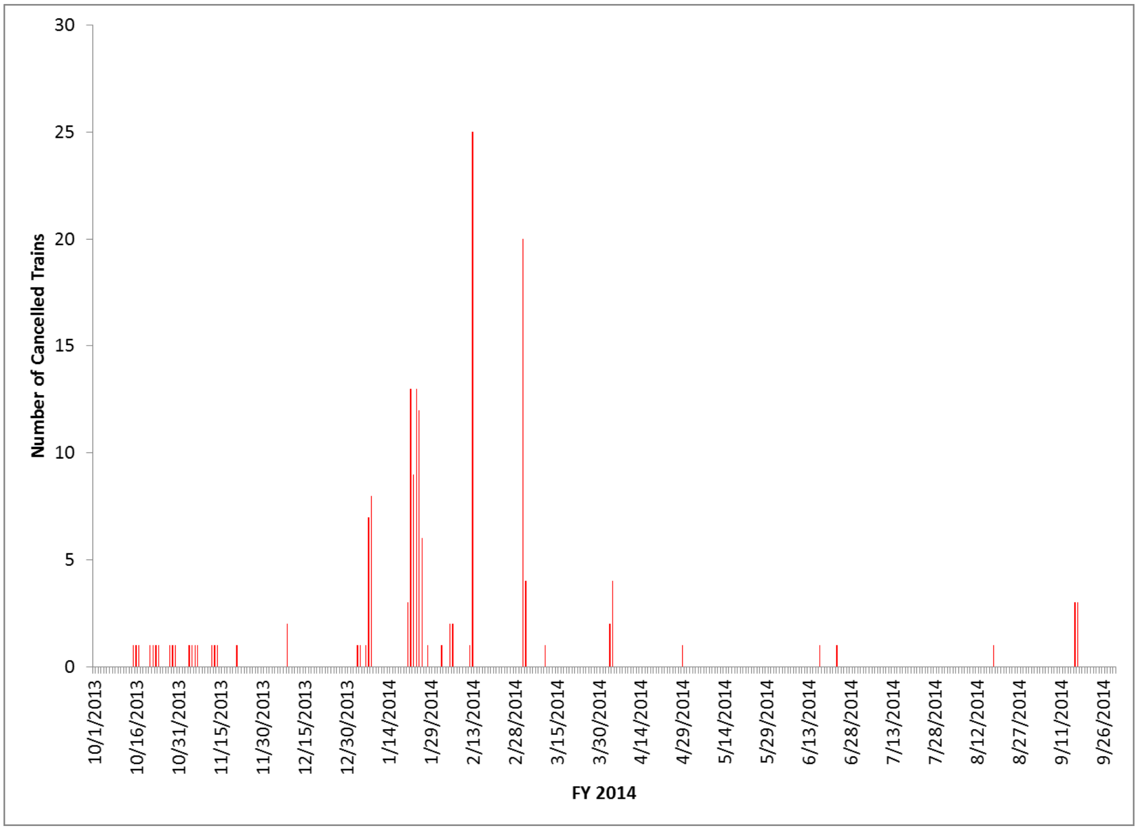

Figure 6.20: FY 2014 Number of Cancelled Regional Trains

In summary, although the train cancellations on Regional are not disturbingly high on an average day, they cause a substantial amount of inconvenience and disutility to travelers and thus must be accounted for in service performance metrics. The need for a more precise cumulative service performance index is discussed in Section 8.4.

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6.6 Capacity Analysis

This section analyzes the capacity on Regional trains between FY 2005 and FY 2014. The goal of the capacity analysis for this thesis was to provide a caveat to the analysis on the impact of Amtrak service performance on demand. Demand in the Northeast Corridor is currently alleged to be above the capacity of Amtrak trains, especially Acela trains. However, the capacity analysis was expanded to Regional services to provide a comprehensive and comparative analysis of the Regional service as the Acela in Chapter 5. The section presents actual segment level volumes on each Regional train operated in both directions for some chosen dates with peak ridership in FY 2005, FY 2012, FY 2013 and FY 2014.

Capacity analysis of the Regional service is more complex than on the Acela service. The Regional system is made up of an assortment of trainsets having 7 – 10 passenger cars and with seating capacity ranging from about 450 to 550. In addition, the number of Regional trains in operation varied by day of week from about 51 trains on Saturdays to 64 trains on Mondays and 67 trains on Fridays. Consequently, unlike the Acela that has a definitive capacity of 304 seats per train each day, the capacity on Regional depends on the day of week and what train equipment were operated on the given day.

6.6.1 FY 2005 to FY 2014 Southbound Through Regional Trains

The four plots in Figure 6.21 show segment level ridership for each southbound through (BOS-WAS) train that was operated on the specific dates (indicated in the figure) in FY 2005, FY 2012, FY 2013 and FY 2014 with the highest ridership. The legend shows the train numbers in order by departure time from BOS, such that the colors that correspond with each train is the same across the different years. For example, the red line represents Train 95 on all charts.

Train 95 departs at 6:10AM, Train 171 departs at 8:15AM, Train 83 departs at 9:30AM, Train 173 departs at 11:15AM, Train 137 departs at 1:40PM, Train 175 departs at 3:20PM, Train 177 departs at 5:35PM, Train 179 departs at 6:45PM, and Train 67 departs at 9:30PM. Because these are through trains, although the departure time from the originating station was in an off-peak time of day, the arrival times at other stations en-route could be during the peak periods. For example, Train 173 and Train 137 departs from NYP at 3:35PM and 6:25PM, respectively and arrives in the south end of the corridor during the PM peak time of day.

In FY 2005, the maximum passenger loading was around 350 riders in the south section of the corridor between NYP and WAS. However the passenger loading in the south section increased to almost 500 in FY 2012, but dropped to about 400 in FY 2013, and further to under 400 by FY 2014. The ridership decline in the south section (NYP-WAS) on Regional trains between FY 2012 and FY 2014 is opposite of the growth observed on the Acela trains. However, similar to the Acela trains, the load factor in the north section of the corridor between BOS and WAS grew steadily between FY 2005 and FY 2014. The FY 2005 chart (top left) shows low ridership between BOS and NYP, and a spike in ridership at NYP, suggesting low ridership in the north section and high ridership in the south section of the corridor. In comparison, by FY 2014 (bottom right) the ridership in both the north section (BOS-NYP) and south section (NYP-WAS) of the corridor were high. Overall, the through trains are now more frequently near-fully loaded along the entire length of the corridor. Assuming a through train capacity of 500 seats, the load factor of the most loaded train in FY 2014 was about 80%.

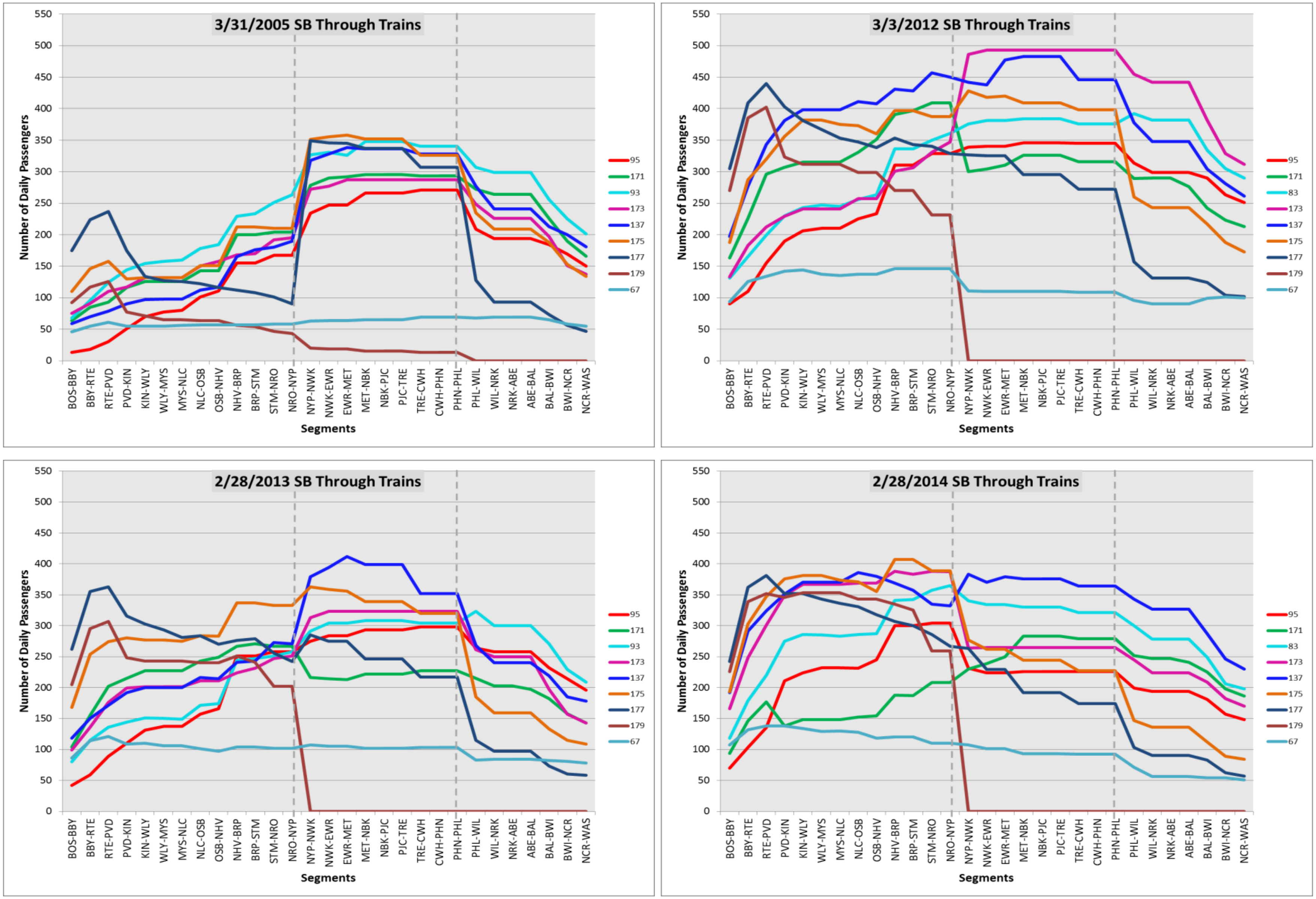

Figure 6.21: FY 05 - FY 14 SB Segment Level Through Train Capacity

6.6.2 FY 2005 to FY 2014 Southbound South-End only Regional Trains

The four figured in Figure 6.22 show segment level demand for each southbound south-end only Regional service that was operated on the specific dates in FY 2005, FY 2012, FY 2013 and FY 2014 with the highest ridership. The southbound south end only Regional services originate in NYP and terminate in WAS. The legend shows the train numbers in order by departure time from NYP such that the colors that correspond with each train is the same across the different years. The additional Regional-Keystone trains that operate in the south end between NYP and PHL are not included in this analysis because they operate well below capacity.

Train 151, Train 181, Train 183, Train 185, Train 141, Train 125 and Train 133 are AM trains while Train 85, Train 127, Train 129, Train 193, Train 189 and Train 187 are PM trains. From the figure, in FY 2013 and FY 2014, the trains with the highest ridership volumes were Train 127 (in red), which departed from NYP at 4:05PM and Train 129 (in blue), which departed from NYP at 4:42PM.

Similar to the through trains, the number of Regional riders on the south end trains declined between FY 2005 and FY 2014. The maximum passenger loading was around 430 in FY 2005, and remained at that level in FY 2012 but dropped to about 400 in FY 2013 and further down to under 350 passengers by FY 2014. Again, the ridership decline on Regional trains between FY 2005 and FY 2014 in the load factor in the south section (NYP-WAS) is opposite of the growth observed on the Acela trains.

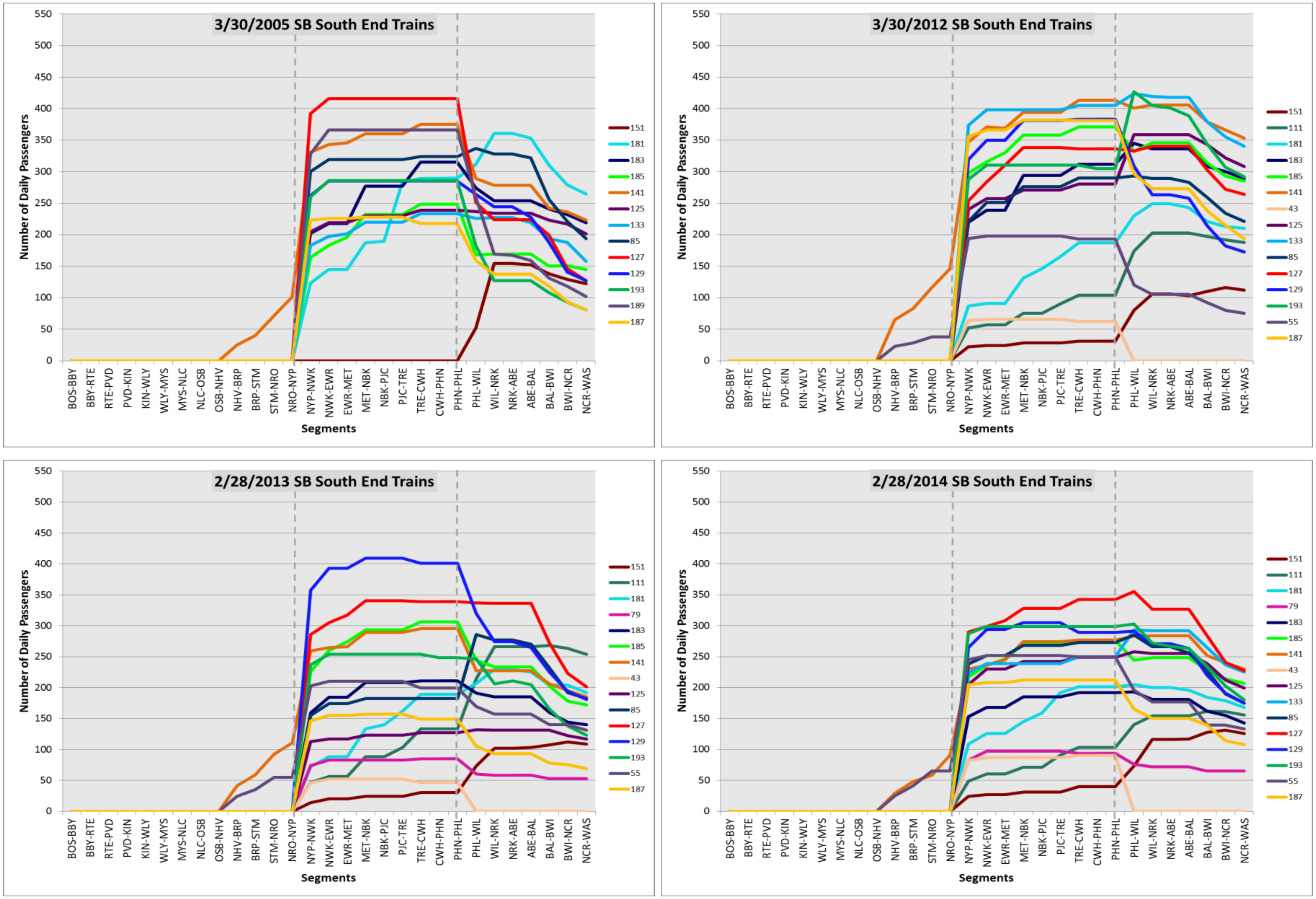

Figure 6.22: FY 05 - FY 14 SB Segment Level South End Train Capacity

6.6.3 FY 2005 to FY 2014 Northbound Through Regional Trains

The four plots in Figure 6.23 show segment level demand for each northbound through Regional service operated on the specific dates (indicated in the charts) in FY 2005, FY 2012, FY 2013 and FY 2014 with the highest ridership. The northbound through Regional services originate in WAS and terminate in BOS. The legend shows the train numbers in order by departure time from WAS so that the colors corresponding with each train is the same across the different years. For example, Train 66 is shown in yellow in all the charts.

