A New Procedure for Scoring Rail Transit Connections to U.S. Airports

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Civil Engineering

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April 30, 2012
Falls Church, VA

Keywords: airport, public transportation, rail transit access, system evaluation, mode share

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ABSTRACT

25 airports have a connection with the local rail transit system, but each is unique. Variables such as network size, train frequency, type of airport station, time, and cost vary by airport. Both airport passengers and planners should have a technical basis of selecting which system is the most useful, efficient, and reliable. To date, there have been no scoring procedures created to rank the airports in order of quality of connection.

This thesis analyzes rail transit accessibility for all 25 airports (3 of which have 2 separate transit systems) by investigating 8 characteristics, 3 of which are market factors and 5 of which are system factors. The 5 system factors are travel time difference between car and train, transit cost difference between car and train, airport/transit connection type, network size, and train frequency. The 3 market factors are rail transit mode share, business traveler percentage, and low-cost carrier percentage.

A scoring system was then developed and each airport's characteristics were inputted. The airports were scored using three different methods and were subsequently

evaluated to understand why airports received the scores they did. This evaluation led to a better understanding of airport transit best practices. The scoring system was used again to evaluate an airport (Washington-Dulles) undergoing radical changes to understand by what factor a score can improve. A "top 10" list of airport transit connections was produced with JFK coming in first. This method is a starting point for developing a robust system to evaluate transit connections to airports.

ACKNOWLEDGMENTS

Thank you to Alasdair Cain for helping me understand what my purpose and goal in writing a thesis should be.

Thank you to Sharon Podobnik for constant emotional support and for keeping me on track to complete my thesis.

Thank you to Dr. Ralph Buehler for recommendations on how to make the thesis more approachable and informative to readers.

Thank you to Dr. Sam Tignor for your repeated efforts and persistence to better my thesis and suggest valuable additions that validate my work.

Special thanks to Dr. Shinya Kikuchi for being there with me every step of the way, from acceptance into graduate school, to advising me on appropriate courses, to finding internships, and for believing in me, encouraging my thesis topic, and ensuring the final product was relevant to the real world.

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1. Introduction

In the United States, air travel continues to grow. As airports continue to experience a growing influx of passengers, increasing strain is put on the road networks leading from the city to the airport. Many cities have chosen to combat this congestion issue by building rail transit systems that connect the city's central business district with the airport terminal. Taking rail transit to and from the airport can save a traveler time and money and can reduce stress by making it easier to get between the city and the outlying airport without having to worry about traffic conditions. The quality and reliability of these systems, however, vary among the cities. To date, no scoring rubric has been created to rank each individual airport transit system in comparison to all the others. This thesis seeks to accomplish that task in order to provide airport planners as well as airport passengers evidence-based guidance as to the quality of the airport transit connection. Each one of the country's 25 air to rail connections will be scored by several distinguishing characteristics about the local transit system operation, the way it interfaces with the airport, and ultimately how well the airport passengers are served.

2. Literature Review

In addition to the exhaustive review of details about airport transit systems supplied by the airports and transit systems themselves, several previous reports concerning this subject were researched. The past research has already begun to analyze why certain airport-rail connections work and why others do not, but still collectively leave a gap in making the connection between why a transit connection performs well and what it means for the users of it. Additionally, the usefulness of past indicators was evaluated to determine which can and cannot be used for this thesis.

In 1999, Joshua Schank presented an exhaustive review of a select few of the country's airports with rail transit connections, and detailed their respective connecting transit systems [(1)]. He used mode share percentage as a way to define success and established 11 propositions to determine which characteristics had the largest impact on mode share. Mode share is defined as the percentage of airport passengers who arrive to the airport using rail transit. Through his analysis, he determined the three most reliable factors at producing a higher mode share: First, that the smaller the travel time difference between taking a train from the Central Business District (CBD) to the airport and the equivalent trip via private automobile, the greater the mode share; second, that on-site stations attract a higher mode share than off-site stations; and third, that a connecting transit system that effectively serves population and employment centers will increase mode share. The weakness with this research now is that much of the data used for the airport systems is over 13 years old and does not include some of the more recent additions and improvements made to airport transit, as well as the lack of analysis inclusive of the new airport transit systems built in the last decade.

In 2009, Andrew Goetz and Timothy Vowles performed research that included analysis of all current existing airport-rail connections [(2)]. They established a hierarchical system using GAO definitions and the 50 largest U.S. airports to classify the existing transit connections based on the physical characteristic of their intermodal connections with 5 categories:

- Class 1 – Airports are points on national/regional rail system (no U.S. airports, European and Asian examples only)
- Class 2 – Airports are points on a local rail system (12 U.S. airports)
- Class 3 – Airport has dedicated access to local/regional/national rail system (12 U.S. airports)
- Class 4 – Airport has public transit access (non-dedicated) to local/regional/national rail system (3 U.S. airports)
- Class 5 – Airport has no access to rail system/city has no rail system (23 U.S. airports)

Differentiating the type of connection will be important when it comes time to rank the airports, as connections of a higher class will earn a higher score compared to connections with a lower class due to the increased benefit and convenience to airport passengers. Class 5 airports will not be considered at all, as they do not include rail connections.

In 2008, Airport Cooperative Research Program (ACRP) Report 4 provided extensive research on rail connection lessons not just in the U.S., but other countries as well [(3)]. By updating the initial findings of Transit Cooperative Research Program (TCRP) Reports 62 [(4)] and 83 [(5)], the ACRP report provides the most up-to-date data and conclusions currently available. While that report focused on all forms of public transportation to the airport, including bus and van service, the conclusions made concerning rail service are useful in the creation of the rankings, and, most importantly, distill down 7 desirable characteristics of rail service to U.S. airports:

1. Proportion of air travelers with trip ends in downtown or the transit-rich core areas
    - A higher proportion of travelers whose final destination is the CBD/downtown or a transit-rich area will lead to better service
    - Cities such as D.C. have 33% of all air travelers going downtown, which makes for a better air-rail connection than in most airports where fewer than 15% of passengers are heading downtown
2. Characteristics of air traveler market
    - Travelers with little to no checked bags, such as business travelers, are more likely to use rail service
    - Therefore, airports with a higher proportion of business travelers will be more successful
    - Airports with a higher proportion of tourist travelers are less likely to use transit

3. Regional travel time
    - Rail systems that connect the CBD to the airport without transfers is highly preferable to passengers to reduce hassle
    - Systems with 15 or more stops between the CBD and the airport have been shown to be less successful
4. Ability to walk between station and destination
    - Travelers will find rail connections more attractive if they can walk to their final destination from the destination station
    - It is less attractive and less convenient if they have to transfer to a second mode such as a bus or taxi to reach their final destination
5. Extent of regional coverage
    - Cities with a comprehensive rail network serving a large catchment area will serve a larger market than a system that consists of a single spoke line serving only the airport
    - A larger network also provides air travelers with more opportunities for travel, such as going to the airport directly from work and then going directly home when they return
6. Intra-airport travel time
    - Travel time between rail station and airport gate is important to travelers
    - Airports with a single centralized terminal such as ATL or MDW make it easier to reach final gate from rail terminal; JFK or BOS have multiple terminal buildings and require internal people movers, shuttles or walking

7. Frequency of service
    - Waiting time of 10 minutes or less is preferred. Longer wait times for a train may push the traveler to use on-demand cab service instead
    - Availability of late-night and weekend service is important

Many of these characteristics will be used as evaluation criteria in the creation of the rankings. The first characteristic concerning location of trip ends may be difficult to determine for each airport due to scarce data. However, the other 6 characteristics can most certainly be researched for each airport.

Characteristics of air traveler market can be determined by investigating the percentage of business travelers. In addition, the percentage of low-cost carriers can assist in determining the quantity of price-sensitive passengers who may be more willing to use transit.

Regional travel time is simple to determine, requiring only a study of a city's rail transit timetable or online "schedule planners" to determine length of trip from city center to the airport.

Ability to walk between station and destination is also a straightforward characteristic to determine, as many airport and transit websites clearly lay out how to connect between the rail system and the terminal. Studying geographical maps will also aid in this process.

Extent of regional coverage can be determined by obtaining the total track miles for each connecting rail transit system. Often this information is available on the transit system's "info" page.

Intra-airport travel time may be difficult to obtain due to a lack of easily available data concerning the specific time it takes to get from rail station to terminal. However, the placement of the rail station (on-site vs. off-site) will most certainly provide an easy way to determine the length of time it will take a traveler to move between the terminal and the train.

Finally, frequency of service will be simple to obtain, as most, if not all, transit agencies publish either an exact timetable of trains or publicize the expected headways.

The past research done on this topic covers many of the fundamental points that will need to be embedded in the new scoring system as it is designed. Specifically, Schank's propositions, Goetz and Vowles' connection classifications, and the ACRP report's desirable characteristics for transit connections will all be incorporated into the final product.

3. Thesis Scope and Purpose

3.1 Problem Statement

The past research does a fine job of determining what characteristics are important to consider for dependable and reliable airport transit. However, none of the past work attempted to assign a numerical score to the airports to be used as a way to rank them by quality of transit connection. This thesis will fill the gap of work in that area, by developing a ranking system, scoring the airports, and analyzing why airports ended up with the score they received.

3.2 Who Is This For?

The final rankings produced by this thesis may be used in two different ways. First, from a consumer/traveler standpoint, the rankings can be used to allow travelers to see which airports have good transit connections, which may influence their travel decisions. For instance, perhaps a traveler who lives in a city with a high-ranking airport transit connection is accustomed to taking a cab from downtown to the airport, and is unaware of the ease of use of his city's system. The rankings would validate that the transit is easy to use, reliable, and makes the journey of getting to the airport a seamless one that is comparable (or better) in travel time to taking a cab, at a fraction of the cost.

Additionally, from the other side of the spectrum, the planners and/or managers of the airport authority can use these rankings as a method of self-improvement. Airports with high rankings will confirm that the methods they have in place are effective at drawing travelers to use transit and also airport service. These airports should continue their best practices and work to improve them where possible. Conversely, airports with a low ranking should evaluate their practices to see where improvements can be made. Although shortcomings with service may occur, that are related to issues that cannot be fixed, such as types of travelers coming into the city, some practices, such as extent of network, connections, and frequency, can, and should be, improved.

3.3 Types of Transit Included

In all cases, a connecting rail system is a necessary component to be considered in these new airport rankings. Rail is the most competitive type of transport with compared to using a cab or private automobile due to its speed, ability to avoid traffic congestion, and comfort. The most obvious examples of transit systems to be included are ones that have extensive rail networks with stations specifically designed or purposed for airport connectivity.