The Regional northbound through trains exhibit similar patterns as the southbound trains. The late night/early morning trains departing from WAS at 10:10PM (Train 66), 3:15AM (Train 190) and 4:52Pm (Train 170) show the lowest segment loading of about 230 riders each year, except in 2005 where Train 170 had a maximum passenger load of about 520 riders in the south section. Train 174 departing WAS at 10:20AM, Train 176 departing WAS at 12:25PM, Train 94 departing WAS 2:02PM and Train 178 departing WAS at 4:02PM have the highest segment loading ranging from 400 to 450 passengers in the south section in 2014.

Again comparing FY 2005 to FY 2014, Regional trains exhibit decline in segment ridership on each peak train.

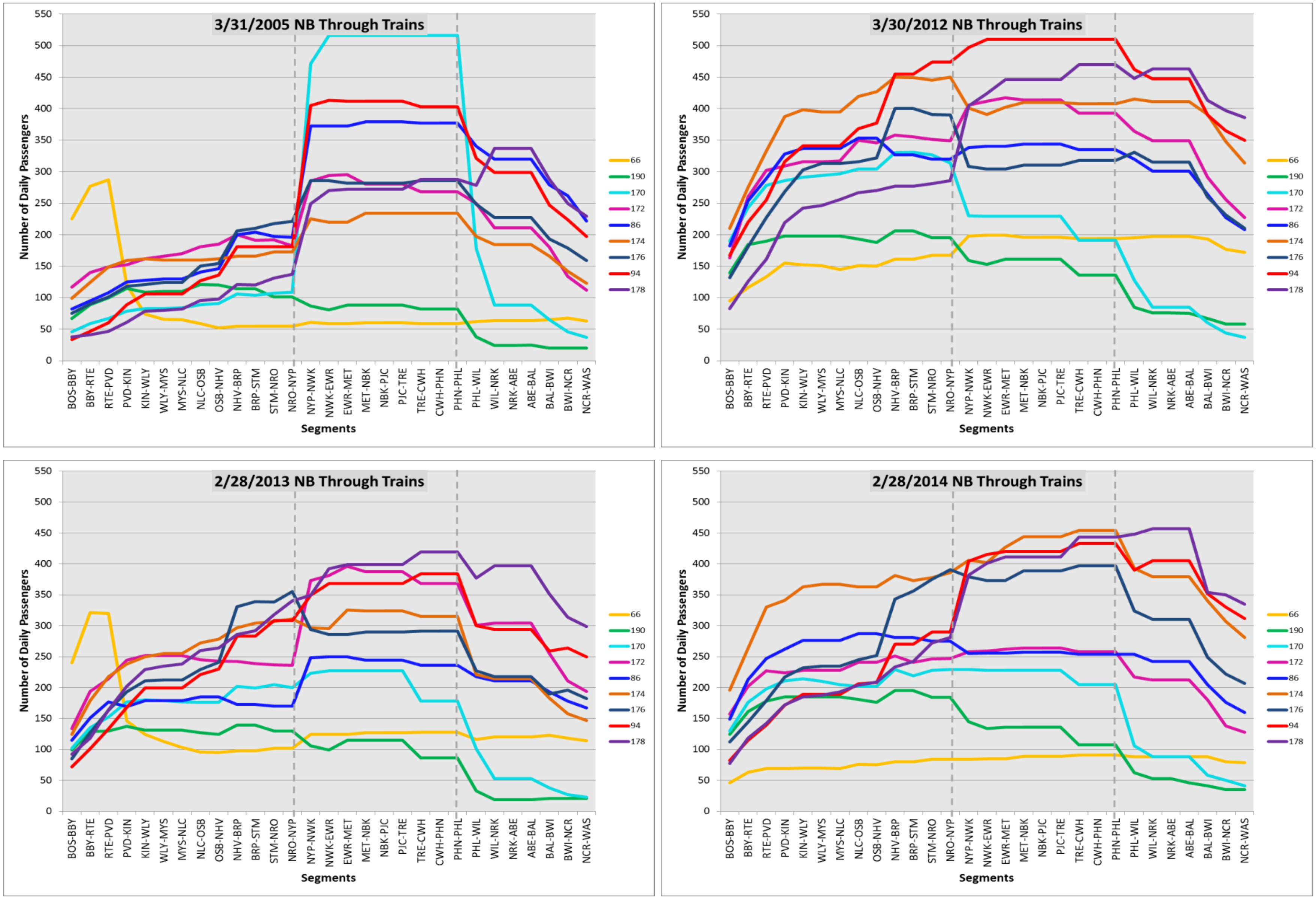

Figure 6.23: FY 05 - FY NB Segment Level Through Train Capacity

6.6.4 FY 2005 to FY 2014 Northbound South-end Only Regional Trains

The four plots in Figure 6.24 show segment level demand for each northbound south-end only Regional service operated on the specific dates (indicated in the charts) in FY 2005, FY 2012, FY 2013 and FY 2014 with the highest ridership. The northbound south-end only Regional services originate in WAS and terminates in NYP. The legend shows the train numbers in order by departure time from WAS so that the colors corresponding with each train is the same across the different years.

The northbound south-end only trains appear to have the highest segment load factor. The peak loading ranged between 450 and 550 passengers between BWI and PJC (Princeton Junction). Unlike all the other Regional trains, the northbound south-end only trains show segment-loading growth on the peak trains between FY 2005 and FY 2014

Overall, in summary, except the northbound south-end only Regional trains, the Regional service do not appear to be currently capacity constrained.

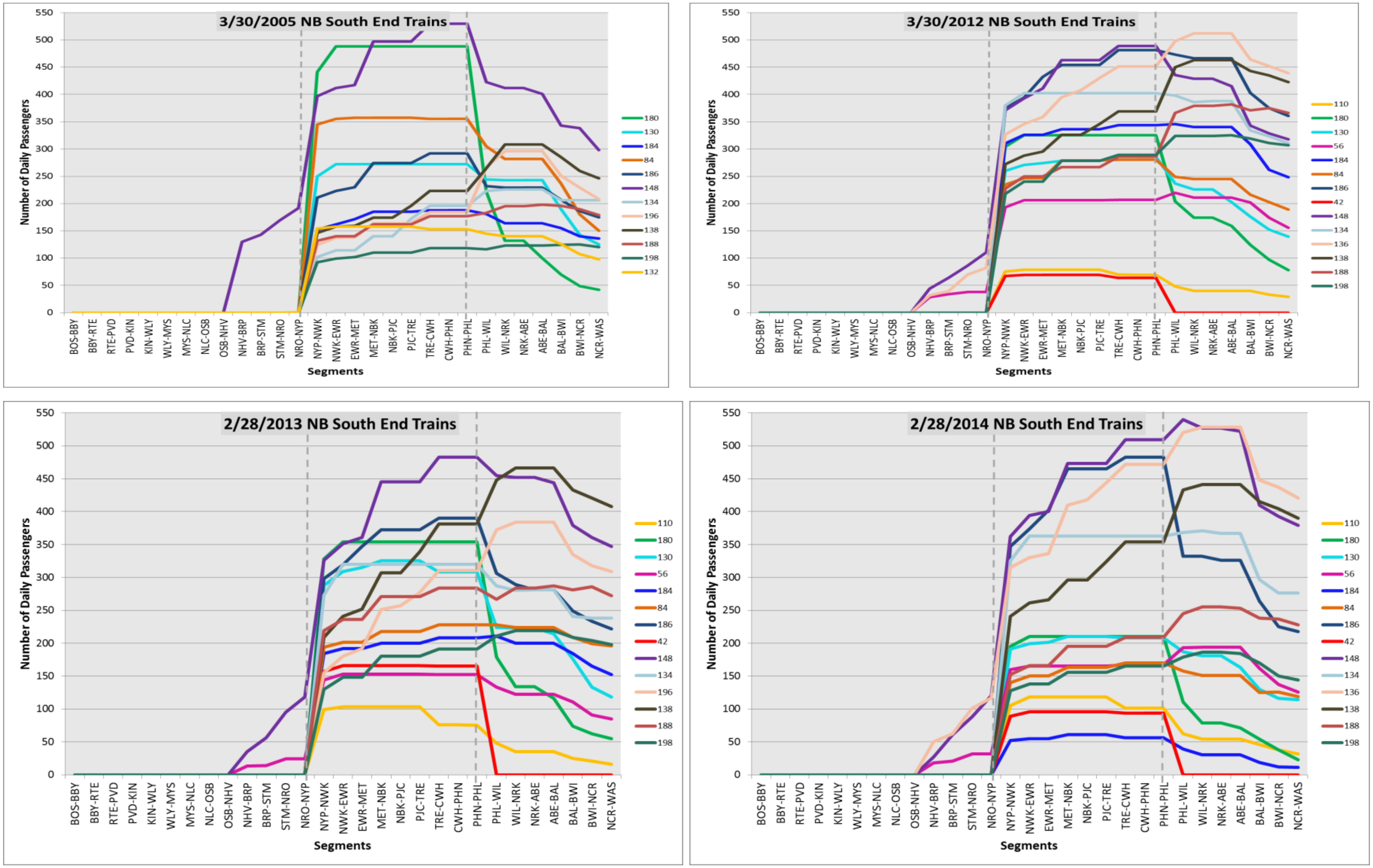

Figure 6.24: FY 05 - FY 14 SB Segment Level South End Train Capacity

6.7 Demand Response to Regional Service Performance

The main question examined in this section is: Do Amtrak Regional passengers modify their future travel choices in response to past Regional performance that either they experienced or were informed about? As a practical constraint, there needs to be a period of time between when travelers experience or learn about performance information and when they make future travel decisions. This time is usually referred to as a lag period. Following this concept, a simple analysis was conducted comparing total annual ridership each year with Regional train performance from the prior year. This assumes a lag of one year. In other words, the goal of the analysis was to test the assumption that a relationship exists between ridership in a given year and OTP or total delay from the prior year

6.7.1 Annual Ridership to Annual OTP

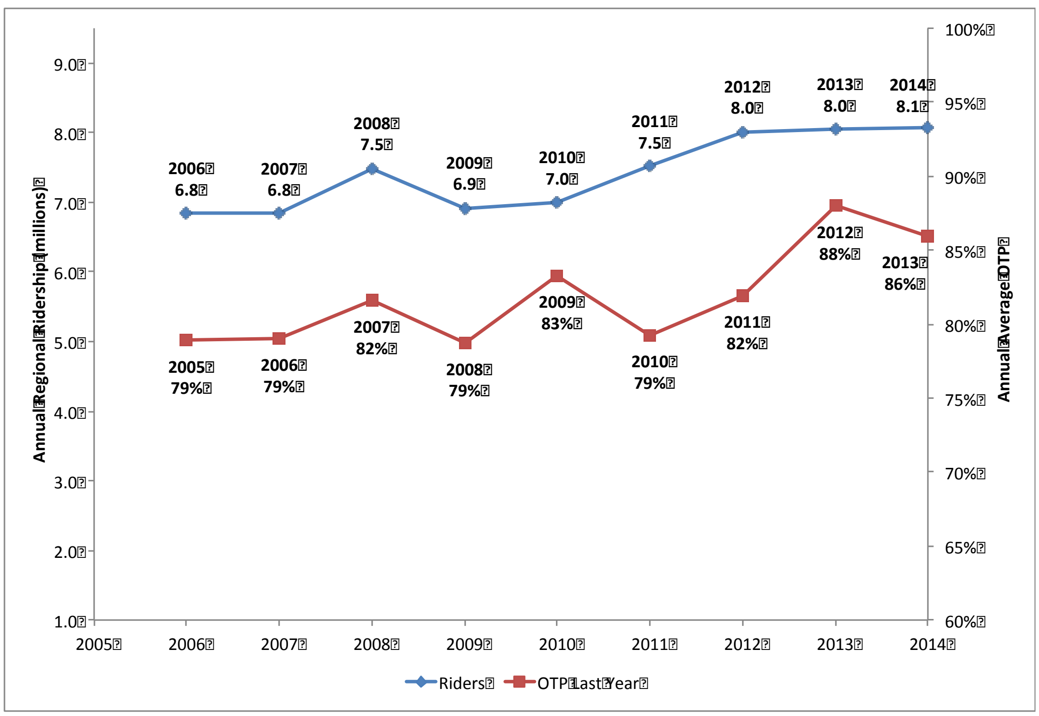

Figure 6.25: Lag Annual Ridership to OTP

Figure 6.25 shows the total annual Regional ridership (blue) between FY 2005 and FY 2014 and the annual average OTP (red) from the prior year. For example, the first data points show total FY 2006 ridership (6.8 million) and FY 2005 average OTP (79%). The relationship between OTP in two consecutive years is typically associated with a similar relationship between the ridership in the following years. For example, an upward trend in average OTP between FY 2005 and FY 2006 is followed by a similar upward trend between the annual ridership in FY 2006 and FY 2007. This correlated relationship is observed between FY 2005 and FY 2010. However, in FY 2010, even though the performance deteriorated between FY 2009 and FY 2010, Regional ridership continued to grow between FY 2010 and FY 2011. The relationship continued again between FY 2011 and FY 2013 but broke down in FY 2014 with ridership increasing despite performance deteriorations in FY 2013. As discussed in Section 6.5, two of the major causes of poor performance in FY 2014 were as a result of the Polar Vortex and Hurricane Arthur, both of which had a worse impact on airline services, perhaps explaining why the ridership grew in FY 2014 despite poor performance in the prior year. The correlation coefficient between the annual ridership and lagged annual on-time performance on the Regional service between FY 2005 and FY 2014 is 0.74. Although this correlation is not perfect (equal to 1), it is sufficiently high to propose that the ridership in a given year is associated with service performance from the prior year.