There are essentially two types of airport rail transit connections. Many airports have systems that are designed to have the transit stations directly in the terminal, while others have stations that are off-terminal, but have a connecting shuttle (bus or people mover) to bridge the gap. These two types of airport transit connections will be the only types considered in this ranking system, as these are examples of best practices. Other types of connections include using connecting local bus services that are not airport-designated services. These services are characterized by frequent stops and usage of local roads, making it unfavorable as a type of airport transit. These types will not be considered for the rankings. In other countries, airports are served by buses with dedicated lanes in which to operate, and in those cases, they have proven to attract a high mode share [3]. However, in the U.S. very little attention is given to buses with their own lanes. In only two cases (Boston, DC-Dulles) are buses with dedicated lanes present, but their influence is limited, and are often a supplement to existing rail service. These examples will be examined in later sections. In summary, airports without direct in-terminal rail access but with bus or people mover connections will only be considered as long as that shuttle bus or people mover is marked as a dedicated, direct airport shuttle or connecting service.

4. Evaluation Criteria

The airports will be evaluated based on 8 criteria developed from the key points deduced in the literature review, covering a wide variety of characteristics that affect how successful an airport transit connection would be. These criteria are selected in a way that ensure there will be variability among the collective airport data. For example, criteria that have values that are almost all the same across all the airports, such as a standalone transit cost of between $2-$3, are not as important as a comparison criterion such as transit cost vs. cost of driving to the airport. The criteria are broken down into two categories, System Factors and Market Factors. The former refers to the supply side of the transportation system and the latter refers to the demand side.

4.1 System Factors

These are criteria that are mostly controlled directly by the transit system with the sole exception being the exact placement of the station; the airport authority often determines this aspect with input from the transit agency. These factors represent the supply side of a transportation system. Procedures for determining the values are explained in the following sections.

4.1.1 Cost

The one-way cost of riding transit between downtown and the airport will be determined using the transit agency's website. In cases of multiple fare levels, the level used will be the full one-way fare at peak time. Where applicable, multiple costs across different modes will be combined, such as if a connecting shuttle bus or people mover requires a fare for usage in addition to the baseline rail cost. The driving cost will be calculated from the distance between the CBD and the airport using the fastest route according to Google Maps, in addition to using the Internal Revenue Service (IRS) driving reimbursement rate of $0.55/mile and multiplying by 2 to represent a round-trip. The reason behind the doubling is the need of the automobile to return to its origin empty in the scenario where the traveler either elects someone else to drive him or her to the airport or take a cab. Not all cabs are required to return empty, but in some cases, exclusivity agreements between cab companies and an airport may not allow non-airport branded cabs to pick up passengers, such as is the case at Washington-Dulles (IAD). Due to this rule present at several airports it will be assumed that cabs are required to return empty. Transit does not encounter this issue of a wasted trip, as the return trip can have the same utility as a departing trip.

The driving cost uses the IRS travel reimbursement rate of 55 cents/mile [6]. The rationale behind using the IRS reimbursement rate is to find a way to officially quantify car usage. Most drivers do not think of wear and tear and depreciation as expenses their car suffers, and instead choose only to think about fuel costs. Additionally, fuel prices vary wildly around the country, so using a fuel rate as a way to find driving cost would not be practical. The IRS reimbursement rate is an official rate used for driving cost that is designed to cover fuel costs, wear and tear, and depreciation in one simple rate. This rate is traditionally used for business reimbursement.

For reasons of too much variability, driving costs do not include parking fees or cab fares, but rather just the cost to drive the vehicle.

The metric used to compare airports will be the cost difference between driving and transit usage [x = cost(driving) – cost(transit)].

4.1.2 Travel Time

Transit travel time is calculated using a transit agency's published schedule of trains between the CBD and the airport station(s). In cases where a shuttle bus transfer is necessary, the appropriate in-shuttle travel time is added. Walking transfer times are not accounted for, as they can vary vastly between airports.

Driving time is determined using Google Maps and querying driving directions between a central area of the CBD to the entrance of the airport terminal. The center of the CBD is determined by where Google places the location marker when just the city name is typed in (73). In all cases, travel time between CBD and airport will be under optimal, congestion-free conditions. In some cities, frequent congestion makes the driving time somewhat longer.

The metric used to compare airports will be the time difference between driving and transit usage [x = time(driving) – time(transit)].

4.1.3 Airport/Transit Connection Type

Connection type represents the type of physical, spatial connection that exists in order to move passengers from the rail system to the main terminal. Every airport has a unique type of rail connection so the only way to easily compare them is to develop a ranking system, based off of Goetz and Vowles' research [2]. The five types of physical connections are represented by values 1-5 as outlined below:

5: Station is in terminal (<1000 ft. walking)

4: Station is near terminal, no transfer required (>1000 ft. walking)

3: Station is near airport, rail people mover required

2: Station is near airport, one shuttle bus required (5-10 min. bus)

1: Station is near airport, two transfers required (or one bus >10 min.)

The metric used to compare airports will be the assigned numerical value. [x = connection value (1-5)]

4.1.4 Network Length

Past research has shown that a traveler is attracted to transit when he/she can walk to their final destination in transit rich areas [3]. Transit systems that have a large supporting network are more likely to attract airport passengers, under the assumption that with more choice and larger regional coverage, the easier it will be to walk to their final destination. Airports with transit connections only leading to downtown on a single line will not be as desirable as larger systems with multiple lines, due to the fact that the traveler will most likely need to transfer to an automobile at some point. Essentially, the more track, the more final destinations the traveler can get to on foot. It should be noted that for this metric, the *track* length is used, not the *route* length. Route length double counts tracks that share multiple lines, and are not an accurate representation of the number of unique destinations a traveler can get to.

The metric used to compare airports will be the mileage of revenue track used by transit [x = track miles of connecting transit].

4.1.5 Frequency

Past research has shown that frequency of service is very important [(3)]. Trains should be arriving every 10 minutes or less; more than this, and a traveler is more inclined to use on-demand cab service. The frequencies of trains are found either via the airport's dedicated "public transit" website or the transit agency's published schedule. Most airports are busiest in the mornings and the afternoons, especially in airports with high percentages of business travelers. Therefore, the train headway at rush hour will be used as the primary means of measurement. Late night and weekend service is also important, but will not be used as a scoring criterion for this procedure due to the difficulty with scoring it as separate, but complementary, to rush hour service.

The metric used to compare airports will be the headways at the designated times [x = minutes of headway].

4.2 Market Factors

These criteria have an indirect impact on the transit system's effectiveness. They indicate airports that have a healthy proportion of travelers willing to take transit, including the proportion that actually do, which in turn benefit the system by providing a steady stream of users. Cities that score points in this category should be aware of their passenger characteristics and, if their mode share is low, should make necessary upgrades that, in turn, persuade more users to take transit.

4.2.1 Quantity of Low-cost Carriers

Low-cost carriers are defined as the set of newer airlines that focus more on the "no-frills" leisure market and generally do not provide business or first class [(7)]. Ticket prices are also generally lower for these carriers when compared to the legacy carriers. For this thesis' purposes, the following airlines will be considered low-cost carriers [(8)]:

- JetBlue
- Southwest/AirTran
- Frontier
- Allegiant
- Spirit
- Sun Country
- Vision

An airport with a higher percentage of low-cost carriers indicates more travelers who are price-sensitive and therefore more likely to use transit. These airports will receive higher scores because of the market willingness to support increased transit opportunities.

The metric used to compare airports will be the percentage of travelers using low-cost carriers, interpreted through the airport's published statistics. [x = % low-cost carrier usage].

4.2.2 Percentage of Business Travelers

Ironically, price-sensitive users are not the only ones who will drive more transit usage. Past research has shown that business travelers tend to carry less luggage and therefore are more willing to use transit due to the reduced hassle of movement within the terminal, within a transit vehicle, and/or while making transfers.

Airports with higher percentages of business travelers will receive higher scores, as this indicates a traveler population that is willing to take transit.

The metric used to compare airports will be the percentage of business travelers (where available) [x = % business traveler].

4.2.3 Mode Share

Mode share in this case represents the percentage of travelers going to the airport via rail transit. In the most basic terms, this defines how successful an airport transit connection is because it represents the percentage of people who consider the transit system and style of airport connection preferable to accessing the airport via automobile. However, this is not always the case. For instance, in some markets mode share may be high strictly because of the sheer numbers of travelers going to the airport who want to avoid congested roadways. In others, it may be low overall but still claim a high percentage of travelers originating in the CBD. Essentially, it is a very useful metric, but not the sole metric to score airports. For this thesis, the most recent mode share available will be used, sourced from either recent past synthesis reports, recent passenger surveys conducted by the airports, or personal interviews with airport planners.

The metric used to compare airports will be the percentage of airport travelers who use rail transit to get to the airport. [x = % of travelers using rail transit].

5. Airport Characteristics

Detailed characteristics of each airport's transit system involved in this study are provided below. Each airport is evaluated on Service Characteristics and Design Characteristics. Service Characteristics include factors that can be changed by the transit agency relatively easily since they control how the trains operate and serve the airport. Design Characteristics include factors that are more permanent, such as station design and network size. The specific factors examined (that are components of the eight main criteria) include: distance from central business district/downtown, passenger enplanements (passengers with that airport as their starting point, does not include connecting passengers; used as a method to judge scale of airport passenger traffic), business traveler percentage (where available), low-cost carrier percentage, rail mode share, connection type, driving time from CBD, travel time difference (transit vs. private auto), walking distance to terminal (when applicable), driving cost, transit cost, cost difference (transit vs. private auto), network length, and frequency.

This lengthy section describes in detail each airport transit system being analyzed. Readers wishing to skip ahead to the summary may go to Section 5.2.6 on page 57.

5.1 Atlanta (ATL)

Hartsfield-Jackson Atlanta International Airport is located 8 miles south of the CBD of Atlanta. Currently, 66% of travelers through ATL are business travelers [4], and 14% of flights are with a low-cost carrier [10]. In 2010, 43,130,585 passengers enplaned at ATL [9]. In 2005, the rail transit mode share was estimated at 10% [3].

5.1.1 Service

Atlanta's MARTA rapid rail system has served the airport directly since 1988, and currently runs two lines to the airport, the Red and Gold. The airport station is the terminus of both lines. Service to the airport is fairly frequent, with 15-minute headways from 6 am – 7pm on weekdays, and 20-minute headways all other times. Service runs until 1 am every day. MARTA runs 67 weekday trains and 57 weekend trains [44].

5.1.2 Physical Characteristics

MARTA's 48-mile network utilizes the highest quality of connection with ATL, with an in-terminal station. Walking distance is negligible and the baggage claim area is very nearby. ATL is unique in that AirTran/Southwest and Delta have check-in and ticketing areas in or very close to the station, saving a traveler much time over the traditional check-in counters at the airport. ATL's station is attractive because it is closer to the terminal than the on-site parking garages [44].