6.7.2 Annual Ridership to Annual Delay

Figure 6.26 shows the total annual Regional ridership (blue) and the total annual delay (red) from the prior year. The annual ridership and annual delay exhibit a similar lagged relationship as the annual ridership and annual average OTP. Improvements in performance (that is reduction in total annual delay) appear to be associated with ridership increase the following year. However, unlike the high correlation coefficient between annual ridership and lagged annual OTP, the correlation between annual ridership and lagged annual total delay between FY 2005 and FY 2014 is 0.2. Although, as expected the correlation between FY 2005 and FY 2010 is much higher 0.46, it is still comparatively low.

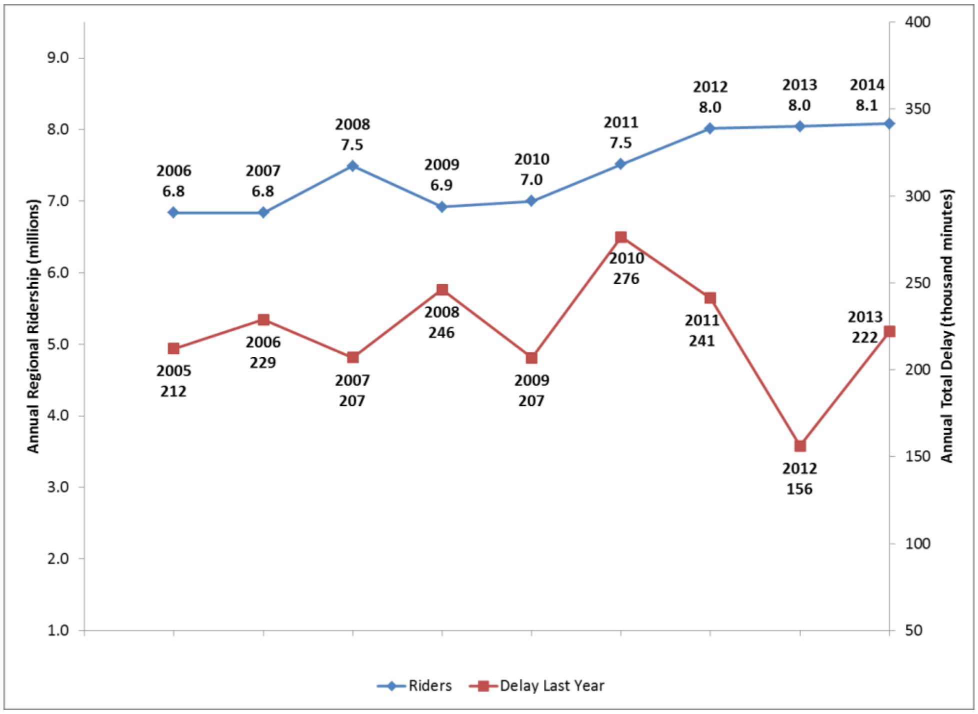

Figure 6.26: Lag Annual Ridership to Delay

It is unclear whether the one-year lagged correlation exhibited between performance and ridership is a cause-effect relationship or simply a correlation caused by other external factors. The Acela service also exhibited a similar lag of one year, which suggests that the correlations are worth looking into.

6.8 Regional Summary

This section summarizes the analyses in Chapter 6.

In FY 2014, 42% of Regional trains arrived on-time, 29% arrived late but within 10 to 20 minutes, and the remaining 29% experienced delays greater than 10 to 20 minutes. Altogether, similarly to the Acela service, 71% of trains arrived within 10 minutes of the scheduled time. However, compared to Acela (11%), more Regional trains (13%) arrived with a delay greater than 30 minutes.

On-time performance and delay minutes are 70% correlated, and both are useful metrics in quantifying performance. However, neither of them includes the effect of cancelled trains, which are important to quantify from a passengers point of view.

In terms of seasonality, excluding January and February, the monthly ridership for Regional appeared to be roughly the same, suggesting that Regional passengers might be regular riders, who have similar travel patterns throughout the year. Additionally, the ridership pattern on the Regional service was unlike that of the Acela service, which exhibited clear seasonal variations. Similarly to Acela performance, Regional performance exhibited seasonal variations with summer months usually being the worst due to heat restrictions and infrastructural issues (catenary wire drooping).

Regarding day of week performance, Regional ridership volumes were lowest on Tuesdays and Saturdays and highest on Fridays and Sundays. In terms of performance, overall, performance appeared to be roughly the same on all days of the week, however, it was usually slightly better on Tuesdays, Saturdays and Sundays, and slightly worse on Fridays. The weekend improvements were likely because fewer Amtrak and Commuter services operate on weekends.

In terms of time of day performance variations, AM and PM peak trains are usually more prone to delays than trains during other off-peak times of the day.

The first train analysis revealed that a major portion of Regional delays appeared to be attributable to late departures from originating station, which accumulate and propagate at each consecutive station downstream. In addition, unscheduled terminal time at stations and poorly estimated segment train speeds and travel times lead to additional en-route delays. On an average day, delays attributed to interference from other Amtrak trains are limited because of the scheduled spacing between trains throughout the day.

The performance of Regional service is occasionally affected by unanticipated changes in travel conditions such as bad/extreme weather, crashes and incidents, equipment failure or other unexpected infrastructure malfunctions. Unanticipated weather-related and third-party events are responsible for about 12% of Amtrak train delays (based on FY 2012 and FY 2014 analysis). Furthermore, in FY 2012, there was only one major delay caused by operational issues, however, by FY 2014, 12% of delays were associated with equipment and infrastructural issues. Lastly, not including days with severe weather issues, Amtrak rarely cancels Regional trains.

The capacity analysis revealed that Regional trains are not at capacity but some peak period trains operate close to load factors of about 80%.

Finally, Regional ridership appears to lag service performance by a year. However, it is unclear whether the one-year lagged associations exhibited between OTP or total delay and ridership are cause-effect relationships between service performance and demand or just correlations.

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7 TIME SERIES ANALYSIS

In Chapter 5 and 6, the relationship between demand and service performance was investigated. Amtrak ridership appeared to be correlated with service performance from the prior year. However, it was unclear whether the one-year lagged associations exhibited in the FY 2005 to FY 2014 dataset between OTP or total delay and ridership were cause-effect relationships between service performance and demand. The correlation between Amtrak ridership and lagged service performance of Amtrak Acela services will be investigated further in this chapter.

The collection of Amtrak ridership and service performance data between FY 2005 to FY 2014 can be considered as a time series dataset because it contains an ordered sequence of observations at equally spaced time intervals. Moreover, time series modeling provides techniques to abstract the underlying structures of a dataset, as well as meaningful relationships, characteristics and statistics of data attributes. In the most disaggregate form, the demand and train operation data over the ten-year period can be modeled as time progressions at the minute or hourly level. On one hand, the disaggregate level could highlight fine details in Amtrak ridership and performance, but on the other hand, the detail might be unnecessary and conclusions about the system at such a disaggregate level would likely be noisy and highly volatile. As such, there are tradeoffs between the level of disaggregation chosen for a time series model and the stability of the model. Keeping the tradeoffs in mind, for the purpose of this research, the times series observations of Amtrak FY 2005 to FY 2014 ridership and service performance would be evaluated at the daily, weekly, monthly or annual levels, until an informative and stable model is obtained.

The objective of the time series analysis is to explore the characteristics of the datasets, in order to account for the underlying structure (autocorrelation, trends and seasonality) in the data points over time. The time series analysis would explore:

i. Serial Correlation - statistical dependence between observations of an attribute in a dataset at different times as a function of time lags. Other terms used to describe this dependence are Autocorrelation or Seasonality. In this context, seasonality refers to regular systematic or periodic variations in a dataset that are typically calendar-related. For example, monthly seasonality is observed when data twelve months apart are related. Seasonality exists if there are regular spaced and reasonably consistent variations in terms of the timing, direction and magnitude of a data attribute. For example, if delays have been consistently low in January of prior years, they can be expected to be low in current observation of January delays. Nevertheless, seasonal data could still exhibit random variations within a particular season when compared over multiple years. Seasonal variations are usually an effect of natural conditions (e.g. weather) or social events (e.g. holidays and vacation).

ii. Trends - long-term directions in the time series that are not calendar related. For example, in a given time period, a positive trend could be an increase in total year-over-year ridership while a negative trend could be a decrease in total year-over-year delay. Trends are usually an effect of changes in population, employment and other socioeconomic characteristics

iii. Cross Correlation - the condition that a current observation of an attribute in the dataset is a function of lagged observations of <u>other</u> attributes. For example, the ridership in a given time period could depend on performance in prior time periods. Cross Correlation can be a result of cause-effect relationships between attributes.

7.1 Time Series Analytical Methods

In the literature the following methods are frequently used to analyze time series data:

i. Smoothing
ii. The family of ARMA - Autoregressive Moving Average (ARMA), Autoregressive Integrated Moving Average (ARIMA), ARIMAX (dynamic regression)
iii. Transfer Function Models

The next section provides a brief overview of each method as well as a selection of an appropriate technique to be used in this thesis.

7.1.1 Smoothing

As discussed earlier, even though the demand and train operation data exhibit seasonal patterns, the clarity of the pattern can sometimes be muffled by the random variations. A technique called "smoothing" is often times used to highlight trends, seasonality, or cyclic components of times series data. Smoothing involves some form of statistical combination of proximal data points such that the nonsystematic components of individual observations cancel each other out[ix]. There are two different statistical measures typically used to estimate the central tendency of the dataset- averages and medians. Although averages are used more frequently, the median is sometimes preferred because it is not affected by unusually high or low values of the observation (outliers). An advantage of using means over median is that it allows individual observations to be weighted differently based on proximity of the data points. In moving average smoothing, each observation in time is replaced with the simple or weighted means of N surrounding observations, where N refers to the width of the smoothing window[x]. In single moving average smoothing, simple averages are applied and all observations in the smoothing window are weighted equally. In comparison, in exponential moving average smoothing exponentially decreasing weights are assigned to observations within the smoothing window that are older. The equation for moving average smoothing is:

$$M_t = \frac{w_t Y_t + w_{t-1} Y_{t-1} + \cdots + w_{t-N+1} Y_{t-N+1}}{N}$$

Where,

Y_t are the original time series observations

w_t are the weight applied to time dependent observations

N is the number of observations in the smoothing window

M_t is the moving average

7.1.2 Autoregressive Moving Average (ARMA), Autoregressive Integrated Moving Average (ARIMA), ARIMAX

Box and Jenkins (1976) developed the family of ARMA models to explore the characteristics of time series datasets made up of systematic variations as well as large errors or random variations in order to reveal hidden or unclear patterns in the data. An ARMA model consists of two parts, an autoregressive process (AR) and a moving average process (MA). Both processes are described below. However, the ARMA model is much simpler if the time series are stationary

Stationarity requirement

The basic idea of the stationarity requirement is that the time series observations do not accumulate past effects over time. In essence, time series that exhibit growth or decay over time are not stationary. Specifically, a process is said to be stationary if the joint distribution of random variables is the same irrespective of time. In other words, the probability laws that govern the behavior of the time series process do not change over time. The trend effects in a non-stationary time series can be eliminated through mean adjustments. The mean-adjusted series, $y_t = Y_t - \bar{Y}$, where Y_t is the original time series, $\bar{Y}$ is the sample mean.

Autoregressive Process: $AR(p)$

The autoregressive process controls the serial correlation between current values and past values in a time series, in that at any given time, the process "remembers" some of the past values in the series. The autoregressive model expresses a time series as a linear function of one or more time-lagged elements (past values). In effect, the model is simply a linear regression of current values of the series against prior values of the series, including an error component. The *order* of the AR model, p is the number of lagged elements in the model, such that,

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \cdots + \alpha_p Y_{t-p} + \varepsilon_t$$

Where Y_t is the original time series, α_p is the autoregressive coefficient associated with each time-lagged element, and ε_t is white noise (also called error, random shock or residual). An autoregressive coefficient (α_p) value equal to zero indicates that there is no temporal dependence between the time series elements, while large α_p values indicate that current values in the series are highly influenced by the past values. A useful autoregressive model captures the dependence structure in the data accurately enough so that the series of error component is random (not autocorrelated) and normally distributed.

Moving Average Process: $MA(q)$

In addition to the autoregressive process, each observation in the time series can be affected by past errors (or random shocks or residuals) not accounted for by the autoregressive component. The process is a moving average of a series of shocks such that current values of the series can be found from current shocks as well as past shocks/errors ε. In other words, each observation in the model is made up of a random error component and a linear combination of prior random shocks/errors. The order of the MA model, q is the number of lagged shocks included in the model, such that,

$$Y_t = \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}$$

Where Y_t is the original time series, ε_t is the shock/error, and θ_i is the moving average coefficient.

Autoregressive Moving Average Process: $ARMA(p,q)$

An $ARMA(p,q)$ process is a combination of the $AR(p)$ and $MA(q)$ processes, which includes lagged terms of the time series itself and lagged terms of the series of error components.

Autoregressive Integrated Moving Average Process: $ARIMA(p, d, q)$

The "I" in ARIMA stands for "Integrated", which refers to the process of differencing non-stationary series through one or more mean-adjustments to achieve stationarity. In essence, instead of using the original time series, the differenced or mean-adjusted series are used in the ARMA processes. The first differenced series, $y_t = Y_t - \bar{Y}$, where Y_t is the original time series, $\bar{Y}$ is the sample mean. Consequently, the ARIMA process is made up of three separate processes i) the autoregressive process with p lags of the series, ii) differencing process with d mean-adjustments, and iii) the moving average process with q lags of the error series. For example, an $ARIMA(1,1,3)$ refers to a model with 1 autoregressive parameter, p and 3 moving average parameters, q which were computed for the series after it was differenced once. Observing the autocorrelation plots provide a good rule of thumb in deciding which process to use. The expected pattern of the autocorrelation and partial autocorrelation plots for the AR(p), MA(q) and ARMA (p,q) are shown in Table 7.1 and described in detail in Section 7.2.