5.1.3 Time/Cost

Driving time to ATL from the CBD is 17 minutes, as is the transit time on MARTA. This makes taking MARTA very competitive with driving.

The driving cost is $8.88 and the transit cost is $2.50 [44], yielding a transit cost savings of $6.38.

5.2 Baltimore (BWI)

Baltimore/Washington International Thurgood Marshall Airport is 8 miles south of downtown Baltimore and 27 miles northeast of Washington, DC, and is one of three airports serving the Washington metropolitan region. Currently, 45% of travelers through BWI are business travelers (36), and 72% of flights are with a low-cost carrier (13). In 2010, 10,848,633 passengers enplaned at BWI (9). In 2010, the rail transit mode share for MARC/Amtrak was estimated at 3% (45). In 2005, the rail transit mode share for LRT was <1% (3).

5.2.1 Service

Transit connections to BWI are provided to both downtown Baltimore as well as downtown Washington, DC. Since opening an in-terminal rail station in 1997, Maryland MTA has provided light rail directly to the terminal via the Hunt Valley (Blue) line. Maryland MTA also provides MARC commuter rail service (Penn Line) to a separate off-terminal station on weekdays only. That station, opened in 1980, is also shared with frequent Amtrak train service (Northeast Regional, Acela Express, and Vermonter). Light rail service to the airport runs every 20-30 min. until 11 pm on weekdays and Saturdays and 7 pm on Sundays. There are 50 weekday trains, 40 Saturday trains, and 21 Sunday trains. MARC train service runs every 20-70 minutes, with 24-27 trains per weekday (depending on direction). There is also a once-daily train from Washington to BWI that bypasses all intermediate stops, saving the traveler much time (74). Amtrak trains run slightly more frequently, due to the three different lines providing service versus MARC's one. BWI is serviced by 28-32 Amtrak trains per day (depending on direction), 20-21 of which are the low-cost, frequent Northeast Regional trains (45).

The light rail system connects to Baltimore's Metro Subway (rapid rail) downtown, providing an additional transit service. This service has traditional subway system frequency of every 8-10 minutes during weekday peak period, 11-minute frequency on weekday evenings, and 15-minute frequency on weekends and holidays (75).

MTA's MARC train (Penn Line) covers a distance of approximately 77 miles. Because the station is off-site, use of a free shuttle bus is required, which runs every 15 minutes most of the day, except for 1 am – 5am, when it runs every 25 minutes (45).

In general, BWI is very well served by multiple transit connections, especially when the traveler is originating from Baltimore.

5.2.2 Physical Characteristics

MTA light rail is a 40-mile network, which connects with the 15.5-mile Metro Subway in downtown Baltimore (46). BWI's light rail station is located directly in the terminal and requires negligible walking. BWI's MARC/Amtrak station is located about 1 mile from the terminal, and requires usage of a free shuttle bus.

5.2.3 Time/Cost

Driving time to BWI is 19 minutes from Baltimore's CBD, and 52 minutes from Washington D.C.'s. Transit time is 29 minutes on light rail from Baltimore, 30-38 minutes on MARC from Baltimore, and 40-47 minutes on MARC from Washington. Amtrak times are comparable to MARC times, if slightly less due to fewer stops. This makes taking transit a large advantage for travelers coming from Washington (up to a 12-minute time savings), but less attractive for travelers coming from Baltimore (10-19 minutes longer on transit).

The driving cost from Baltimore is $8.88 and $29.98 from Washington. Light rail costs are $1.60, MARC from Baltimore costs $4.00, and MARC from Washington costs $6.00. Using transit from Baltimore yields of savings between $4.88 and $7.28, while Washington travelers can save $23.98 (74,75). The combined time and cost savings make transit to BWI a much more attractive option to Washington travelers than Baltimore travelers.

5.3 Washington – Reagan (DCA)

Ronald Reagan Washington National Airport is located 3 miles south of Washington, D.C.'s CBD, and is one of three airports serving the Washington metropolitan region. Currently, 52% of travelers through DCA are business travelers (37), and 2% of flights are with a low-cost carrier (15). In 2010, 8,736,804 passengers enplaned at DCA. In 2005, it was estimated to have a rail transit mode share of 13% (3).

5.3.1 Service

Washington's WMATA rapid rail system has served the airport directly since 1977, and currently runs two lines through the airport, the Blue and Yellow. Originating from Washington, both lines pass through the airport and continue on their path to

Franconia/Springfield and Huntington, respectively. Service to the airport is very frequent, with 3-7 minute headways during weekday rush period, and 10-20 minutes all other times. Service runs until 3 am on Friday and Saturday nights, and midnight all other times [78]. Due to the Blue and Yellow lines both serving the airport and entering/serving D.C. at different locations/paths, the variety of one-seat destinations within D.C. is larger than most other cities. The Blue and the Yellow Lines also connect with the other three lines downtown, allowing access to WMATA's full network.

5.3.2 Physical Characteristics

WMATA's 106-mile network connects with DCA utilizing the highest quality of connection, an in-terminal station. Walking distance is negligible and the baggage claim area is very nearby, one floor below. DCA has check-in and ticketing areas for a select few airlines including U.S. Airways at the exit of the walkway from the station/parking garage. This allows transit users to bypass the possibly longer lines upstairs in the main ticketing area. DCA's station is attractive because it is closer to the terminal than the on-site parking garages [76].

5.3.3 Time/Cost

Driving time to DCA from the CBD is 10 minutes, while the transit time on WMATA can be up to 18 minutes, depending on where in the CBD the trip is originating. This makes taking WMATA very competitive with driving, especially given Washington's notorious traffic, especially in afternoon rush hour when trying to cross the bridges into Virginia where DCA is.

The driving cost is $3.33 and the transit cost is $2.55 [76], yielding a transit savings of $0.78.

5.4 Washington – Dulles (IAD)

Washington Dulles International National Airport is located 23 miles northwest of Washington, D.C.'s CBD, and is one of three airports serving the Washington metropolitan region. Currently, 51% of travelers through IAD are business travelers [39], and 13% of flights are with a low-cost carrier [20]. In 2010, 11,276,481 passengers enplaned at IAD [9]. In 2005, it was estimated to have a rail transit mode share of less than 1% [3].

5.4.1 Service

The rail connection to IAD is indirect, as the nearest WMATA station is 14 miles away from the airport. The West Falls Church-VT/UVA station on WMATA's Orange Line provides a direct coach service operated by Washington Flyer, the dominant cab service at IAD. The Flyer bus runs every 30 minutes, takes on average 25 minutes to reach the airport, and carries a cost of $10 one-way [77]. However, the bus is able to run in dedicated airport lanes en route, bypassing the toll plazas and any other traffic heading to/from the airport. Because this bus is a direct, non-stop, airport labeled service, it is being considered as a shuttle bus service similar to other airports with off-airport rail stations, albeit with a cost and longer transit time.

Orange Line service to West Falls Church varies by time of day, with 3-7 minute headways during weekday rush period, and 10-20 minutes all other times. Service runs until 3 am on Friday and Saturday nights, and midnight all other times [78]. The Orange Line runs directly into and through downtown. Connections can be made to all other WMATA lines downtown.

5.4.2 Physical Characteristics

WMATA's Metro network is 106 miles. IAD does not yet have a direct rail station, instead utilizing a paid coach shuttle bus system. The coach is clearly labeled as the airport bus, and is accessible from a dedicated bus bay at the West Falls Church station. The bus runs in dedicated airport traffic lanes to IAD, bypassing most traffic. At Dulles, it arrives/departs curbside on the upper level of the baggage claim area, providing a very short walk from collecting bags. Signs are clearly labeled to direct arriving passengers in the baggage claim level to the bus, as well as signage explaining the service.

5.4.3 Time/Cost

Driving time to IAD from the CBD is 35 minutes under optimal conditions, which only happens at very limited times and days of the week. Transit time on WMATA/Washington Flyer Coach takes approximately 47 minutes if the rail/bus transfer time is minimal. This transit time is somewhat longer than the driving time under free-flow traffic conditions, but could possibly save some time if traffic on I-66 is heavy. Planning an optimal schedule is important if the user wants to minimize wait time at West Falls Church for the twice-hourly bus.

The driving cost is $25.53 and the transit cost is $13.90, yielding a savings of $11.60 to take transit. This premium can be well worth it though when the traveler wants to use IAD during afternoon rush hour. It should also be noted that if the traveler wishes to arrive and depart IAD using the Washington Flyer service, a round-trip ticket could be purchased for $18, which saves $1 off the cost each way [77].

5.5 Chicago – Midway (MDW)

Chicago Midway International Airport is located 8.5 miles southwest of Chicago's CBD, and is one of two airports serving the Chicago metropolitan region. Currently, 37% of travelers through MDW are business travelers [4], and 95% of flights are with a low-cost carrier [23]. In 2010, 8,518,957 passengers enplaned at MDW [9]. In 2004, it was estimated to have a rail transit mode share of 6% [3].

5.5.1 Service

Chicago's CTA rapid rail system has served the airport directly since 1993. CTA's orange line runs from Chicago's Loop directly to the airport. Service operates all day, every day except for between 1 am and 4 am, and after 11 pm on Sundays until 4 am Monday. During the morning and evening peak rush hours, service runs every 6 to 10 minutes, and every 10-15 minutes off-peak. In the Loop downtown, connections can be made to any other CTA train, providing easy access to CTA's full network [56].

5.5.2 Physical Characteristics

CTA's rail network is 224 miles. MDW has a CTA station directly at the airport, although a parking garage stands in between the station and the terminal. A 1500 ft. walk is required through the garage, though the walkway is clearly marked [56].

5.5.3 Time/Cost

Driving time to MDW from the CBD is 19 minutes, while the transit time on CTA can be 20-25 minutes, depending on where in the Loop the trip is originating. An additional 5 minutes should be added as well to account for the walk from the station to the terminal. This makes taking CTA very competitive with driving, for travelers originating at/headed to the Loop, especially in the afternoon rush hour when traffic on the connecting freeways can be heavy [56].

The driving cost is $9.44 and the transit cost is $2.25 [56], yielding a savings of $7.19.

5.6 Chicago – O'Hare (ORD)

Chicago O'Hare International Airport is located 15.5 miles northwest of Chicago's CBD, and is one of two airports serving the Chicago metropolitan region. Currently, 50% of travelers through ORD are business travelers [4], and 2% of flights are with a low-cost carrier [27]. In 2010, 32,171,831 passengers enplaned at ORD [9]. In 2004, it was estimated to have a rail transit mode share of 5% [3].