Test	AR(p)	MA(q)	ARMA(p,q)
Autocorrelation	Tails off	Cuts off after lag **q**	Tails off
Partial Autocorrelation	Cuts off after lag **p**	Tails off	Tails off

Table 7.1: Autocorrelation and Partial Autocorrelation Tests for Identifying AR, MA and ARMA models

Seasonal Autoregressive Integrated Moving Average Process: $SARIMA(p, d, q)\mathrm{x}(\mathrm{P}, \mathrm{D}, \mathrm{Q})_m$

Seasonal ARIMA models rely on seasonal lags and differences to fit the seasonal pattern. The seasonal part of the ARIMA model has three additional components, where P is the number of seasonal autoregressive terms, D is the number of seasonal differences, Q is the number of seasonal moving average terms, and m is the number of periods per season.

7.1.3 Transfer Function Models

Transfer function models allow for lagged and decaying effects of covariates. The ARIMAX and regression with ARMA errors are special cases of transfer functions.

ARIMAX (p, q, d) includes the linear effect that one or more exogenous series have on the stationary response series of Y.

$$Y_t = \sum_{i=1}^{p} \alpha_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t + \sum_{k=1}^{r} \beta_k x_{t-k}$$

where, the first sum is the AR component, the second sum is the MA component, and the third sum is the dependence on other variables component.

7.2 Time Series Analysis of Amtrak Data

The time series analyses of the Amtrak data are presented in this section. The section is organized by the different statistical methods used in identifying the time series data. The time series analysis was conducted in R statistics software. Some section of the .R script are presented in this section in text boxes formatted as shown below:

```
>#Welcome to R
>AmtrakMonthlyData <- read.csv("~../Analysis/AcelaRegionalMonthlySeries.csv")
```

The methods used in identifying the time series processes are organized under the following subsections: Section 7.1.1 discusses linear additive decomposition; Section 7.1.2 discusses the Dickey-Fuller Test and Augmented Dickey Fuller Test for Stationarity. Section 7.1.3 is on autocorrelation functions (ACF), partial autocorrelation functions (PACF), and cross correlation function (CCF). And finally Section 7.1.4 is on the family of ARMA models.

7.2.1 Linear Additive Decomposition

A time series can be additively decomposed into a set of independent functional forms referred to as trend, seasonal and random components. The trend is the deterministic, non-seasonal component. The seasonality or periodicity captures systematically repeating processes between groups of successive observations. And the random component contains the stochastic or irregular elements of the series, but could exhibit autocorrelations with the series. The linear additive decomposition is written as:

$$Y_t = T_t + S_t + \varepsilon_t$$

where Y_t is the original time series, T_t is the trend component, S_t is the seasonal component and ε_t random or error component.

The Amtrak Acela ridership and performance series were additively decomposed in R.

```
>AcelaMonthlyRiderscomp <- decompose(AmtrakMonthlyTS[,4])
>Plot(AcelaMonthlyRiderscomp)
```

Figure 7.1 shows the decomposition of Acela monthly ridership into four blocks; the first block shows the original time series, the second block shows the trend, the third block shows the seasonal component, and the last block shows the random variations. The trend line exhibits a steep upward slope till 2008, a negative trend between 2008 and 2010, a positive and then relatively flat slope between 2010 and 2013, and finally a slight upward slope between 2013 and 2014. The seasonal portion shows Acela ridership series with peaks at the end of winter/beginning of spring and fall, and troughs in the summer and end/beginning of the year. The random component represents a combination of unsystematic variations in the Amtrak ridership in response to various external events.

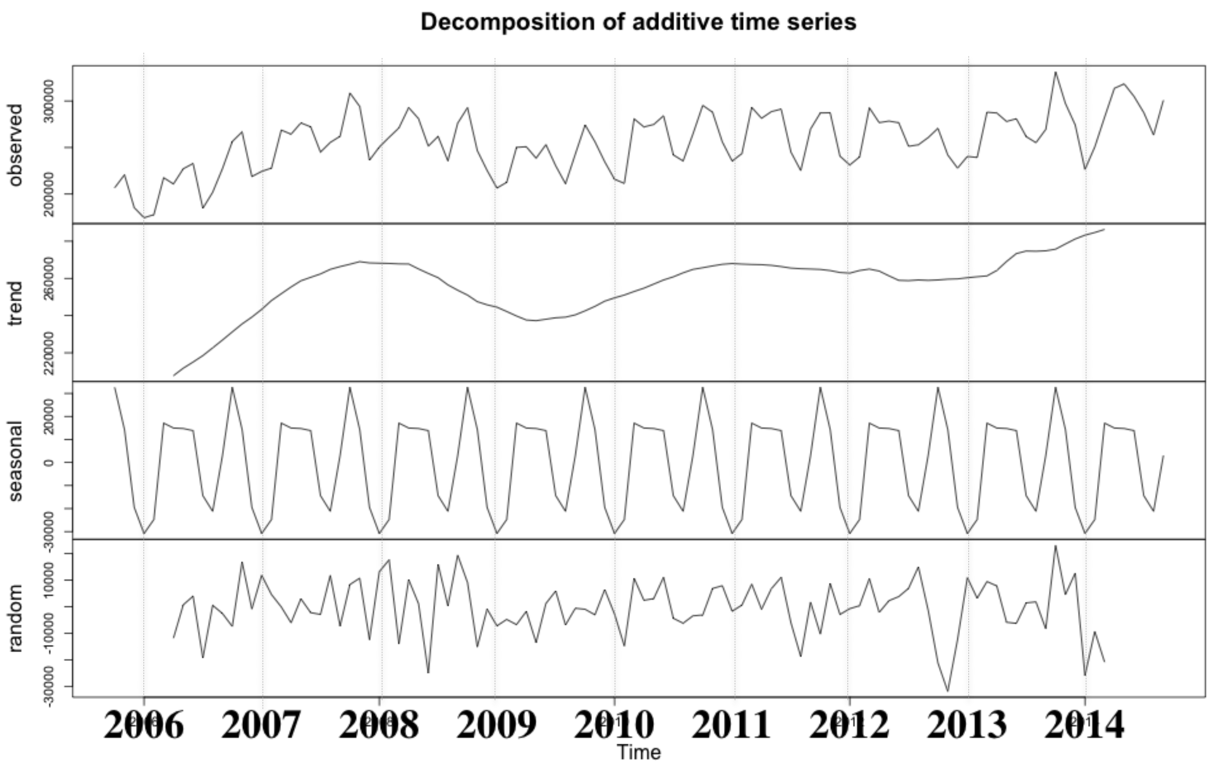

Figure 7.1: Acela Monthly Ridership Additive Decomposition

Figure 7.2 and Figure 7.3 show the decomposition of Acela monthly OTP and average delay per mile time series into the trend, seasonal and random components. The trends of both series show performance deterioration between 2006 and 2014 with OTP decreasing and delays increasing through the series. The seasonal components show high performance in February and September corresponding with peaks in the OTP chart and troughs in the average delay chart, and vice versa in the summer and at the end/beginning of the year. The random shock components show the residuals not explained by the trend or seasonal components.

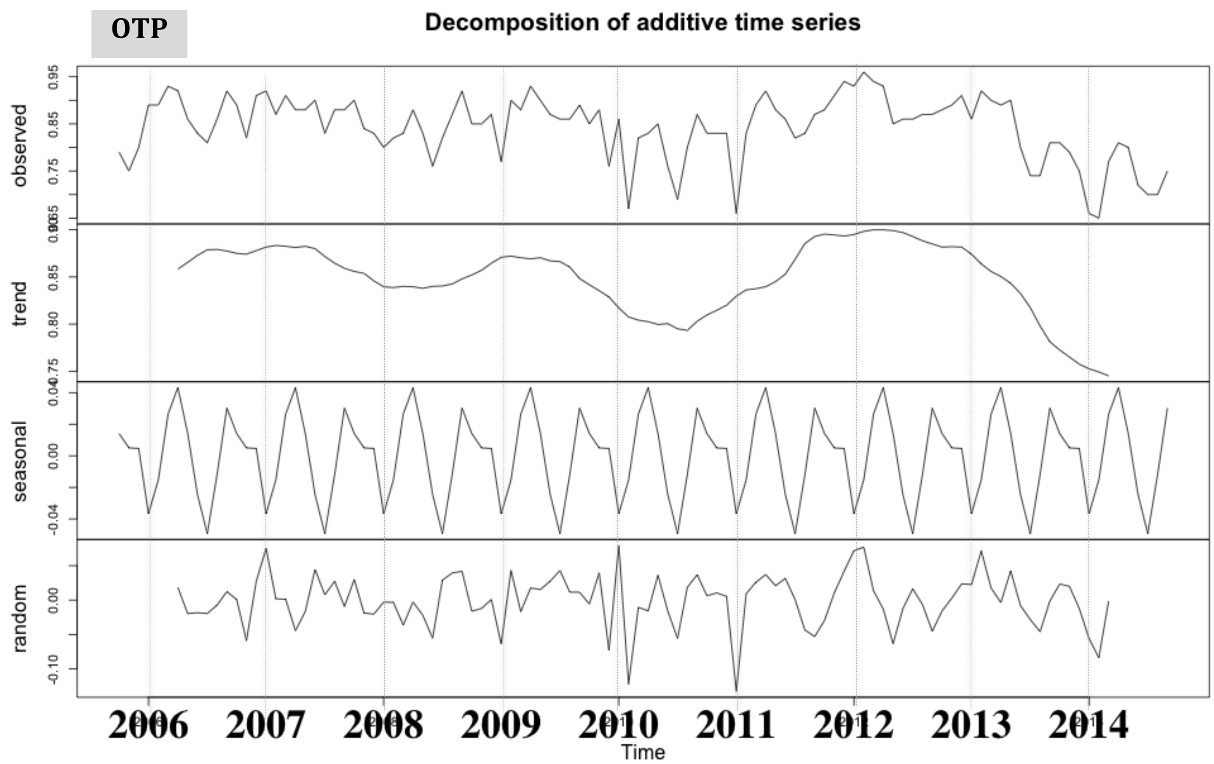

Figure 7.2: Acela Monthly OTP Additive Decomposition

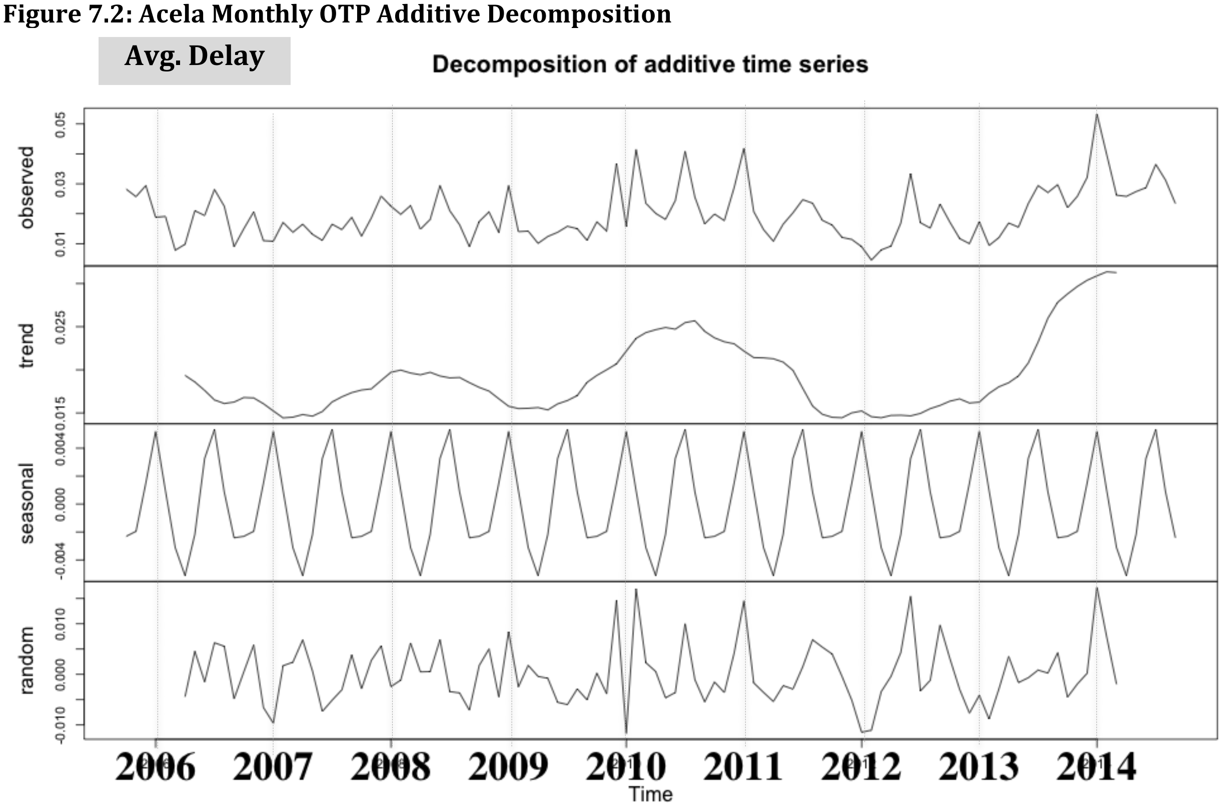

Figure 7.3: Acela Monthly Average Delay Per Mile Additive Decomposition

7.2.2 Dickey-Fuller Test (DF) and Augmented Dickey-Fuller (ADF) Test for Stationarity

The Dickey-Fuller Test was used to check for stationarity, that is, whether increasing or decreasing effects in the time series aggregate or die out over time. The Dickey-Fuller (DF) Test is expressed as

$$Y_t = \alpha Y_{t-1} + \varepsilon_t$$

$$\nabla Y_t = (\alpha - 1)Y_{t-1} + \varepsilon_t = \gamma Y_{t-1} + \varepsilon_t$$

where ∇ is the first difference operator and $\gamma = \alpha - 1$. When $\gamma = 0$, $\alpha = 1$ (unit root), and the series is not stationary. A non-stationary process where $Y_t = Y_{t-1} + \varepsilon_t$ is also referred to as a random walk. However, if serial correlation also exists in the original times series then the Augmented Dickey-Fuller (ADF) test is used to test for stationarity. Said and Dickey (1984) augmented the basic autoregressive unit root test to accommodate general ARMA models with unknown orders. The ADF Test is expressed as:

$$Y_t = \alpha Y_{t-1} + \sum_{i=1}^{p-1} \varphi_i Y_{t-i} + \varepsilon_t$$

$$\nabla Y_t = (\alpha - 1)Y_{t-1} + \sum_{i=1}^{p-1} \varphi_i Y_{t-i} + \varepsilon_t = \gamma Y_{t-1} + \sum_{i=1}^{p-1} \varphi_i Y_{t-i} + \varepsilon_t$$

where p is the order of the autoregressive component. The null hypothesis for non-stationarity is H_0: $\gamma = 0$ ($\alpha = 1$, unit root), and the hypothesis that there is a unit root is rejected if the test statistic is significant. The expression for the ADF test in R is shown in black below and the R output is shown in blue. If the p-value is small when the alternative is stationary, reject the null hypothesis.

```
>adf.test(AcelaMonthlyRiders, alternative="stationary", k=0)
Augmented Dickey-Fuller Test
Dickey-Fuller = -5.6596, Lag order = 0, p-value = 0.01
alternative hypothesis: stationary
```

The output (in blue) shows that the p-value is small so the Acela ridership series from FY 2005 to FY 2014 is overall stationary.