5.6.1 Service

Chicago's CTA rapid rail system has served the airport directly since 1984. CTA's blue line runs from Chicago's Loop directly to the airport terminal, and connects with the intra-airport rail service to connect all terminals. Service operates all day, every day. During the morning and evening peak rush hours, service runs every 2 to 7 minutes, and every 10-15 minutes off-peak. In the Loop downtown, connections can be made to any other CTA train, providing easy access to CTA's full network [56].

Additionally, Chicago's METRA commuter rail service has an airport station located off-site that is served by 11 weekday-only North Central Service trains in each direction. This provides a suitable alternative for travelers coming from the northwestern suburbs as far north as Antioch, IL (some 45 miles away). It also provides an alternative to get to ORD from downtown if the CTA blue line has a service interruption. There is also a once-daily train from downtown to O'Hare that bypasses all intermediate stops, saving the traveler much time [79].

5.6.2 Physical Characteristics

CTA's train network is 224 miles, while the connecting METRA station provides access to the 55.7-mile North Central Service. ORD has a CTA station directly at the airport terminal in an underground station, allowing for direct access to Terminal 2, and an easy connection to Terminals 1, 3, and 5 via free people mover [56].

ORD's METRA station is located off-site. This station requires a connection with a free shuttle bus and people mover to get to the main airport terminals. The shuttle bus takes travelers at the O'Hare Transfer METRA station to a remote parking lot, where travelers must then transfer to O'Hare's own free people mover transit system, which will bring the traveler to the terminal of choice (79).

5.6.3 Time/Cost

Driving time to ORD from the CBD is 23 minutes, while the transit time is 44 minutes on CTA and 43 minutes when using Metra + connections. There is one METRA train in the afternoon that skips all intermediate stops between O'Hare Transfer station and Union Station, taking only 22 minutes before connections (79). Regardless, driving time is still much less, with a savings of up to 21 minutes. This gain may be less though during afternoon rush hour on I-90, as traffic congestion will slow the trip down.

The driving cost is $17.21 and the transit cost is $2.25 for CTA (56) and $4.75 (79) for METRA, yielding a savings of $12.96 on METRA and $14.96 on CTA. This is a fairly large savings for using transit.

5.7 Cleveland (CLE)

Cleveland Hopkins International Airport is located 10 miles southwest of Cleveland's CBD. Currently, 50% of travelers through CLE are business travelers (47), and 11% of flights are with a low-cost carrier (14). In 2010, 4,591,097 passengers enplaned at CLE (9). In 2000, it was estimated to have a rail transit mode share of 5% (3).

5.7.1 Service

Cleveland's RTA rapid rail system has served the airport directly since 1968. It is worth noting that CLE holds the distinction of being the first international airport in North America to have rapid transit service. RTA's red line runs from Cleveland's Tower City station downtown directly to the airport terminal. Service operates all day, every day. During the majority of the day, service runs every 15 minutes. On weekends, this headway increases to 20 minutes. Service operates from 4 am until 1 am everyday. 80 trains run in each direction on weekdays. Downtown, connections can be made to RTA's blue and green light rail service, providing further access to western suburbs and the waterfront (80,81).

5.7.2 Physical Characteristics

In total, the airport connects to 37 miles of track (red, green, and blue lines). CLE has an RTA rapid rail station directly at the airport terminal in an underground station, allowing for direct access to all terminals. Baggage claim is very close to the station (80).

5.7.3 Time/Cost

Driving time to CLE from the CBD is 20 minutes, while the transit time is 30 minutes. Congestion on the roadway may increase driving time to be more in line with transit time.

The driving cost is $11.10 and the transit cost is $2.25 (81), yielding a savings of $8.85.

5.8 Minneapolis (MSP)

Minneapolis-St. Paul International Airport is located 7 miles southeast of Minneapolis's CBD. Currently, 32% of travelers through MSP are business travelers [43], and 11% of flights are with a low-cost carrier [25]. In 2010, 15,512,487 passengers enplaned at MSP [9]. It was recently estimated to have a rail transit mode share of less than 5% [3].

5.8.1 Service

Minneapolis' Hiawatha light rail system has served the airport directly since 2004. Service operates from 5 am until 1 am every day, every 7-10 minutes during rush hour, and 10-15 minutes all other times of the day. 110 trains a day run in each direction between downtown and the Mall of America. The line also acts as a free rail shuttle service between the 2 MSP terminals, with service 24 hours a day, 7 days a week [57].

5.8.2 Physical Characteristics

The Hiawatha line runs for 12.3 miles from its southern terminus of the Mall of America, through 2 separate airport stations (separate stations for the Humphrey and Lindbergh terminal), and through downtown, terminating at Target Field. At the Humphrey station, which is the smaller of the two, the station is above ground, and the terminal can be reached after a 1200 ft. walk through the parking garage. At the larger Lindbergh terminal, the station is underground in the middle of the U-shaped terminal. The terminals can be reached on foot, but there is also a people mover system running through the terminals and to baggage claim and ticketing, making it easier for passengers with a large amount of luggage to get to check-in when departing the airport and after picking it up when arriving [57].

5.8.3 Time/Cost

Driving time to MSP from the CBD is 21 minutes, as is the transit time on the Hiawatha line [57], making transit very competitive with driving, especially considering congestion on the freeways may increase driving time.

The driving cost is $7.77 and the transit cost is $2.25 [57] at rush hour, yielding a savings of $5.52.

5.9 Philadelphia (PHL)

Philadelphia International Airport is located 7 miles southeast of Center City Philadelphia. Currently, 13% of flights are with a low-cost carrier [29]. In 2010, 14,951,254 passengers enplaned at PHL [9]. It was recently estimated to have a rail transit mode share of 3% [3].

5.9.1 Service

Philadelphia's SEPTA regional rail system has served the airport directly since 1985. The Airport line (formerly called R1) runs from 5 am until midnight everyday, with service every 30 minutes from Center City's three downtown stations as well as north to Temple University station. The trip from the airport to downtown is approximately 30 minutes and everyday, 39 trains run in each direction to and from the airport. Between 30th St. Station and Market East Station, a traveler can seamlessly transfer to all other Regional Rail Lines in the Greater Philadelphia region with access to over 150 stations. Also, a connection can be made downtown to SEPTA's two rapid rail lines (Broad Street Subway & Market-Frankford Line) [82].

5.9.2 Physical Characteristics

SEPTA's regional rail system spreads over 100 miles, while also connecting with the rapid rail lines downtown that extend a combined 25 miles from the CBD. PHL's Regional Rail Airport station is unique in that despite being a heavy rail system, it has 4 separate stations directly outside the various terminals of PHL (82). The stations are very close to the terminals and baggage claim areas, and are claimed to have among the shortest walks from baggage claim to train in the world (3).

5.9.3 Time/Cost

Driving time to PHL from the CBD is 14 minutes, while taking the train can take between 25 and 30 minutes (82), depending on which downtown station is utilized. Under free flowing traffic conditions, this makes driving more attractive, but during busy rush hour times, the train can be competitive.

The driving cost is $7.77 and the transit cost is $6.25 (82) yielding a transit savings of $1.52.

5.10 Portland (PDX)

Portland International Airport is located 6 miles northeast of downtown Portland. Currently, 36% of travelers through PDX are business travelers (4), and 26% of flights are with a low-cost carrier (28). In 2010, 6,582,227 passengers enplaned at PDX (9). In 2005, it was estimated to have a rail transit mode share of 6% (3).

5.10.1 Service

Portland's MAX light rail service has operated the red line to the PDX airport station since 2001. The red line runs directly into Portland Center City. Trains run between 4:45 am and midnight 7 days a week. During the majority of the day on weekdays, trains run approximately every 15 minutes, with frequency decreasing to every 30 minutes in the early morning and late night. These frequencies change to 17/35 and 18/35 on Saturdays and Sundays, respectively. On weekdays, 69 trains serve the airport in each direction [(60)].

5.10.2 Physical Characteristics

The MAX network has 52.4 miles of track. PDX's MAX light rail line station is directly in the terminal, very near baggage claim and check-in areas. The station serves as the terminus of the red line leading directly into Center City Portland without transfers [(60)].

5.10.3 Time/Cost

Driving time from Portland to PDX is approximately 21 minutes under ideal traffic conditions, while the MAX to PDX takes 38 minutes [(60)], 17 minutes longer than driving. Driving cost is $6.66 while the MAX costs $2.40 [(60)], yielding a savings of $4.26.

5.11 San Francisco (SFO)

San Francisco International Airport is located 12 miles south of downtown San Francisco. It is one of three airports serving the San Francisco Bay Area. Currently, 41% of travelers through SFO are business travelers [(4)], and 10% of flights are with a low-cost carrier (31). In 2010, 19,359,003 passengers enplaned at SFO (9). In 2006, it was estimated to have a rail transit mode share of 9% (69).

5.11.1 Service

Bay Area Rapid Transit (BART) has served SFO directly since 2003. SFO is served by BART's Pittsburg/Bay Point line, which runs through downtown SF and out to the East and North Bay. Trains run between 5:30 am and 1:30 am on weekdays, 7:30 am and 1:30 am on Saturdays, and 9 am to 1:30 am on Sundays. On weekdays, trains run every 15 minutes all day until 8:45 pm at which they revert to a 20-minute headway until closing. On weekends, trains always run every 20 minutes until closing. 76 trains serve SFO in each direction on weekdays (83).

Additionally, travelers wishing to access destinations further south on the Peninsula or South Bay can take BART one station in the opposite direction of downtown to the Millbrae station. There, they can transfer to Caltrain commuter rail service, which runs hourly at most times of the day (86).

5.11.2 Physical Characteristics

The BART system covers 104 miles of track, while the Caltrain connection provides another 77.4-mile connection. SFO's BART station is located directly in the international terminal of SFO, and provides direct access to travelers using that terminal. If travelers wish to use one of the domestic terminals, they are required to transfer to a free people mover. Baggage claim is either located in the international or domestic terminal, so bringing baggage on the people mover may be necessary (83,86).

5.11.3 Time/Cost

Driving time to SFO from downtown San Francisco is 18 minutes under optimal conditions, compared to BART, which takes 32 minutes [83], a 14-minute difference. Driving cost to SFO is $13.32 whereas BART cost is $8.10 [83]. The higher than average transit cost traces back to the decision by BART to impose a $4 surcharge onto all trips starting or ending at the airport. Nevertheless, using BART yields a cost savings of $5.22.

5.12 Oakland (OAK)

Oakland International Airport is located 7 miles southeast of downtown Oakland. It is one of three airports serving the San Francisco Bay Area. Currently, 50% of travelers through OAK are business travelers [4], and 73% of flights are with a low-cost carrier [26]. In 2010, 4,673,417 passengers enplaned at OAK [9]. In 2006, it was estimated to have a rail transit mode share of 14% [69].