The series for the OTP and average delay were also stationary.

7.2.3 Autocorrelation Function (ACF), Partial Autocorrelation Function (PACF)

After the time series was stationarized, the next step was to determine whether AR or MA terms were needed to correct any autocorrelation that existed in the series. The autocorrelation function (ACF) between Y_t and Y_{t-k} is given by:

$$\frac{Covariance(Y_t, Y_{t-k})}{Variance(Y_t)}$$

The Partial Autocorrelation Function (PACF) captures the correlation between Y_t and Y_{t-k} that is not explained by the correlations at all lower-order lags (lag 1 through k-1). Specifically, the ACF and PACF are useful in identifying the order of the autoregressive (AR) and moving average (MA) models.

ACF and PACF plots are typically used as visual aids to identifying the orders of an ARMA model. The plots show the correlation coefficients for a specified number of lags in the series, as well as 95% confidence interval bands for statistical significance. For example, Figure 7.4 shows the ACF plot for the Acela monthly ridership up to a lag of 120 months (10 years).

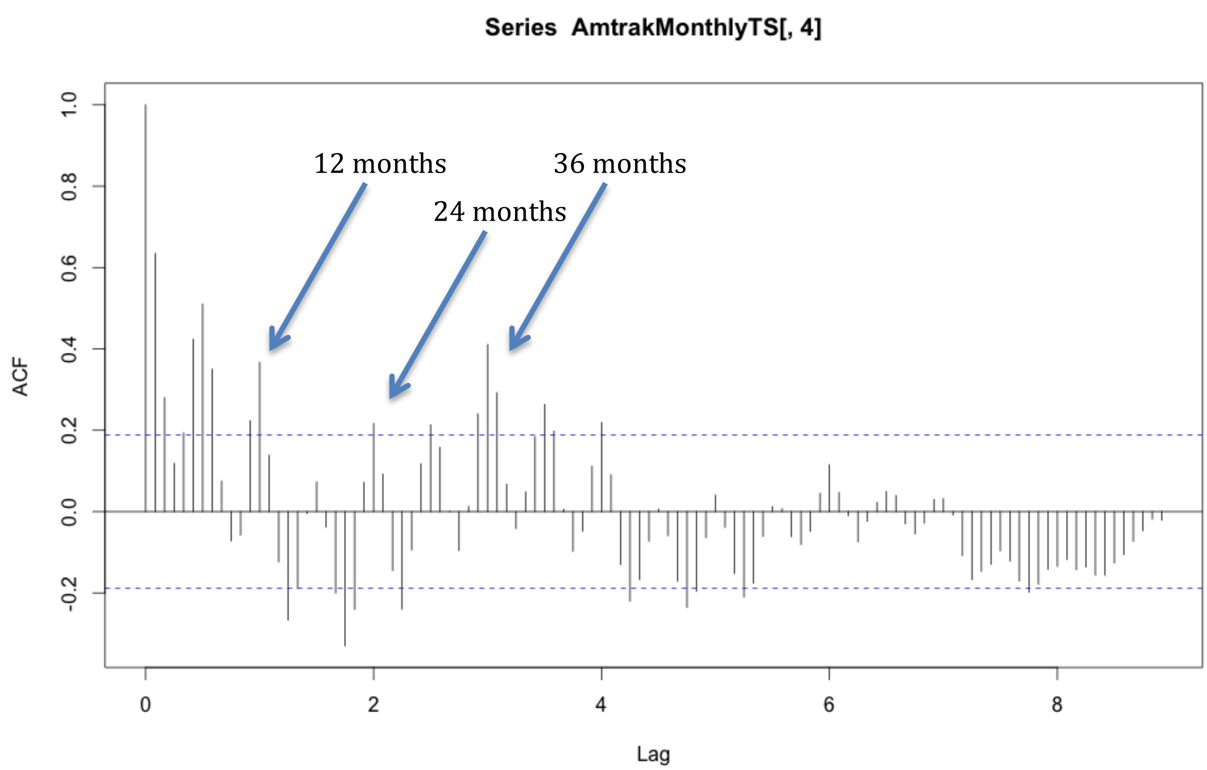

Figure 7.4: ACF for Monthly Acela Ridership at Max Lag = 120 months

The first bar in the autocorrelation plot (ACF) shows the correlation with itself at 0 lag and thus always has a coefficient equal to 1. The second bar shows a 0.6 correlation coefficient between the ridership series and the 1-month lagged series. The plot also shows an alternating pattern of positive and negative spikes, and significant correlations every 12 lags, which indicates the presence of seasonal effects. To help identify the non-seasonal components, the seasonal component was removed and the ACF plot was generated on the seasonally differenced series.

```
>Ridersseasonallyadjusted <- AmtrakMonthlyRiders - AcelaMonthlyRiderscomp$seasonal
>acf(Ridersseasonallyadjusted, lag.max=120)
```

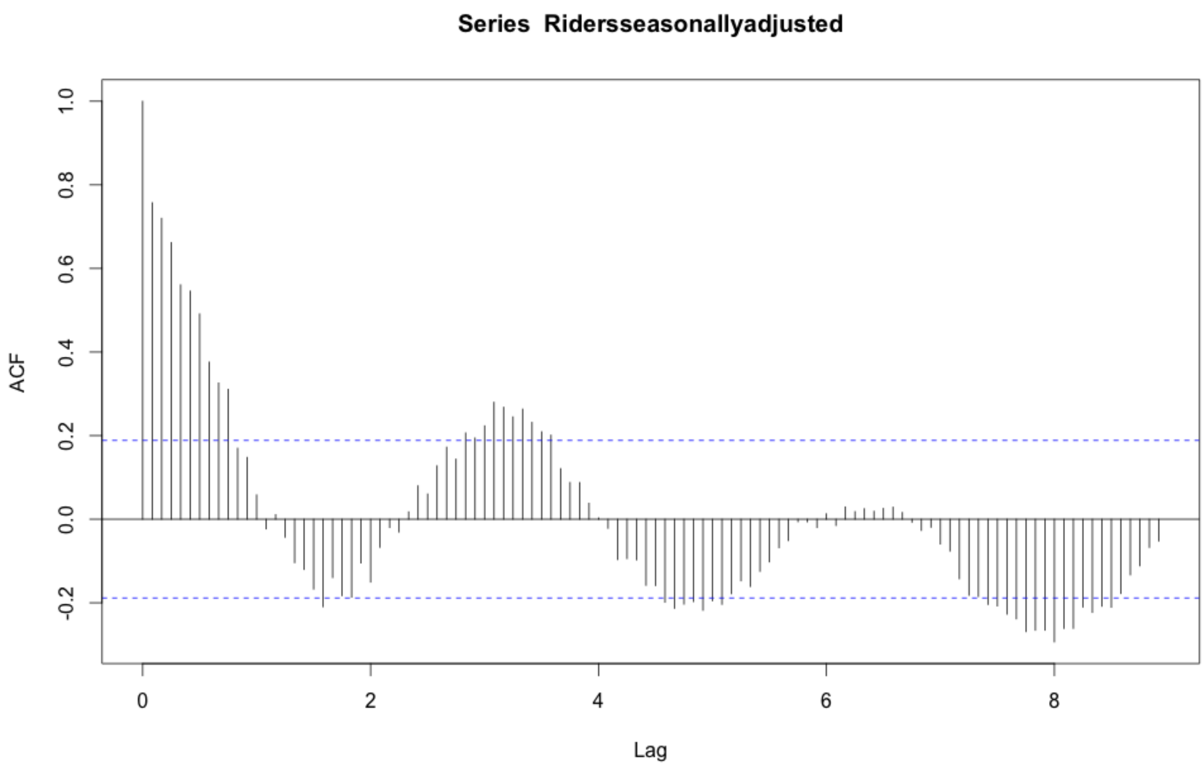

Figure 7.5: ACF of Seasonally Differenced Monthly Acela Ridership Series

Figure 7.5 shows a mixture of exponential decay and a sinusoidal pattern, which indicates that an seasonal ARMA model with order greater than one may be appropriate. The partial autocorrelation function (PACF) plot was also generated on the seasonally differenced ridership series. Figure 7.6 shows the PACF plot. Unlike the ACF plot, in the PACF plot, the first bar at lag 0 shows the correlation after the first lag is removed. Consequently, the coefficient of lag 0 in the PACF is proportional to the coefficient of lag 1 in the ACF.

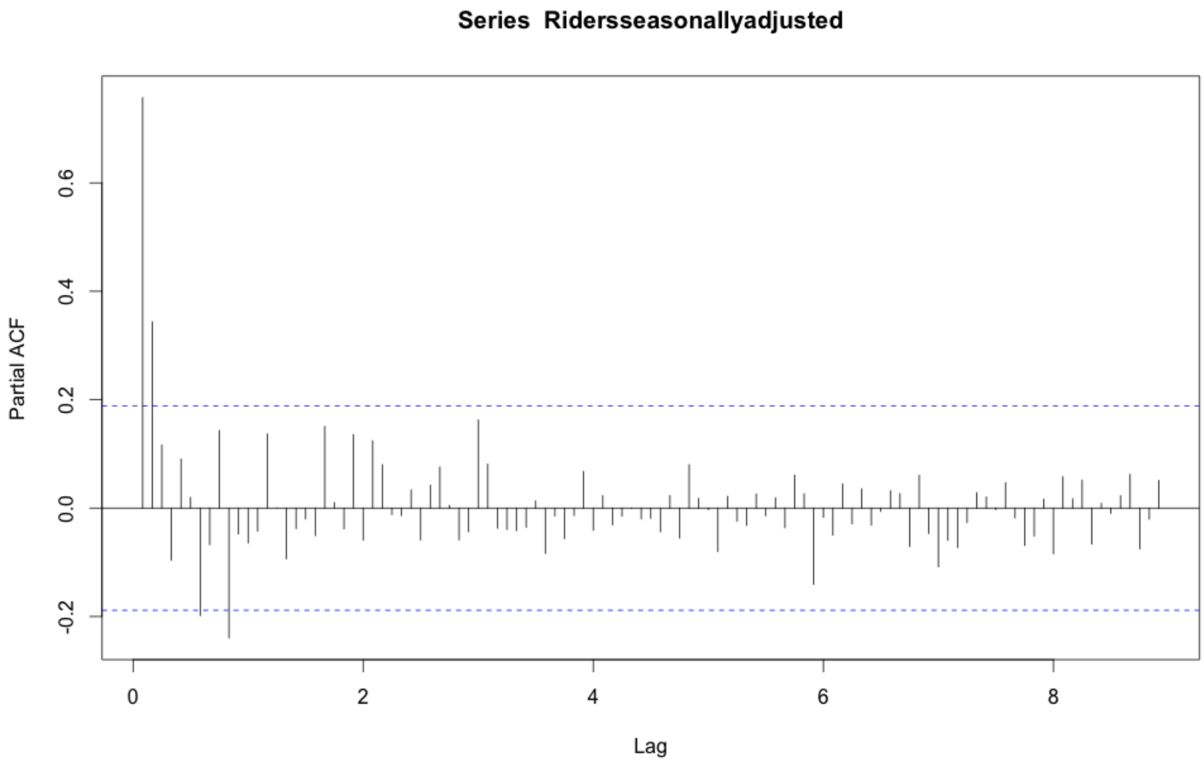

Figure 7.6: PACF of Seasonally Differenced Monthly Acela Ridership Series

The partial autocorrelation (PACF) plot shows significance on the second lag and pretty much non significance in the rest of the series, which suggests that an MA(2) model might be appropriate. The 7^{th} and 10^{th} lag were also significant, indicating some remaining seasonality.

Figure 7.7, Figure 7.8, Figure 7.9 and Figure 7.10 show the ACF and PACF of the Monthly Acela OTP and Average Delay time series. Both ACF plots exhibit a mixture of exponential decay and a damped sinusoidal pattern, while the PACF plots show significance at the 1^{st} and 2^{nd} lags, and again at the 12^{th} lag, which suggest an MA(2) process and some remaining seasonality.

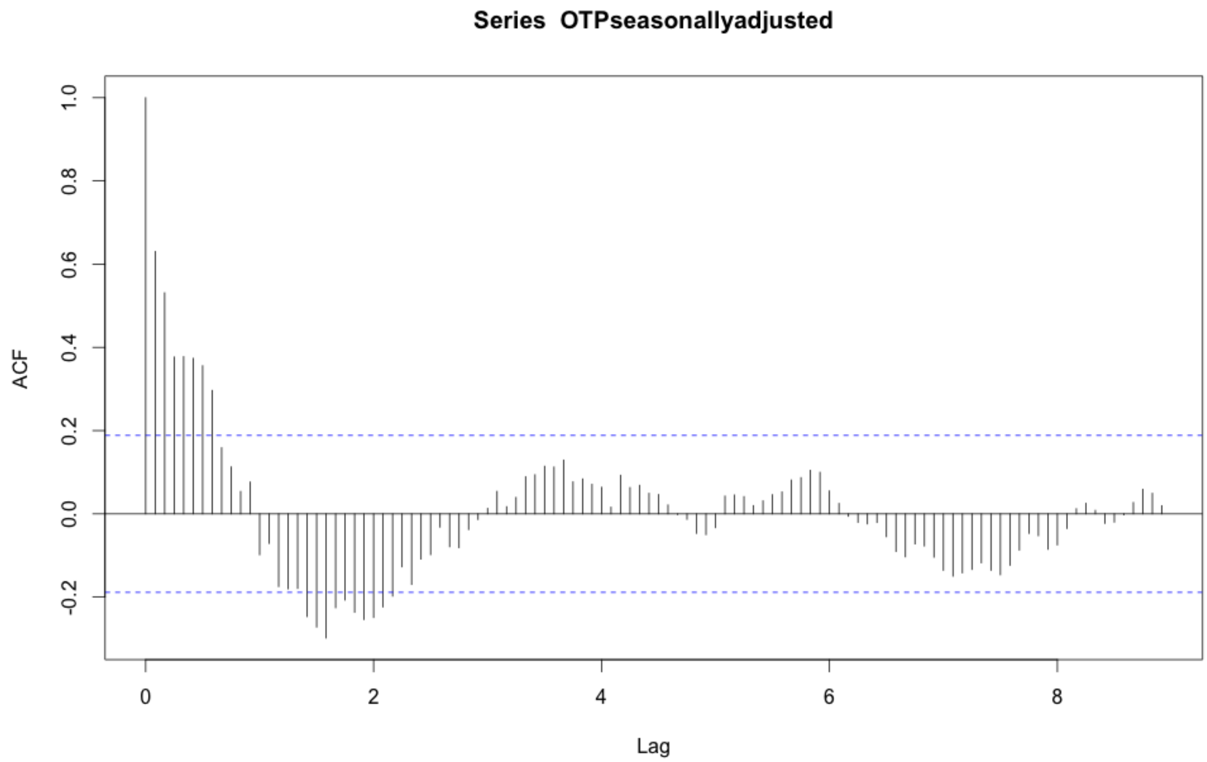

Figure 7.7: ACF of Seasonally Differenced Monthly Acela OTP Series

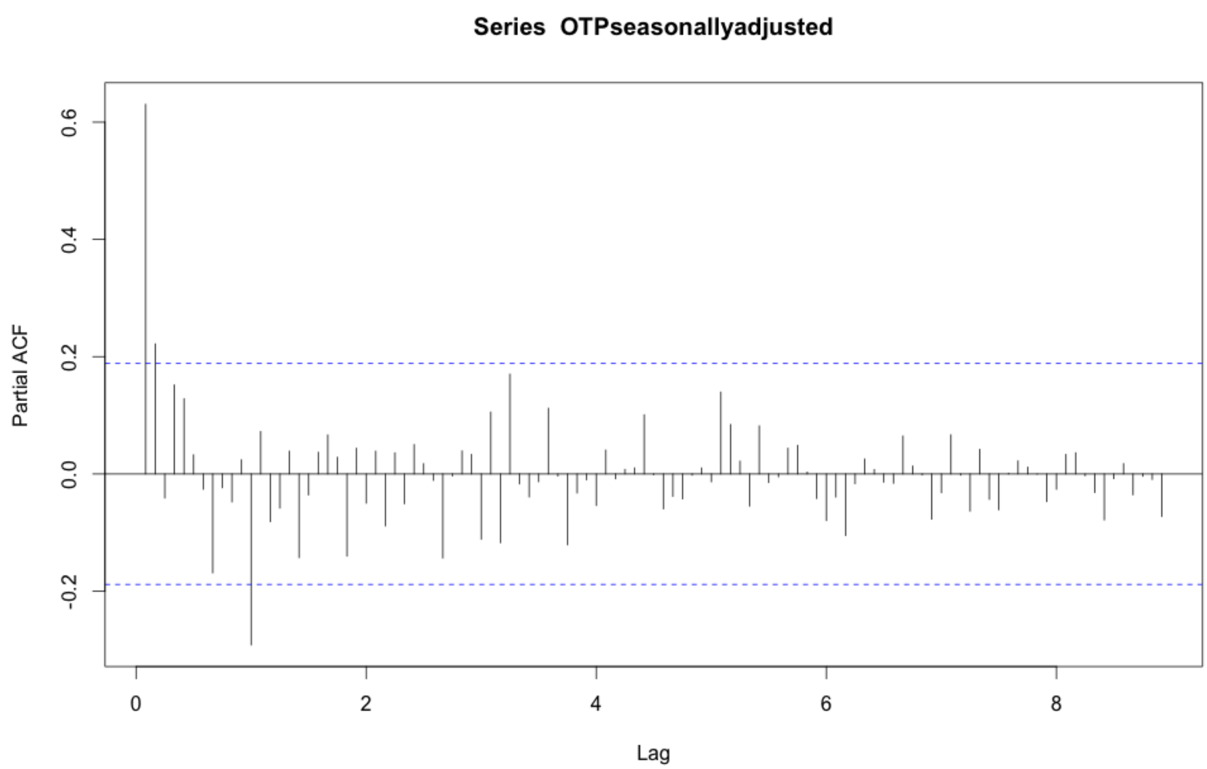

Figure 7.8: PACF of Seasonally Differenced Monthly Acela OTP

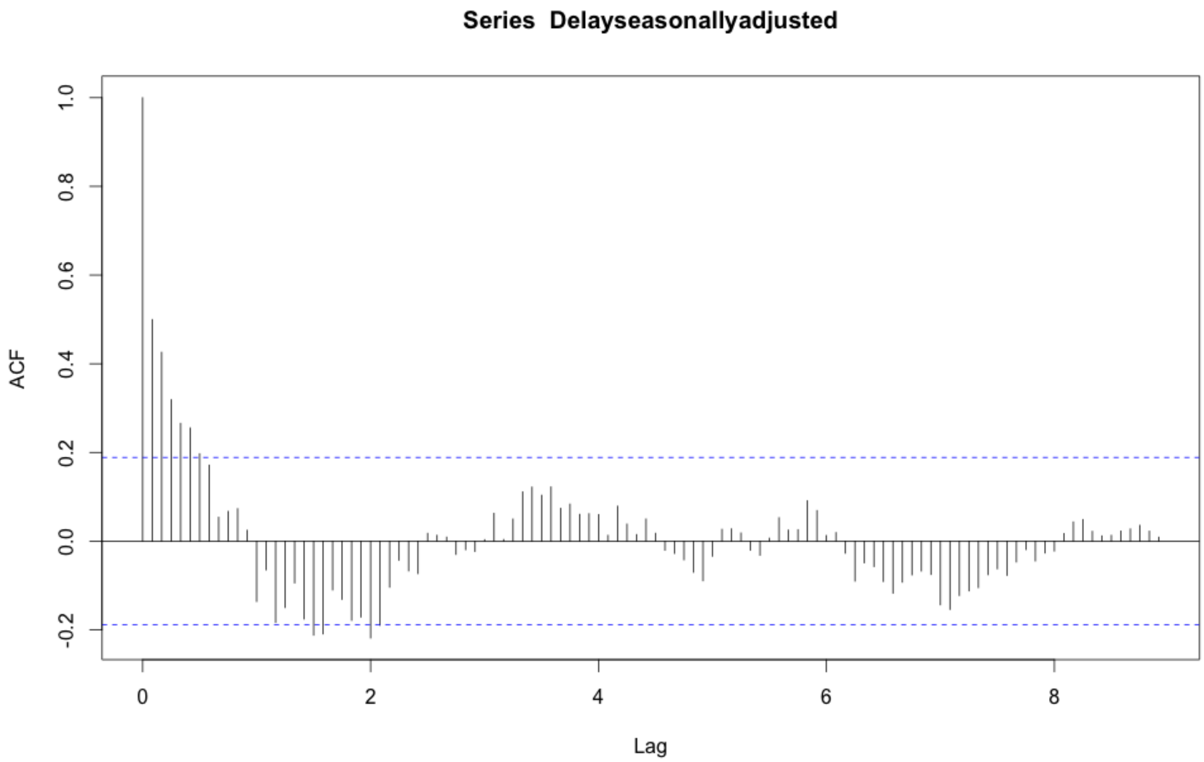

Figure 7.9: ACF of Seasonally Differenced Monthly Acela Average Delay

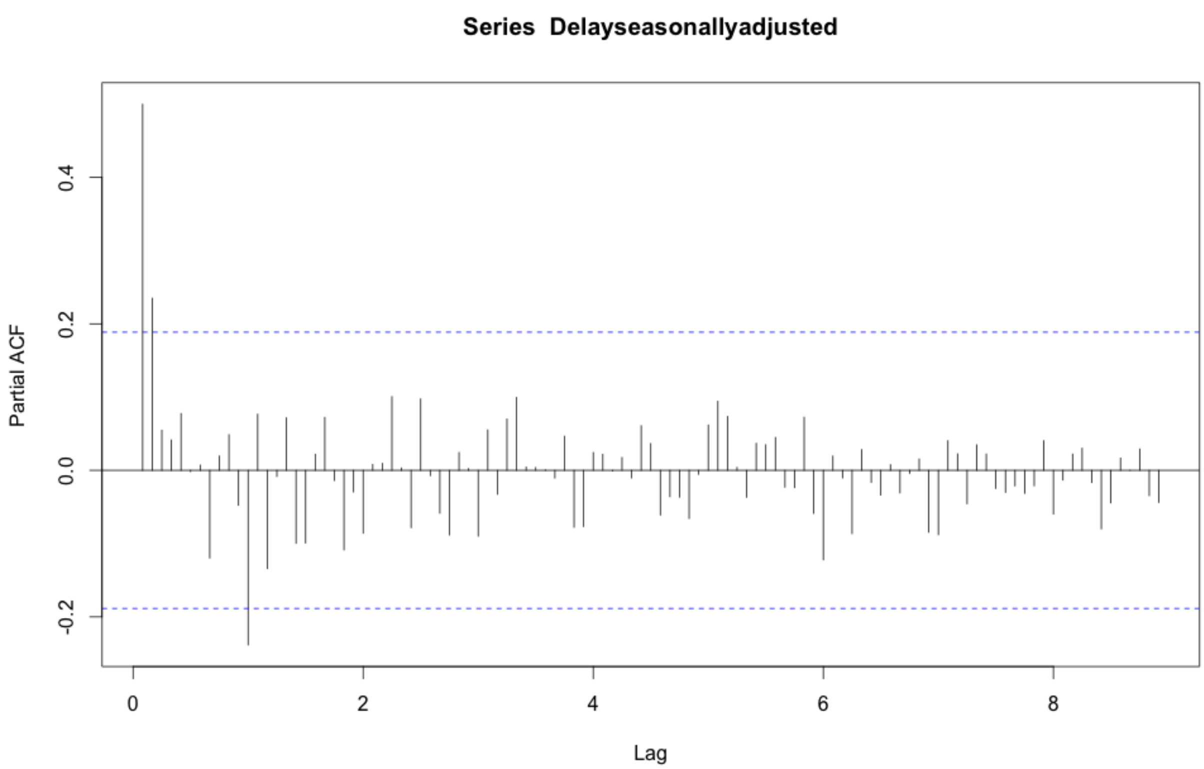

Figure 7.10: PACF of Seasonally Differenced Monthly Acela Average Delay

Starting with the performance metrics, based on the observations of the ACF and PACF plots, a seasonal ARIMA(1,1,1) model was used to fit the original Monthly Acela OTP time series data

$$X_t - X_{t-1} = \theta_1(X_{t-1} - X_{t-2}) + \alpha_1\varepsilon_{t-1} + \psi_1(X_{t-12} + X_{t-13}) + \varphi_1\varepsilon_{t-12} + \varepsilon_t$$

Where θ_1 is the AR(1) parameter, α_1 is the MA(1) parameters, and ψ_1 and φ_1 represent the seasonal parameter. The R expressions (in black) and outputs (in blue) are shown below:

```
>ma = arima(AcelaMonthlyOTP order = c(1, 1, 1), seasonal=list(order=c(1,0,1), period=12))
>ma
Coefficients:
        ar1      ma1      sar1     sma1
     0.2941  -0.7544   0.9943  -0.9553
s.e. 0.1541   0.1062   0.0375   0.1483
sigma^2 estimated as 0.002514:  log likelihood = 164.53,  aic = -319.05
```

Then the Box-Ljung Test was used to test that the residuals from the model up to 30 lags are random with adjusted degrees of freedom to account for the 3 estimated parameters. Under the Box-Ljung Test, the null hypothesis is that the residuals are random.

```
>BLT = Box.test(ma$residuals, lag=30, type = "Ljung-Box", fitdf=3)
>BLT
X-squared = 35.2654, df = 27, p-value = 0.1323
# To determine critical region:
>qchisq(0.95,27)
40.11327
```

Since the X-squared statistic is less than the qchisq critical value, the null hypothesis of the Box-Ljung test was not rejected and the fitted model was adequate.

A seasonal ARIMA(1,1,1) model was also used to fit the original Monthly Acela Average Delay time series data and is shown below:

```
>ma_delay = arima(AcelaMonthlyDelay, order = c(1, 1, 1), seasonal=list(order=c(1,0,1),
period=12))
>ma_delay
Coefficients:
      ar1      ma1      sar1     sma1
     0.2916  -0.8287  0.9915  -0.9646
s.e. 0.1600  0.1073   0.0564   0.1245
sigma^2 estimated as 5.384e-05:  log likelihood = 372.17,  aic = -734.34

>BLT_delay = Box.test(ma_delay$residuals, lag=30, type = "Ljung-Box", fitdf=3)
>BLT_delay
X-squared = 27.5248, df = 27, p-value = 0.4358

# To determine critical region:
>qchisq(0.95,27)
40.11327
```

Similarly, the Box Ljung test was not rejected since the X-squared statistic was less than the qchisq critical value.

There were a lot of complex trends in the ACF and PACF of the ridership and seasonally different ridership series, thus the auto.arima function in R was used to identify the seasonal model useful for fitting the original Monthly Acela Ridership time series. The R expression and outputs are shown below. An ARIMA(1,0,1)(2,1,1)[12] with drift was identified.

```
> auto.arima(AcelaMonthlyRiders)

ARIMA(1,0,1)(2,1,1)[12] with drift
Coefficients:
      ar1    ma1    sar1    sar2    sma1    drift
   -0.4550  0.6425  -0.4626  -0.6308  -0.3357  369.3629
s.e.   0.1874  0.1749   0.0967   0.0602   0.2088   47.8278
sigma^2 estimated as 170176354:  log likelihood=-915.19
AIC=1870.53   AICc=1871.8   BIC=1888.48

>BLT_delay = Box.test(ma_delay$residuals, lag=30, type = "Ljung-Box", fitdf=3)
>BLT_delay
X-squared = 22.7545, df = 27, p-value = 0.6981

# To determine critical region:
>qchisq(0.95,28)
41.33714
```

7.3 Transfer Functions and Cross Correlation Function (CCF)

This section focuses on modeling the relationship between two time series, where one could be related to past lags of the other series. The cross correlation function (CCF) is often used to identify lags of one series that might be useful predictors of the other series. The CCF is defined as the set of correlations between the predictor series X_{t+h} and the "independent" series Y_t for h lags. Negative values of h suggest that the X_t series leads the Y_t series, while positive h values suggest the opposite. For example, $h = -1$ indicates that current values of Y_t are influenced by X_{t-1}, the values of the X_t series from the prior period.