5.12.1 Service

Bay Area Rapid Transit (BART) serves OAK via the Coliseum/Oakland Airport station, which has been in service since 1972 and is a stop on three different BART lines, marked Blue, Orange, and Green on maps. Travelers are required to transfer to an airport-branded shuttle bus called AirBART to take them the final 3 miles to the airport. This shuttle bus runs every 10 minutes, 5 am to midnight Mon-Sat and 8am to midnight Sunday [59].

With three BART lines serving OAK, service is very frequent on weekdays; trains arrive every 6-9 minutes destined for San Francisco and points beyond, and every 15 minutes serving downtown Oakland and points beyond. Trains also continue south towards Fremont and southeast towards Castro Valley, Dublin, and Livermore at the same frequencies. On weekends, these headways slightly widen with SF-bound trains every 9 minutes and downtown Oakland-bound trains every 20 minutes (59).

Additionally, travelers from points south down to San Jose as well as destinations further northwest out to Sacramento can get to OAK on transit via the Capitol Corridor Amtrak service. Trains run 7 times a day in each direction and stop at the same complex at which the BART station is located (84). Travelers would still be required to transfer to the AirBART bus to complete the journey.

5.12.2 Physical Characteristics

Once in the BART network, travelers have access to 104 miles of track spreading to the East Bay, North Bay, San Francisco, and Peninsula. The stop for AirBART is located directly outside the main terminal and baggage claim area, and is well signed. Once at OAK, only 200 feet separate the bus station from the main terminal.

5.12.3 Time/Cost

Driving time to OAK is 20 minutes from downtown Oakland. The trip on BART + AirBART takes 30 minutes (59).

The driving cost to OAK is $7.78 from downtown Oakland. The AirBART shuttle bus costs $3 one-way, and is taken into consideration for the total transit cost. Adding the shuttle bus cost to the BART fares results in total costs of $4.75 from Oakland, yielding a transit savings of $3.03 [59].

Travelers using the Amtrak service also have to pay the $3 for the AirBART shuttle, but Amtrak costs are not considered due to the variability in origins/destinations.

5.13 San Jose (SJC)

Norman Y. Mineta Memorial San Jose International Airport is located 3.5 miles northwest of downtown San Jose. It is one of three airports serving the San Francisco Bay Area. Currently, 48% of travelers through SJC are business travelers [4], and 43% of flights are with a low-cost carrier [32]. In 2010, 4,056,167 passengers enplaned at SJC [9]. Mode share data has not been acquired for this airport, but is most likely 1% or less due to its transit system similarities with other airports of published mode share of 1%.

5.13.1 Service

Santa Clara Valley Transportation Authority (VTA) serves SJC via the Metro/Airport VTA light rail station. The main 2 light rail lines both stop at this station, providing direct access to all but two of the system's 62 stations. Trains serve the Metro/Airport station from 5 am until 1 am and run every 7 minutes between downtown San Jose and SJC [85].

At this station, travelers can either walk the mile to the main terminals or take a free VTA Airport Flyer shuttle bus. This shuttle bus operates from 5:30 am to 11:30 pm on every day, with service every 15 minutes on weekdays and 30 minutes on weekends [70].

Additionally, travelers can access SJC using the Santa Clara Caltrain commuter rail station, located on the opposite side of the airport as the VTA station. Trains serve this station approximately every hour, and can reach destinations further north up the peninsula. The same shuttle bus that serves the VTA station also serves the Caltrain station.

5.13.2 Physical Characteristics

VTA light rail's network provides 42.2 track miles, while the Caltrain network is 77.4 miles. Both the Caltrain and the VTA light rail station are located off-site of the airport, and require a free shuttle bus connection. The shuttle bus has 2 stops directly at the airport, in front of Terminal A and Terminal B. The VTA station is marketed clearly as an airport station while the Caltrain station is not [70].

5.13.3 Time/Cost

Driving time to downtown San Jose is 9 minutes, while taking VTA is 22 minutes [85]. This extra time can be attributed to the required shuttle bus transfer.

Driving cost is $3.89 while the transit cost is $2.00 [85], a savings of $1.89.

5.14 St. Louis (STL)

Lambert-St. Louis International Airport is located 12 miles northwest of downtown St. Louis. Currently, 45% of flights are with a low-cost carrier [(34)]. In 2010, 6,044,760 passengers enplaned at STL [(9)]. In 2000, the transit mode share was estimated to be 3% [(3)].

5.14.1 Service

STL is served directly by MetroLink light rail (red line), with two stations located at its two separate terminals. The two airport stations serve as the western terminus of the red line. Service runs 4:30 am - 12:30 am on weekdays, and 5:30 am - 12:30 am on weekends. 78 trains in each direction serve STL on weekdays, with headways ranging from 12-20 minutes. On weekends, 60 trains in each direction serve STL, with 20-minute headways [(72)].

5.14.2 Physical Characteristics

MetroLink's network is 46 miles. Both of STL's MetroLink stations are directly at the terminal, however Terminal 2's station requires travelers to walk approximately 250 feet through a parking garage before accessing the terminal. Terminal 1's station is directly in the terminal [(72)].

5.14.3 Time/Cost

Driving time from downtown St. Louis to STL is 21 minutes, while transit time is 30 minutes [(72)].

Driving cost is $13.32, while transit cost is $2.25 [72], a savings of $11.07.

5.15 Seattle (SEA)

Seattle-Tacoma International Airport is located 11 miles south of downtown Seattle. Currently, 54% of travelers through SEA are business travelers [4], and 10% of flights are with a low-cost carrier [66]. In 2010, 15,406,243 passengers enplaned at SEA [9]. It was recently estimated to have a rail transit mode share of 5% [87].

5.15.1 Service

SEA has been served directly by Sound Transit's Link light rail since 2009. Service runs 5:00 am - 1 am on weekdays and Saturdays, and 6 am - 12:00 am on Sundays. On weekdays, trains run to SEA every 15 minutes from 5 am – 6 am, every 7.5 minutes 6 am – 8:30 am, every 10 minutes 8:30 am – 3 pm, every 7.5 minutes 3 pm – 6:30 pm, every 10 minutes 6:30 pm – 10 pm, and every 15 minutes 10 pm – close. On Saturdays and Sundays, service runs every 10 minutes all day except for early morning and late night, when it runs every 15 minutes [65].

5.15.2 Physical Characteristics

The SeaTac/Airport Station is located near the airport terminal, at the southern terminus of the 17.3-mile Link light rail system. A 700 foot walk is required from the station over a pedestrian bridge and through a parking garage [65].

5.15.3 Time/Cost

Driving time from downtown Seattle to SEA is 20 minutes, while transit time is 37 minutes [65].

Driving cost is $12.21, while transit cost is $2.75 (65), a savings of $9.46.

5.16 Newark (EWR)

Newark Liberty International Airport is located 11 miles southwest of midtown Manhattan. It is one of 3 airports serving the NYC metropolitan area, 2 of which are directly accessible by rail transit. Currently, 38% of travelers through EWR are business travelers (38), and 3% of flights are with a low-cost carrier (52). In 2010, 16,571,754 passengers enplaned at EWR (9), while in the same year, the rail transit mode share was 6% (52).

5.16.1 Service

New Jersey Transit (NJT) as well as Amtrak trains have served EWR since 2001 via the Newark Liberty International Airport train station located off-site. A paid people mover is required to connect travelers arriving at the train station with the main terminals. This train runs 24/7; every 3 minutes between 5 am and midnight and every 10 minutes between 12:01 am - 5 am. NJT trains to Manhattan as well as destinations further south in New Jersey frequently stop at the station, with various trains arriving every 3-30 minutes between 5 am and 2 am (88).

Amtrak trains stop on the same platform as NJT and run parallel service, albeit with less frequent headways of about 1 hr.

5.16.2 Physical Characteristics

From the Newark airport train station, a traveler can access most stations on NJT's 163-mile network. The Newark train station is located off-site from the main terminals and requires a connection with Newark AirTrain, a paid people mover train. There are three separate stations for each terminal at EWR, as well as 4 other stations for parking garages nearby. The western terminus of AirTrain connects with the main train station via an elevated walkway over the tracks [51].

5.16.3 Time/Cost

Driving time from midtown Manhattan to EWR is 30 minutes, while transit time is 24 minutes [88], a savings of 6 minutes.

Driving cost is $12.21. Transit cost combines the $12.50 NJT ticket from New York Penn Station with the $5.50 Newark AirTrain charge for a total of $18 [51,88]. This is a premium of $5.79, but the time saving may be worth it given a high chance of severe traffic congestion entering/leaving Manhattan.

5.17 New York – JFK (JFK)

John F. Kennedy International Airport is located 13 miles southeast of midtown and downtown Manhattan. It is one of 3 airports serving the NYC metropolitan area, 2 of which are directly accessible by rail transit. Currently, 37% of travelers through JFK are business travelers [40], and 50% of flights are with a low-cost carrier [21,52]. In 2010, 22,934,047 passengers enplaned at JFK [9], while in the same year, the rail transit mode share was 11% [52].

5.17.1 Service

Since 2003, JFK is served by rail transit via the JFK AirTrain. This is a paid people mover the connects travelers with the A subway line at one end (Howard Beach station), and the E, J, and Z lines of the subway as well as the Long Island Railroad (LIRR) at the other end (Sutphin/Jamaica station). The AirTrain runs 24/7 every few minutes, ensuring the passenger is never waiting long. The A subway at Howard Beach arrives every 5-10 minutes during rush hour and every 15-20 minutes all other times. At Jamaica, the LIRR trains arrive very frequently, especially during rush when trains can arrive every 3 minutes. The E/J/Z subway lines stop at Sutphin every 5-10 minutes during rush hour and every 8-12 minutes all other times [(53)].

5.17.2 Physical Characteristics

At both subway stations, a traveler connecting to the subway has access to 209 track miles to take them to their final destination. Taking the AirTrain to the LIRR station allows a traveler full access to LIRR's 594 track miles [(54)]. The JFK AirTrain runs 2 different lines that connect to regional transit, both of which congregate directly at the 8 terminals. Because of JFK's satellite terminal design, each terminal requires its own station, with only terminals 2 & 3 and 5 & 6 sharing a station. All AirTrains serve each terminal station, and then either depart JFK to the west en route to Howard Beach station (A subway), or to the north en route to the Jamaica station (LIRR)/Sutphin Blvd. station (E/J/Z subway). The Sutphin Blvd. subway station and Jamaica LIRR station are adjacent to each other. All connections with AirTrain are direct and require little walking to transfer between modes [(53)].