The cross correlation plots of the seasonally differenced monthly OTP and ridership series is shown in Figure 7.11 and that for the seasonally differenced monthly average delay and ridership series is shown in Figure 7.12.

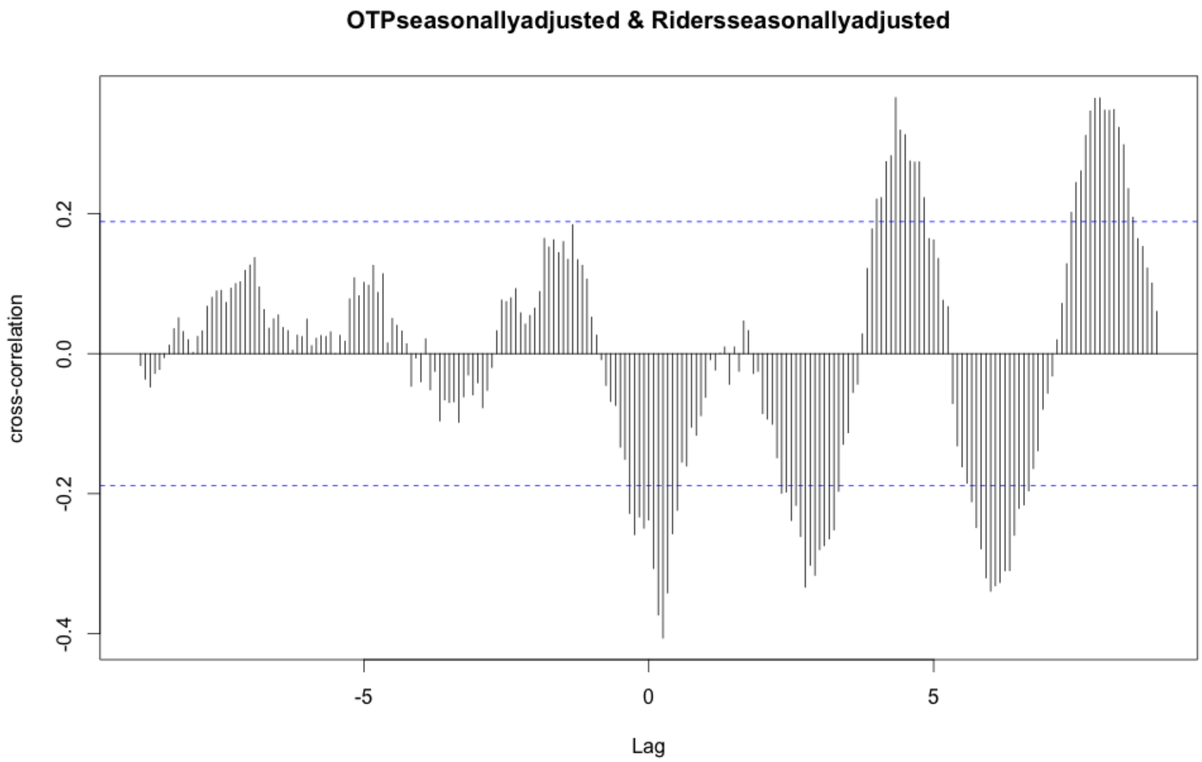

Figure 7.11: CCF between Monthly Acela OTP and Ridership Series

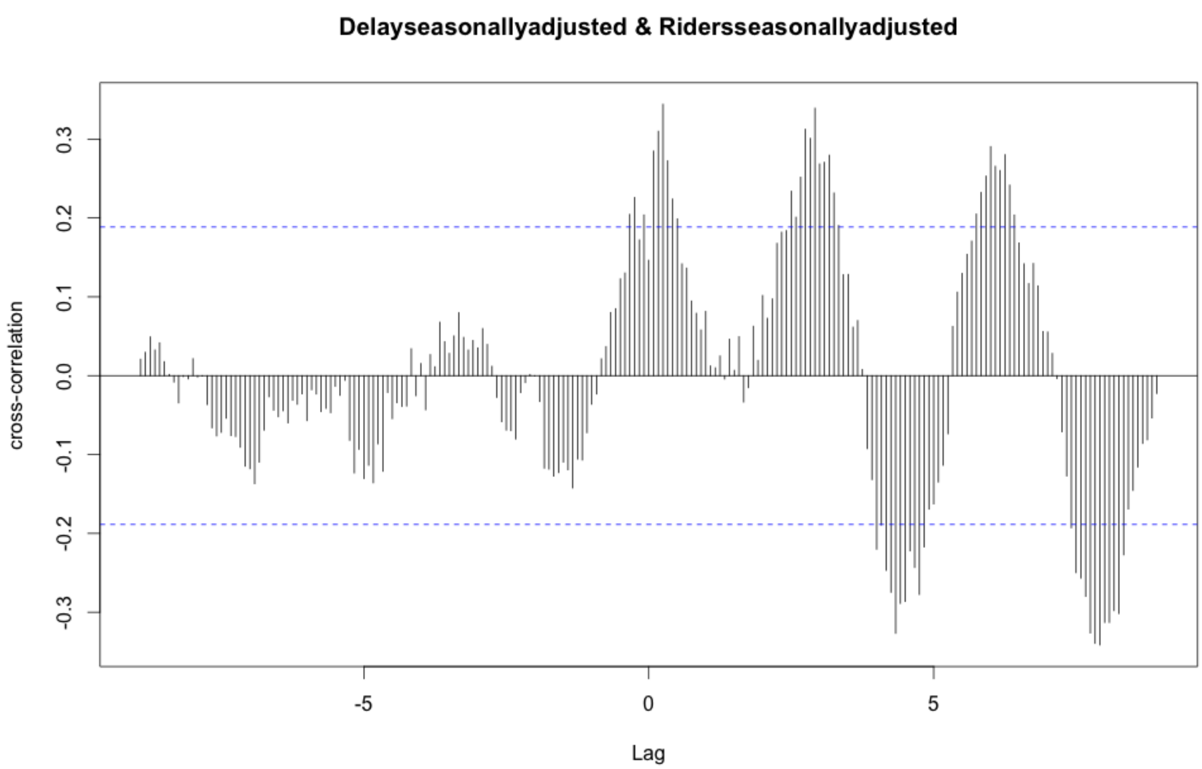

Figure 7.12: CCF between Monthly Acela Average Delay and Ridership Series

The significant and dominant cross correlations in both figures occur for positive values of h, which suggests that the performance series lags the ridership series. The CCF plots of the seasonally differenced series also exhibit a periodic pattern.

Transfer functions are used to model times series e.g. Y_t as a function of past lags of Y_t as well as current and past lags of another series, X_t. Again the auto.arima function in R was used to fit relationship between Acela monthly ridership series and the monthly OTP series. However, the results were complex to interpret and thus are not shown in this thesis.

7.4 Discussion of Time Series Analysis

The time-series analysis of Acela ridership had complex autocorrelations, seasonality, and cross correlations with the performance series, which made it difficult to quantify the effect of performance on ridership. Furthermore, the results obtained are inconclusive and given the time constraint for this thesis, the author was not able to dig deeper into the analysis and thus has made suggestions regarding time series modeling for future work.

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8 SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter provides a summary of findings in **Section 8.1,** thesis conclusions in **Section 8.2** and final recommendations regarding performance of the Acela and Regional services in **Section 8.3**. In addition, **Section 8.4** includes a list of potential topics that could supplement the work done in this thesis for future consideration.

8.1 Summary

The analyses and discussions in Chapter 1 to 7 showed that the Acela and Regional experienced large amount of delays each year between FY 2005 and FY 2014, and more so in FY 2014. In FY 2014, 58% of operated Acela and Regional trains arrived at their final destination later than the scheduled arrival time, causing delays to 66% of total Acela and Regional riders (about 7.7 million passengers). These delays resulted from variability in train travel times and service performance. The author investigated a number of factors that influence service performance and evaluated their impact in FY 2012 and FY 2014. FY 2012 and FY 2014 represented the years with best and worst annual service performance between FY 2005 and FY 2014. In FY 2012, although the percentage of trains impacted by delays were fewer (41% of trains arrived late), some of the factors causing routine delays appeared to be similar to those in FY 2014. The factors characterizing ridership and service performance variations discussed in this thesis were:

8.1.1 Seasonality and Month of Year

On both Acela and Regional services, there were clear signs of monthly performance variations; winter months typically experienced the best performance, except during severe winter weathers and summer months typically suffered poorer performance due to heat restrictions, infrastructural issues (catenary wire drooping) and track work (usually scheduled in good weather months). Similarly, the ridership profile exhibited seasonal patterns. For Regional, January and February regularly had the lowest ridership, which coincided with the end of the winter holiday and vacation, while all other months had relatively similar ridership levels. For Acela, the lowest ridership were observed in January and August likely due to vacation during the winter and summer holidays and highest ridership were usually in the fall and spring months.

8.1.2 Day of week and Time of Day

Other than Saturday, which usually experienced lower levels of delays, service performance on the Acela and Regional did not appear to vary considerably by day of week. Conversely, average ridership on both the Acela and Regional appeared to be much lower on Saturdays. Furthermore, of the weekdays, the ridership was typically the highest on Wednesdays and Thursdays on the Acela and on Thursdays and Fridays on the Regional.

Additionally, time of day was shown to impact Acela and Regional performances as certain morning and evening peak hour trains experienced both high ridership and significant delays. Also, the best and worst performing Acela and Regional trains in FY 2012 and FY 2014 were usually the same suggesting systematic issues. Overall, all trains experienced a significant amount of delays, including the first train of the day, which theoretically should be able to achieve on-time arrivals regularly.

8.1.3 Administration, Management and Control Elements (e.g. operating crew, timetable construction, etc.)

iv. The first train analysis attributed routine delays on Acela and Regional trains to 'avoidable' delays and timetable construction artifacts. Firstly, the analyses in both FY 2012 and FY 2014 revealed that the first train of the day often times departed from the originating stations with about 1 to 3 minutes delays on average, which accumulated and propagated at each consecutive station downstream. Late departures of the first train of the day from the originating station should be avoidable. In terms of timetable construction artifacts, the author could not detect scheduled train dwell time at each station and the scheduled segment speeds and travel times appeared to be different from actual speeds and travel times on average, which led to odd accumulation and dissipation of en-route delays. These effects were noticed on both Regional and Acela, but the segment level deviations were more pronounced on the Acela service. On the Acela, the difference between scheduled and actual average segment travel times and speeds led to delay accumulation in some segments (where average actuals were slower than scheduled), and delay reduction in others segments (where average actuals were faster than scheduled). So for example, end-to-end travel time between Boston and Washington would be close to the timetable but could be late for intermediate stations, suggesting timetable padding to provide an opportunity for a train to "catch up".

8.1.4 Capacity Levels on Trains

Compared to FY 2012, in FY 2014, more Acela trains appeared to be near or at capacity in both the north-end and south-end segments of the corridor, especially the trains operated during morning or evening peak periods. Both Acela and Regional trains operated during the peak time of day exhibited poorer performance.

8.1.5 Accidents and Incidents (e.g. Signal Failures, Weather-related, Track Work, etc.)

Unanticipated weather-related and third-party events were responsible for about 12% of Acela and Regional train delays (based on FY 2012 and FY 2014 analysis). Furthermore, in FY 2012, there was only one major delay caused by operational issues; however, in FY 2014, about 50% of severe daily delays (delays >10,000 minutes) were associated with equipment and infrastructure issues. This evidences the impact of inadequate track renovation and infrastructure maintenance on the Northeast Corridor in recent years[xi]. Furthermore, not including days with severe weather issues, Amtrak rarely cancels Acela and Regional trains.

8.1.6 Interference From Other Amtrak Trains

Interference from other trains occurred on days with severe delays caused by accidents or weather disruptions. However, on an average day most Acela and Regional trains experienced delays less than 30 minutes and since Amtrak usually spaces trains in intervals greater than or equal to 30 minutes, routine delays on one train usually did not cascade to the next scheduled train. The train interference analysis was done by observing consecutive train departures from each station; however a more detailed analysis for future work would be to observe complete daily round-trip of train sets/locomotives and train crews.

8.1.7 Demand Response to Service Performance

The annual demand response to annual delay and annual OTP showed one-year lagged correlations as high as 0.74 indicating that current Acela and Regional on-time performance levels were associated with ridership the following year. It is unclear whether the one-year lagged associations exhibited between service performance and ridership on both the Acela and Regional services are cause-effect relationships between service performance and demand or simply correlations. Furthermore, the times series analysis indicated autocorrelations between Acela ridership in adjacent months, and a similar autocorrelated relationship for on-time performance and delays. The author believes that the time series analyses are inconclusive and could be enhanced to fully understand the impact of service performance on demand.

8.2 Conclusions

In this section, the author refers back to the figures introduced in Chapter 1. Figure 8.1 and Figure 8.2 characterize the large picture of performance on the Acela and Regional services respectively, in the Northeast Corridor (NEC). As a reminder, the black line represents the PRIIA on-time performance goals, which Amtrak set together with the Federal Railroad Administration (FRA) in FY 2010. In both figures, the blue bars show that the actual annual on-time performance on the Acela and Regional services trended towards the PRIIA goals until FY 2012, and then performance deterioration was sustained and amplified between FY 2013 and FY 2014. Consequently, the regrettable conclusion is that both Acela and Regional are currently underperforming. If the positive trend between FY 2010 and FY 2012 had continued in FY 2013 and FY 2014, the conclusions will likely have been different. The major causes of delay and travel time variability were attributed to (i) timetable construction artifacts such as poorly estimated segment speeds and no dwell time allowances at many stations, (ii) minor avoidable issues such as late departure from originating station, (iii) absence of policies and programs to keep Amtrak accountable to established goals, and (iv) infrastructure and rolling stock deterioration. Recommendations are made in Section 8.3 regarding each of these major issues. Furthermore, the relationship between service performance and ridership was assessed through a preliminary correlation analysis, which indicated a one-year lagged correlation but further research is required to ascertain actual cause-effect dependence.