5.17.3 Time/Cost

Driving time from both midtown and downtown Manhattan to JFK is 32 minutes under ideal conditions, which as many NYC drivers know, can be impossible to attain.

Transit time from Manhattan to JFK varies greatly based on which mode is chosen. Regardless of initial rail choice, once at either AirTrain station, the travel time will be 10 minutes to JFK. The shortest trip from midtown Manhattan is via LIRR, which arrives at Jamaica station 25 minutes after departing Penn Station. Taking the E subway from midtown Manhattan to the Sutphin Blvd. station takes 50 minutes due to the higher frequency of stops. Even longer, taking the A subway from downtown Manhattan will get to Howard Beach station in 55 minutes. The J and Z subway lines at Sutphin Blvd. have comparable times to the A and E trains (53). To summarize the rail options:

1. LIRR from Penn Station to Jamaica, AirTrain from Jamaica to JFK = 35 min.
2. E/J/Z subway from midtown Manhattan to Sutphin Blvd, AirTrain from Jamaica to JFK = 60 min.
3. A subway from downtown Manhattan to Howard Beach, AirTrain from Howard Beach to JFK = 65 min.

Despite the longest travel time, the connection at Howard Beach station receives the most ridership (3). Under ideal driving and traffic conditions, transit takes a good deal longer to reach JFK, but congestion along the major roadways out of Manhattan and to JFK are notoriously congested many times of the day. This traffic has been known to cause driving time to double or even sometimes triple, giving transit an attractive benefit of reliable travel time.

The driving cost from Manhattan to JFK is $14.43, not including tolls that may be incurred from expressways, bridges, and tunnels. The cost to use the JFK AirTrain is a flat rate of $5, regardless of which rail connection station is used. In addition to the AirTrain price, using LIRR will cost $8 at rush hour, while using the subway will cost a flat rate of $2.25 [(53)]. Both methods still yield a savings over driving of $1.43 - $7.18.

5.18 Boston (BOS)

General Edward Lawrence Logan International Airport is 2 miles west of downtown Boston. Currently, 33% of travelers through BOS are business travelers [(35)], and 25% of flights are with a low-cost carrier [(11)]. In 2010, 13,561,814 passengers enplaned at BOS [(9)]. In 2005, the rail transit mode share was 6% [(3)].

5.18.1 Service

BOS has had a rail connection since 1952 when the Massachusetts Bay Transportation Authority (MBTA) opened the Airport station on the Blue line of the “T”. In 2004, a new station was opened that was 500 feet to the east of the old station, but still connecting the Blue line to downtown Boston. Once at the station, travelers need to transfer to a free shuttle bus to take them to the terminal of their choice. The Blue line operates between 5:30 am and 1 am on weekdays, when trains stop at the Airport station every 5 minutes during rush hour, and every 9-12 minutes other times. On weekends, the Blue line operates from 6 am – midnight and stops at the Airport station every 14 or 16 min. (Saturday or Sunday, respectively) [89].

A new alternative that is not a necessarily a rail connection, but connects to rail regardless, is the Silver Line BRT service that has been in use at BOS since 2004, around the same time as the new T station opened. The Silver line is a Bus Rapid Transit system, and connects the terminals directly at BOS with Boston South Station, a major transit hub in Boston that connects the T Red line and the MBTA commuter lines out to the suburbs. Since opening, the Silver Line has slowly eroded away the ridership of travelers utilizing the Blue line + shuttle bus connection [3,89].

5.18.2 Physical Characteristics

Connecting to the MBTA system opens up travelers to the 128-mile "T" network. The Blue line connection is accessed at an off-site rapid rail station, requiring travelers to exit the station and wait for a shuttle bus on the curb. This shuttle bus will then connect them with the main terminals [89].

The Silver line connection connects travelers arriving at Boston South Station via the Red Line or MBTA commuter rail directly to the terminals at BOS via dedicated bus lanes. At South Station, travelers descend to the bus tunnels underneath the station and board the Silver Line marked as running to the airport [89].

5.18.3 Time/Cost

Driving time from downtown Boston to BOS is 15 minutes. Utilizing the Blue line + shuttle bus connection, travel time is 14 minutes, while utilizing the Silver line connection is 15 minutes [89].

Driving cost to BOS is $2.22, while transit cost is $2.00 [89], a savings of $0.22.

5.19 Dallas – Fort Worth (DFW)

Dallas – Fort Worth Airport is 16 miles northwest of downtown Dallas. Currently, 57% of travelers through DFW are business travelers [4], and 2% of flights are with a low-cost carrier [17]. In 2010, 27,100,656 passengers enplaned at DFW [9]. It was recently estimated to have a rail transit mode share of <1% [90].

5.19.1 Service

DFW has been served by Trinity Railway Express (TRE) commuter rail since 2000 at the CentrePort/DFW station. Service operates 5:30 am – 11:30 pm, Monday-Saturday, with 24 trains per day in each direction on weekdays and 10 on Saturday. Once at the station, travelers are required to take a shuttle bus that will bring them to the DFW remote lot. Once there, travelers then have to take another shuttle bus taking them to their desired terminal. Separate buses go to separate terminals, so it is important that the traveler board the correct bus at this point. Both of these buses run approximately every 15 minutes [49].

5.19.2 Physical Characteristics

The CentrePort/DFW station is approximately halfway on the 34-mile TRE line between Dallas and Fort Worth. The TRE commuter rail station is a standard commuter rail station, with buses picking up passengers very near the platform. Once at the remote lot, travelers transfer to a second shuttle bus at the same place. These shuttle buses bring travelers directly to their respective terminals on the same departure level as travelers arriving at the airport by car [(49)].

5.19.3 Time/Cost

Driving time to DFW from Dallas is 23 minutes while transit time is 47 minutes [(49)], assuming all connections are made with minimal waiting time. If a shuttle bus is missed, travel time can be increased by as much as 30 minutes (15 minutes waiting time for each bus).

Driving cost to DFW is $17.76 while the transit cost is $3.50 [(49)], a savings of $14.26.

5.20 Fort Lauderdale (FLL)

Fort Lauderdale-Hollywood International Airport is located 20 miles north of downtown Miami, and is often used by travelers destined for the Miami area as an alternative to MIA due to its larger percentage of low-cost carriers. Currently, 23% of travelers through FLL are business travelers [(4)], and 53% of flights are with a low-cost carrier (compared to MIA's 0.3% low-cost carriers) [(19)]. In 2010, 10,829,810 passengers enplaned at FLL [(9)]. Mode share data has not been acquired for this airport, but is most likely 1% or less due to its transit system similarities with other airports of published mode share of 1%.

5.20.1 Service

FLL has been served by South Florida Regional Transportation Authority's (RTA) Tri-Rail commuter service since 2000. FLL has a designated station at Fort Lauderdale/Hollywood International Airport Station. On weekdays, trains run between 5 am and 10 pm, with 25 trains in each direction. On weekends, trains run between 6:30 am and 9 pm, with 8 trains in each direction [91,92].

To get to the Tri-Rail station from downtown Miami, travelers are required to board the Miami Metro system and take it to the Tri-Rail Transfer metro station. Here, they can board the Tri-Rail train to the FLL airport station.

Once travelers arrive at the station, they are required to transfer to a free shuttle bus to take them to the main terminals. These shuttle buses run approximately every 10-20 minutes [91,92].

5.20.2 Physical Characteristics

FLL passengers are given access to the 71-mile Tri-rail network. At FLL, the Tri-Rail shuttle bus has 3 stops at the various terminals. The stops are on the lower baggage claim level of each terminal, making it easy for arriving passengers to board the shuttle bus. At the Tri-Rail station, shuttle riders are dropped off adjacent to the platform. After riding Tri-Rail and alighting at the MetroRail Transfer station, they take an escalator up to the Metro platform, where they transfer to the 25-mile Miami Metro, taking them into downtown [91,92,93].

5.20.3 Time/Cost

Driving time to FLL from downtown Miami is 35 minutes, while transit time is 66 minutes, assuming perfect connections at both mode shifts (Tri-Rail/Metro, Tri-Rail/shuttle). One or more missed connections can add up to an hour of travel time depending on day and time [(91,93)].

Driving cost to FLL from downtown Miami is $22.20, while transit cost for the combined usage of Tri-Rail and Metro is $5.75 ($2.00 Metro, $3.75 Tri-Rail) [(91,93)], a savings of $16.45.

5.21 Los Angeles (LAX)

Los Angeles International Airport is located 11 miles southeast of downtown Los Angeles. Currently, 33% of travelers through LAX are business travelers [(41)], and 16% of flights are with a low-cost carrier [(22)]. In 2010, 28,857,755 passengers enplaned at LAX [(9)]. In 2006, it had a rail transit mode share of 1% [(55)].

5.21.1 Service

LAX has been served by Los Angeles Metro's Green line since 1995 via the Aviation/LAX station (formerly Aviation/I-105). Travelers destined for LAX from downtown Los Angeles must first board the Blue line headed south, transfer at the Imperial/Wilmington station, transfer to the Green line headed west, then alight at the Aviation station. Here, they must then board a free shuttle bus that brings them to the terminals. Both the Green and the Blue Line operate from 5 am – 1 am everyday, with weekday service every 5-6 minutes during rush and up to 12 minutes all other times. Weekend service is provided every 11-15 minutes [94,95].

5.21.2 Physical Characteristics

A traveler using the LA Metro system has access to 79 miles of track. The Blue line starts off in downtown L.A. as a subway and rises up to ground level where it stays for the remainder of the journey. At Imperial/Washington station, travelers exit the train and go up one level to the Green line, which runs perpendicular to the Blue line. Then, at Aviation/LAX station, the traveler alights and returns to street level to a bus bay where a shuttle is boarding, bringing the traveler direct to the terminal of choice [94,95].

5.21.3 Time/Cost

Driving time to LAX from downtown Los Angeles is 22 minutes under ideal conditions, which can be hard to attain on Los Angeles' congested roadways. Transit time is 51 minutes [95], assuming optimal transfers with minimal waiting time. Missing a transfer can add up to 30 minutes to the trip.

Driving cost to LAX from downtown Los Angeles is $12.21, compared to a one-way transit cost of $1.50 [95], a savings of $10.71.

5.22 Burbank (BUR)

Bob Hope Airport is located 11.5 miles northwest of downtown Los Angeles, and is often used by travelers destined for the Los Angeles area as an alternative to LAX due to its larger percentage of low-cost carriers. Currently, 68% of flights are with a low-cost carrier [12]. In 2010, 2,239,804 passengers enplaned at BUR [9]. It was recently estimated to have a transit mode share of <1% [96].