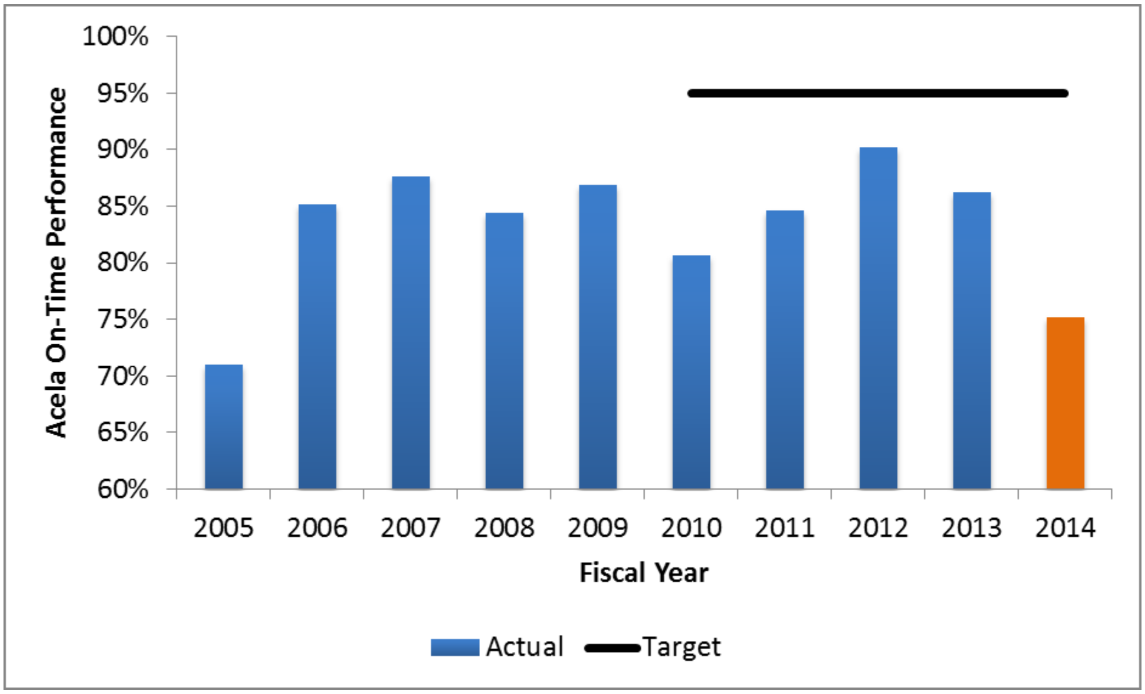

Figure 8.1: Acela FY 2005 – FY 2014 On-Time Performance

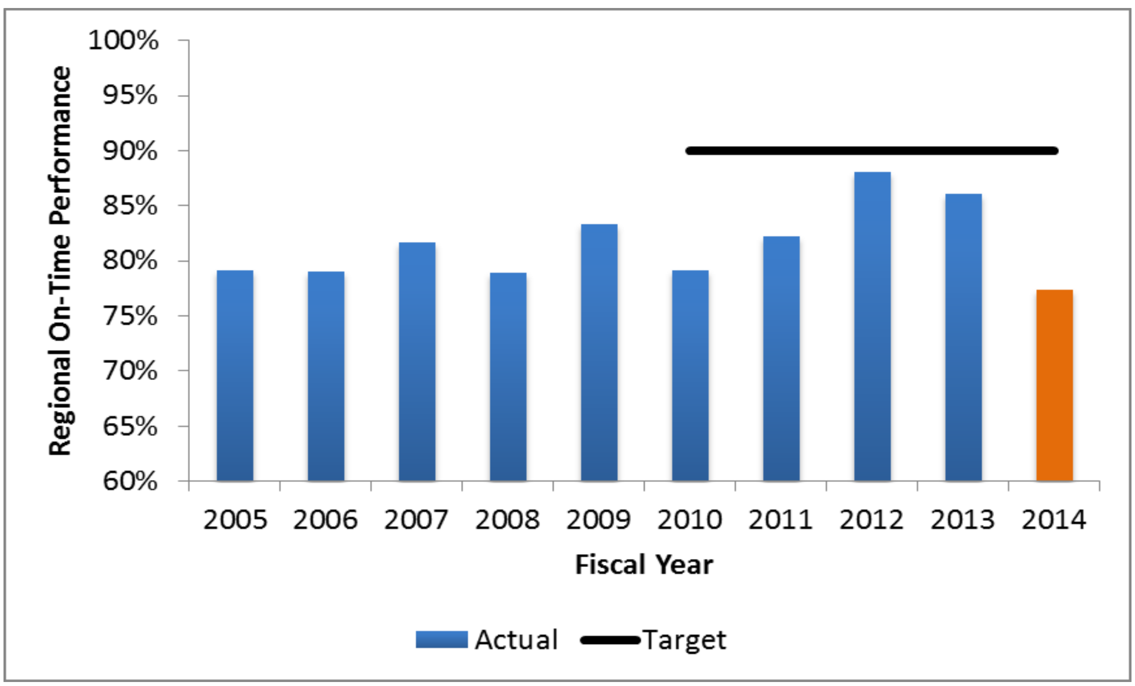

Figure 8.2: Regional FY 2005 - FY 2014 On-Time Performance

The findings presented in this thesis are drawn from analyzing Acela and Regional ridership and service operations databases. Although the findings are reliable, they are preliminary and further research at a more detailed level is required to make precise conclusions about each cause or effect factor discussed. Additionally, the data sources required to make precise judgments will need to be broadened to include not just Acela and Regional ridership and train operations data but also data on NEC commuter and freight service operations, data on the competitive balance between rail and the air, auto and bus modes in the NEC, as well as in-person interviews of Amtrak management and train and operations crews, etc. Some suggestions for future work are made in Section 8.4.

Lastly, the ridership and train operations data used for the thesis analyses were the best of Amtrak's in-house Acela and Regional records. However, the train operations data had shortcomings such as missing or incorrectly entered train arrival or departure times, which were attributed to human error. The defects of the data will likely not change the major conclusions of this thesis, since the conclusions reflect aggregates (totals) and averages over multiple trains and days. However, for more accurate and sophisticated bookkeeping, the actual train operations data entry should be upgraded from a manual method to a more automatic process. The first recommendation in Section 8.3 relates to refining the data records.

8.3 Recommendations

This section provides suggestions and active steps on how Amtrak can monitor and improve actual service performance, as well as service performance records for the Northeast Corridor.

8.3.1 Refine Data Records

In September 2013, Amtrak launched a new interactive tool to track daily train operations in real-time. The train tracker provides accurate information about the location of each train en-route, including train speeds, departure time from originating station, and scheduled and actual arrival times at each successive station. The automatic vehicle locators (AVL) data should replace Amtrak's current train operations database to provide a more accurate record of train performances. This would eliminate the shortcoming of the current dataset, which had missing train information at some stations because the train personnel failed to record the actual arrival and/or departure times of the train. This would make the dataset cleaner and further make train cancellations or stations that were not served clearer in the data records.

8.3.2 Refine Timetables

The author found Amtrak historical timetables[xii] that were effective April 1, 1990 through October 27 1990. In the historical timetables, Train 107 on the Metroliner Service (Acela predecessor) was scheduled to depart from New York at 9:00AM and arrive in Washington, DC at 11:49AM. In comparison, Amtrak current timetables effective January 12, 2015[xiii] shows that Acela Express Train 2151 is also scheduled to depart from New York at 9:00AM and arrive in Washington, DC at 11:49AM. Although the stopping pattern of the trains have changed slightly, this shows that Amtrak has not implemented any significant train schedule adjustments in more than 25 years, even when train technology changed. In this thesis, daily routine delays were attributed to timetable artifacts, which affected both Acela and Regional trains. Routine delays appeared to stem from deviations of operated train from scheduled segment-level speed and travel times and undetectable terminal time at stations, which accumulated at subsequent segments and stations downstream. Consequently, the refined data obtained from the automatic vehicle locator should be used to revamp or in the very least, adjust train timetables. Furthermore, Amtrak should plan to fine-tune the train timetables on an annual basis, and especially when new trains sets and train slots are introduced.

8.3.3 Educate and Reinforce On-Time Culture

Under PRIIA requirements, Amtrak currently has at least 18 delay codes categorized under Amtrak- and third-party-responsible delays, used to report causes of delays and responsible party. Although this database was not provided to the author, other public reports[xiv] indicate that Amtrak-responsible delays include delays causes by passengers boarding and alighting, delays caused by crew lateness, etc, while third-party delays include delays caused by weather-related issues, police-activity issues, etc. While the third party delays are for the most part unavoidable, some Amtrak-responsible delays should obviously continue to be managed and reduced by educating and reinforcing on-time culture for operating and managing Amtrak crewmembers. Furthermore, Amtrak should monitor and utilize the information in the cause of delay and responsible party database in order to tackle, reduce and eliminate some of the minor causes of delays, such as late departure from originating station. Furthermore, delays attributed to train, crew and control center personnel's can be made managed through a monthly or quarterly review process for train managing and operating personnel, or on-board visual aids to help train drivers monitor deviations from scheduled timetables.

8.3.4 Management, Policies and Programs

Strict policies and programs like PRIIA Section 207 are required to help Amtrak meet established goals. The analyses in this thesis showed that even though Amtrak owns most of the track in the Northeast Corridor, both Acela and Regional services experienced an unprecedented high in service performance in FY 2011 and FY 2012 while PRIIA Section 207 was active, and both services have been encountering performance deterioration since PRIIA Section 207 was overturned in FY 2013. In addition to statutory laws like PRIIA, other proven techniques like Six Sigma and Lean (used predominantly in manufacturing systems and more recently in health care systems) could be utilized to improve quality output of train operations by identifying and removing the causes of errors and minimizing variability in service operations.

8.3.5 Upgrade Infrastructure

In the long-term, Amtrak requires adequate funding to address essential track alignment/ curvature renovations, catenary maintenance, bridge and tunnel restorations, and rolling stock and signal improvements along the Northeast Corridor. In FY 2012, there was only one major delay caused by operational issues, however, by FY 2014, about 50% of the severe daily delays (greater than 1,000 minutes) were attributed to equipment and infrastructural issues, which evidences the deteriorating infrastructure in the Northeast Corridor in recent years. Consequently, Amtrak's Northeast Corridor Capital Investment Program[xv], which was designed to achieve a state of good repair and facilitate performance enhancement in the corridor requires a stable, multi-year funding program as opposed to the current unpredictable annual appropriation of funds.

8.4 Future Work

Although this thesis presented a wide range of analyses, the author believes the research only scratched the surface in terms of truly understanding and improving the service performances of Amtrak's Acela and Regional services in the Northeast Corridor. Some suggestions for future research include:

i. Train interference and cascading delays analysis by observing complete daily round-trips of Amtrak train sets/locomotives.
ii. Compare service performance of Amtrak trains with air, auto and bus modes in the Northeast Corridor, especially on the days with really poor performance attributed to weather condition
iii. Cumulative service performance metric that captures not only the magnitude (delay minutes) and frequency of delay occurrence on operated trains (on-time performance), but also the effect of cancelled trains.
iv. Time series and regression analysis to study demand response to service performance using the cumulative service performance metric.
v. A comprehensive impact of performance in the Northeast Corridor, including not just Amtrak Acela and Regional services, but also other Amtrak services, commuter rail services and freight rails services that share the track in the Northeast Corridor.
vi. Investigating Amtrak's on-time culture given that circumstantial evidence suggesting that some delays could be attributed to a poor on-time culture.
vii. Correlation between lateness leaving first station and late arrivals at the final destination.
viii. Analysis on the impact of timetable padding that results in end-to-end travel time being close to the timetable but higher delays at intermediate stations.

Looking into the future: High-speed passenger rail in the Northeast Corridor

The Northeast Corridor is a vital segment of U.S. rail, enhancing connectivity, mobility and economic productivity in the Northeast Region, the densest of the 11 U.S. megaregions. The author believes the ambitious plans to build "true" Next Generation high-speed rail in the Northeast Corridor is viable from a ridership and revenue point of view. In FY 2014, both the Acela and Regional set a record high of 3.55 and 8.08 million annual passengers, respectively and combined annual revenue record of $8.1 billion. Conversely, the rolling stock and service performance of Acela and Regional, as well as the corridor infrastructure exhibited signs of deterioration in the last two years, and especially in FY 2014. Consequently, significant infrastructure investments and service improvements will need to be in place before true international high-speed rail standards can be attained in the corridor.

Coda

Prior to him becoming my academic advisor, I met with Professor Sussman in his office at the beginning of the school year. The first thing I remember noticing was a placard quote attributed to Albert Einstein, prominently displayed on his shelf, that read: "If we knew what we were doing, it wouldn't be called research." In that moment, I would not have guessed that the quote would become such a key source of inspiration and encouragement for me as I worked on my thesis throughout the year. A few weeks after my first meeting with Professor Sussman, I asked him, and he agreed to be my thesis advisor. Every time I went into his office for yet another discussion of my thesis, I took a second to re-read that quote, and to remind myself that having all the right answers during the process would have defeated the very point of doing the research.

Finally, I would like to thank [you] the reader, for paying attention to the analyses and discussions presented in this thesis. I hope the thesis has been informative and useful, and provides a good background to build on in the future.

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9.1 Endnotes

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[i] http://www.nec-commission.com/

[ii] State of the Northeast Corridor Region Transportation System, Cambridge Systematics, Inc. February 2014

[iii] Metrics and Standards for Intercity Passenger Rail Service, Department of Transportation, Federal Railroad Authority, 2009

[iv] Amtrak's Twitter feed - https://twitter.com/AmtrakNEC

[v] Amtrak's Breaking News feed - http://www.breakingnews.com/topic/amtrak/

[vi] Amtrak's Twitter feed - https://twitter.com/AmtrakNEC

[vii] Amtrak's Breaking News feed - http://www.breakingnews.com/topic/amtrak/

[viii] Referring to the artic blast across many states in the U.S. that occurred in January 2014

[ix] http://www.itl.nist.gov/div898/handbook/pmc/section4/pmc4.htm

[x] Box & Jenkins, 1976; Velleman & Hoaglin, 1981

[xi] http://www.amtrak.com/ccurl/412/537/Amtrak-FY2015-Federal-Budget-Request-ATK-14-028,0.pdf

[xii] http://www.timetables.org/

[xiii] http://www.amtrak.com/train-schedules-timetables

[xiv] http://www.amtrak.com/servlet/ContentServer?c=Page&pagename=am%2FLayout&cid=1241245669222

[xv] http://www.amtrak.com/ccurl/412/537/Amtrak-FY2015-Federal-Budget-Request-ATK-14-028,0.pdf