5.22.1 Service

BUR has been served by Amtrak and Metrolink commuter rail since 1992, at the Bob Hope Airport rail station. Combined, they provide fast, reliable service directly to downtown Los Angeles' Union Station. In the direction of LA, there are a total of 20 trips (Metrolink + Amtrak) each weekday between 6 am and 9 pm, and 5 (only Amtrak) on weekends between 9 am and 9 pm. In the direction of BUR, there are a total of 19 trips (Metrolink + Amtrak) each weekday between 7 am and 7 pm, and 5 (only Amtrak) on weekends between 7:30 am and 7 pm [97].

5.22.2 Physical Characteristics

BUR's train station is located outside the terminal, across W. Empire Ave. After alighting from the train, a traveler must exit the station, cross the street, and walk 1400 feet to the terminal entrance. If needed, a shuttle bus is also provided but depending on the wait, may take longer than walking. While on Metrolink, a passenger can travel to anywhere else in the 71-mile Metrolink network, provided they transfer at Union Station downtown [98].

5.22.3 Time/Cost

Driving time to BUR from downtown LA is 23 minutes under optimal traffic conditions. Transit time is between 21 and 33 minutes, depending on the type of train caught (there are some express trains that bypass all stops en route to BUR) [97]. Unlike LAX, these are very competitive travel times.

Driving cost to BUR from downtown LA is $12.77. Transit cost is either $6 for Metrolink or $8 for Amtrak [97], yielding a cost savings of either $4.77 or $6.77, respectively.

5.23 Phoenix (PHX)

Phoenix Sky Harbor International Airport is located 4.5 miles southeast of downtown Phoenix. Currently, 36% of travelers through PHX are business travelers [4], and 33% of flights are with a low-cost carrier [30]. In 2010, 18,907,171 passengers enplaned at PHX [9]. It was recently estimated to have a transit mode share of <1% [99].

5.23.1 Service

PHX has been served by Valley Metro's METRO light rail service since 2008. The 44th and Washington METRO station is the nearest one to the airport, and requires transferring to a shuttle bus. METRO trains serve the 44th and Washington station on weekdays between 4:40 am and 11 pm Sunday-Thursday, 4:40 am to 2:00 am Friday, and 5:00 am to 2:00 Saturday. Trains arrive every 12-20 minutes depending on day and time, with the shorter headways appearing during the weekday rush periods [61].

5.23.2 Physical Characteristics

The 44th and Washington METRO station is on the northeast corner of the airport grounds, and connects with the entire 20-mile METRO network. Upon exiting the train, travelers will find themselves in a bus bay with several different shuttle buses. There are

3 different shuttle buses, one to Terminal 2, one to Terminal 3, and one to Terminal 4 (there is no Terminal 1). These buses drop passengers off directly at the entrance to the terminal [61,63].

5.23.3 Time/Cost

Driving time to PHX from downtown Phoenix is 16 minutes, while transit time is 22 (METRO + shuttle bus) [63].

Driving cost to PHX from downtown Phoenix is $5.00, while transit cost is $1.75 [63], yielding a savings of $3.25.

5.24 Providence (PVD)

T.F. Green Airport is located 7 miles south of downtown Providence. Currently, 51% of flights are with a low-cost carrier [68]. In 2010, 1,951,566 passengers enplaned at PVD [9]. Mode share data has not been acquired for this airport, but is most likely 1% or less due to its transit system similarities with other airports of published mode share of 1%.

5.24.1 Service

PVD has been served by Massachusetts Bay Transportation Authority (MBTA) commuter rail since 2010, with a service expansion in 2011. 10 trains in each direction run between downtown Providence and PVD between 4:50 am and 9:40 pm every weekday. Service does not run on weekends [100].

5.24.2 Physical Characteristics

The 51.2-mile Providence/Staughton line runs between PVD, downtown Providence, and north to Boston South Station (including all intermediate stops). Upon exiting the train at the PVD station, travelers ascend to an elevated enclosed skywalk that leads directly to the main terminal. This skywalk is approximately 2200 feet [64,100].

5.24.3 Time/Cost

Driving time to PVD from downtown Providence is 18 minutes, while transit time is 15 minutes [100].

Driving cost to PVD from downtown Providence is $7.77, while transit cost is $5 [100], yielding a savings of $2.77.

5.25 Milwaukee (MKE)

General Mitchell International Airport is located 6.5 miles south of downtown Milwaukee. Currently, 70% of flights are with a low-cost carrier [67]. In 2010, 4,760,170 passengers enplaned at MKE [9]. It was recently estimated to have a rail transit mode share of <1% [3].

5.25.1 Service

MKE is served by Amtrak’s Hiawatha line at the off-site Milwaukee Airport Railroad Station, which opened in 2005. 7 trains per day stop at this station in each direction, between 6:30 am and 7:45 pm 7 days a week [101].

5.25.2 Physical Characteristics

Once at the station, travelers are required to board a shuttle bus to take them to the main terminal. The shuttle bus picks up and drops off passengers directly outside the baggage claim area of the terminal (102).

5.25.3 Time/Cost

Driving time to MKE from downtown Milwaukee is 15 minutes, as is the transit time (10 minute train, 5 minute shuttle) (101).

Driving cost to MKE from downtown Milwaukee is $7.22, while transit cost is $7.50 (101), a premium of $0.28.

5.26 Airport Characteristic Summary

This section summarizes all of the relevant data from each airport across the 8 scoring criteria. In the case of rush hour frequencies, many transit agencies report a range of frequencies, not just one precise value. For example, DCA has a stated Metro rush hour frequency of 3-7 minutes. In order to calculate a score, an average of these values was used; in this case, 5 minutes. Airports with multiple types of transit connections are displayed as separate systems due to many characteristic differences. During the scoring procedure, this split will be accounted for and scored appropriately.

	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost
ATL	10	0	6.38	5	48	12	66	14
BWI - LRT	1	-10	7.28	5	64	9	45	72
BWI - MARC	3	-15	4.88	2	77	30	45	72
DCA	13	-8	0.78	5	106.3	5	52	2
IAD	1	-12	11.60	1	106.3	30	51	13
MDW	6	-9	7.19	4	224.1	8	37	95
ORD - CTA	5	-21	14.96	5	224.1	5	50	2
ORD - METRA	5	-20	12.96	1	55.7	60	50	2
CLE	2	-10	8.85	5	37	15	50	11
MSP	5	0	5.52	5	12.3	8	32	11
PHL	3	-11	1.52	5	125	30	44*	13
PDX	6	-17	4.26	5	52.4	15	36	26
SFO	9	-14	5.22	5	104	15	41	10
OAK	14	-10	3.03	2	104	8	50	73
SJC	1	-13	1.89	2	42.2	7	48	43
STL	3	-9	11.07	5	46	16	44*	45
SEA	5	-17	9.46	5	17.3	7.5	54	10
EWR	6	6	-5.79	3	162.7	15	38	3
JFK - MTA	11	-30	7.18	3	209	7	37	50
JFK - LIRR	11	-3	1.43	3	594	5	37	50
BOS	6	1	0.22	2	128	5	33	25
DFW	1	-24	14.26	1	34	30	57	1.9
FLL	1	-3	16.45	1	70.9	20	23	53
LAX	1	-29	10.71	1	79.1	5	33	16
PHX	1	-6	3.25	2	20	12	36	33
BUR	1	2	4.77	4	70.9	30	44*	68
PVD	1	3	2.77	4	51.2	60	44*	51
MKE	1	0	-0.28	2	86	120	44*	70
average	4.8	-9.96	6.14	3.32	105.41	21.05	43.52	33.39
maximum	14	6	16.45	5	594	120	66	95
minimum	1	-30	-5.79	1	12.3	5	23	1.9
median	4	-10	5.37	3.5	73.95	13.5	44	25.5

Table 1. Summary of Airport Characteristics

Negative numbers indicate cases where the difference in time or cost between automobile and transit is worse for transit. For instance, negative values of transit time difference indicate airports whose transit lines take longer to get to the airport than cars, i.e. Link light rail to SEA takes 17 minutes longer than the equivalent auto trip in a no-traffic condition. Similarly, negative values for transit cost difference indicate transit trips to the airport that are more expensive than the equivalent auto trip.

Airports that did not have available data for business traveler percentage were given a placeholder value equivalent to the average of all other airports (44%). These placeholder values are designated with an asterisk (*).

A few outliers in the data are present, which may affect the scoring. In the values of track miles, JFK-LIRR's 594-mile network dwarfs all other networks by up to 3 times. The next largest network is Chicago's 224-mile CTA train system, while all other networks average to approximately 88 miles. An additional outlier in the data is the rush hour frequency for MKE's system. This is the only airport not served by a local rail transit service, as Amtrak serves it exclusively. Since Amtrak does not run traditional rush hour frequencies, the 2 hour wait time for next trains stands far above the rest of the systems' average rush hour frequency of 17 minutes. For the purpose of this procedure, these outliers will not be excluded but it may be worthwhile to investigate their impact in future studies.

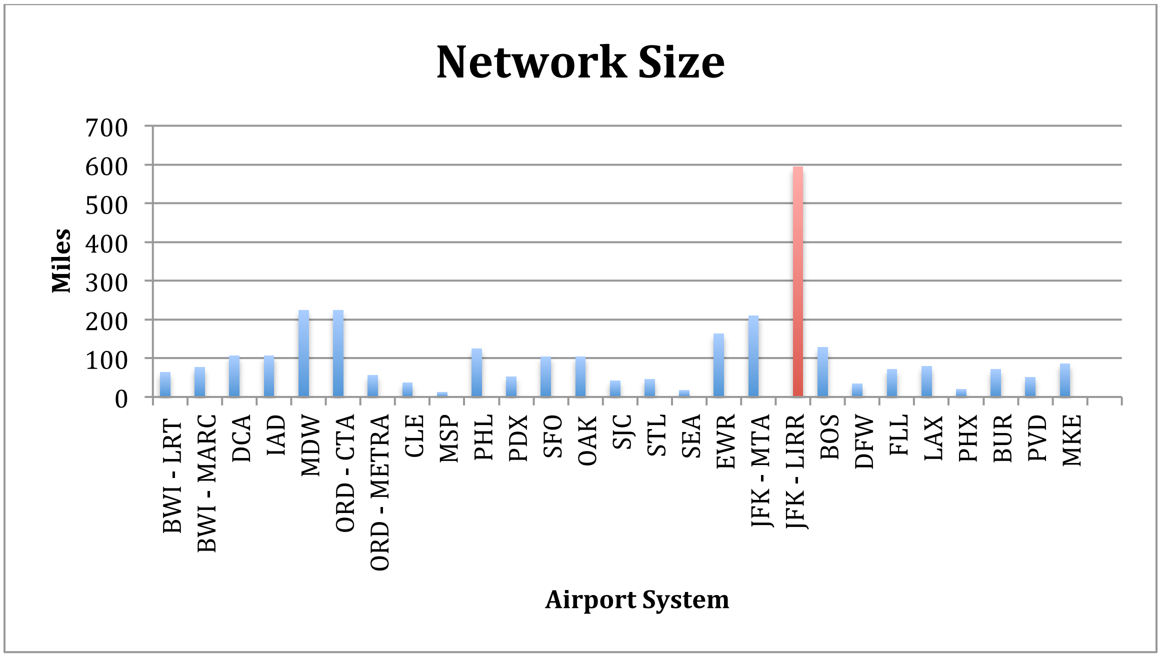

Figure 1. Network Size Outlier

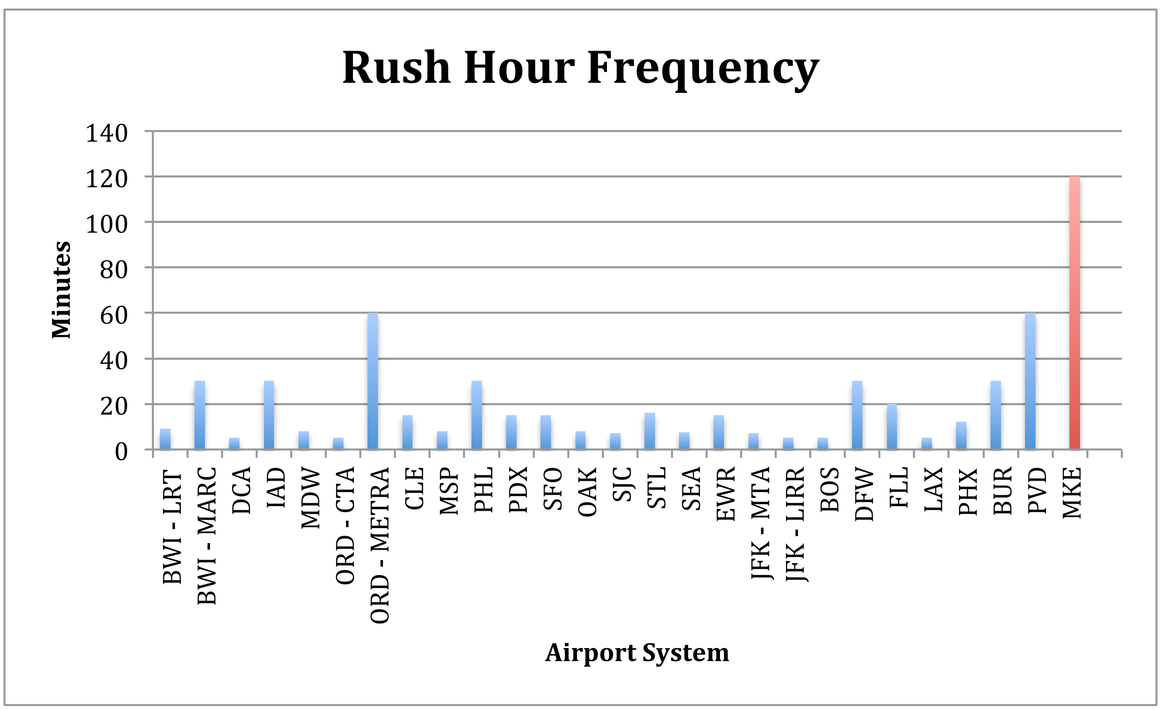

Figure 2. Rush Hour Frequency Outlier

6. Weighting and Scoring

6.1 Methodology

The first step in creating a score for the airports is to establish the weight each of the 8 characteristics has on the outcome. In Schank's research [(2)], he was able to determine significance of airport characteristics by producing a scatter plot of the values of the factors for each airport on the x-axis versus mode share on the y-axis. Then, he would fit a trendline to the scatterplot and note the R^2 value. For two factors, rail travel time and rail vs. auto travel time difference, he was able to get correlations of determination of around .5, indicating a significant relationship. This same process will be repeated here for the seven other (excluding mode share) criteria to determine if using the R^2 value is a reasonable predictor of the importance of individual design, service, or market criteria. The summary of these procedures is in Table 2, with respective scatterplots in Appendix E.

Characteristic	Best-fit formula	R squared
transit time savings	y=-0.0118x+4.6326	0.00077
transit cost savings	y=-0.2236x+6.1217	0.08383
station type	y=1.579x^0.6584	0.16983
network length	y=0.016x+3.0588	0.19852
rush frequency	y=-2.267ln(x)+10.736	0.23005
business travel	y=0.0632x+1.9928	0.01967
low-cost	y=5.1505x^-0.166	0.04618

Table 2. Correlations between Criteria and Mode Share

Judging from these results, the most significant factors that impact mode share are rush frequency, network length, and station type. However, these correlations are much lower than the results seen in Schank's research. Transit time and cost savings as well as the other market criteria (low-cost carrier/business traveler) seem to have almost no significance at all. Another issue is that Schank treats mode share as the dependent variable, while this thesis is treating mode share as an independent variable on an equal level with all other characteristics. As explained in Section 4.2.3, mode share should not be the only indicator of success, and therefore will not be used as a primary means of judgment. Thus, ultimately, repeating Schank's procedure will not be a reliable method of creating weights.

The procedure that will be used to create scores involves three different weighting systems in order to facilitate a sensitivity analysis of the different weighting scenarios. By having a cross-section of different method types, it is ensured that scoring results are not based off of just one (potentially flawed) method.

Weighting System A treats each characteristic evenly, assuming that each characteristic is as important as the next. This is a way of creating a "baseline" condition, i.e. scores that result from no weighting. For this case, each of the eight characteristics is assigned a weight of 12.5%.

Weighting System B can be described as a “design-heavy” method, giving more importance to the design characteristics of the transit system, which are the connection type and track miles. Due to the larger percentages assigned to design characteristics, the other characteristics are given less weight than the System A “baseline” condition.

Weighting System C can be described as a “service-heavy” method, giving more importance to the service characteristics of the transit system, which are time saved by using transit instead of driving, rush hour frequencies, transit cost savings, and mode share. See Table 3 for full breakdown.

	Method A (baseline)	Method B (heavy design)	Method C (heavy service)
transit time savings	12.5%	10%	20.0%
transit cost savings	12.5%	10%	15.0%
station type	12.5%	25%	10.0%
track miles	12.5%	25%	5.0%
rush frequency	12.5%	10%	20.0%
mode share	12.5%	10%	15.0%
business travel	12.5%	5%	7.5%
low cost	12.5%	5%	7.5%
	100.0%	**100.0%**	**100.0%**

Table 3. Weighting Method Values

An intermediate step at this point is to split up airports that have multiple forms of transit. JFK, ORD, and BWI all have two types of transit, a local rail system and a commuter rail system. At each airport, these two types of transit have different design and service characteristics from each other, so they will need to be scored as separate systems. In later steps, their scores will be integrated into one number representing both systems.

The next step is to normalize all the characteristic values. In order to achieve the desired score scale of 0-100, each characteristic for each airport needs to have a value between 0 and 1. To do this, a proportion value is created using the best value as “1” and all other values being a proportion of this. For example, to normalize values of mode share, the highest mode share (OAK’s 14%) is “1”, while MDW’s 6% is 6/14, or “0.429”.

In most cases, this alone creates the needed 0-1 values, however, in some cases, the presence of negative values complicates the process. In order to keep all values positive, all values are increased by the amount of the largest negative value to create new values for each airport that are all non-negative. For instance, most of the travel time savings values are negative, indicating a longer trip on transit versus the trip in an automobile. The largest difference is accessing JFK via NYC subway (MTA), a time loss of 30 minutes. Every value is then increased by 30 minutes so that all values are now non-negative, and the JFK/MTA value is 0.

Once all values for each airport have been normalized to a 0-1 scale, the next step of applying the weightings can continue (see Appendix A for full table of normalized values). Each of these normalized values is multiplied by each weighting method's (A, B, & C) assigned weight. For example, to calculate ATL's weighted mode share under weighting method A, the normalized value of 0.714 is multiplied by the method A weight of 12.5%. 12.5 multiplied by 0.714 results in 8.929.

This process produces three tables, one for each weighting method, using the weights established in Table 2. The final column is the sum of each weighted characteristic value for each airport, which results in an airport score between 0-100, with 100 being the best theoretical score. See Appendices B-D for tables of weighted values for each method.

The final step in determining the scores for each airport is to average each of these final scores from each weighting method to create one absolute score. This ensures that the final score is not wholly dependent on one weighting method, but rather is an equal component of each. The results of averaging are displayed in Table 4, below.

	Method A	Method B	Method C	average
ATL	65.3	62.7	72.6	**66.9**
BWI - LRT	58.6	56.3	60.8	**58.6**
BWI - MARC	47.9	39.0	49.2	**45.4**
DCA	59.8	61.5	66.7	**62.6**
IAD	42.4	35.1	47.5	**41.7**
MDW	65.8	62.5	67.1	**65.2**
ORD - CTA	58.2	63.3	61.2	**60.9**
ORD - METRA	38.1	31.0	41.9	**37.0**
CLE	52.1	53.2	57.5	**54.3**
MSP	53.2	54.8	62.9	**57.0**
PHL	47.9	52.5	50.8	**50.4**
PDX	50.3	52.5	54.5	**52.4**
SFO	54.5	57.6	59.8	**57.3**
OAK	62.3	50.9	67.0	**60.1**
SJC	43.5	36.0	47.7	**42.4**
STL	58.0	56.9	62.5	**59.1**
SEA	53.7	53.8	58.7	**55.4**
EWR	47.3	47.9	55.9	**50.4**
JFK - MTA	54.4	52.3	55.3	**54.0**
JFK - LIRR	68.8	73.6	70.0	**70.8**
BOS	48.7	44.4	57.7	**50.3**
DFW	37.9	29.7	41.8	**36.5**
FLL	48.5	39.1	57.1	**48.2**
LAX	35.0	29.7	39.6	**34.8**
PHX	42.1	35.7	49.4	**42.4**
BUR	56.1	51.7	59.9	**55.9**
PVD	49.5	46.9	52.6	**49.7**
MKE	38.8	32.2	36.7	**35.9**
average	51.4	48.7	55.9	52.0
max	68.8	73.6	72.6	70.8
min	35.0	29.7	36.7	34.8
std. dev	8.9	11.8	9.3	9.8

Table 4. Scoring Results (original)

A graph of the scores produced by the three procedures as well as the average can be found in Figure 3 below. Generally, Method C produced the highest scores while method B produced the lowest scores. Method A's scores ran quite parallel to the average score.

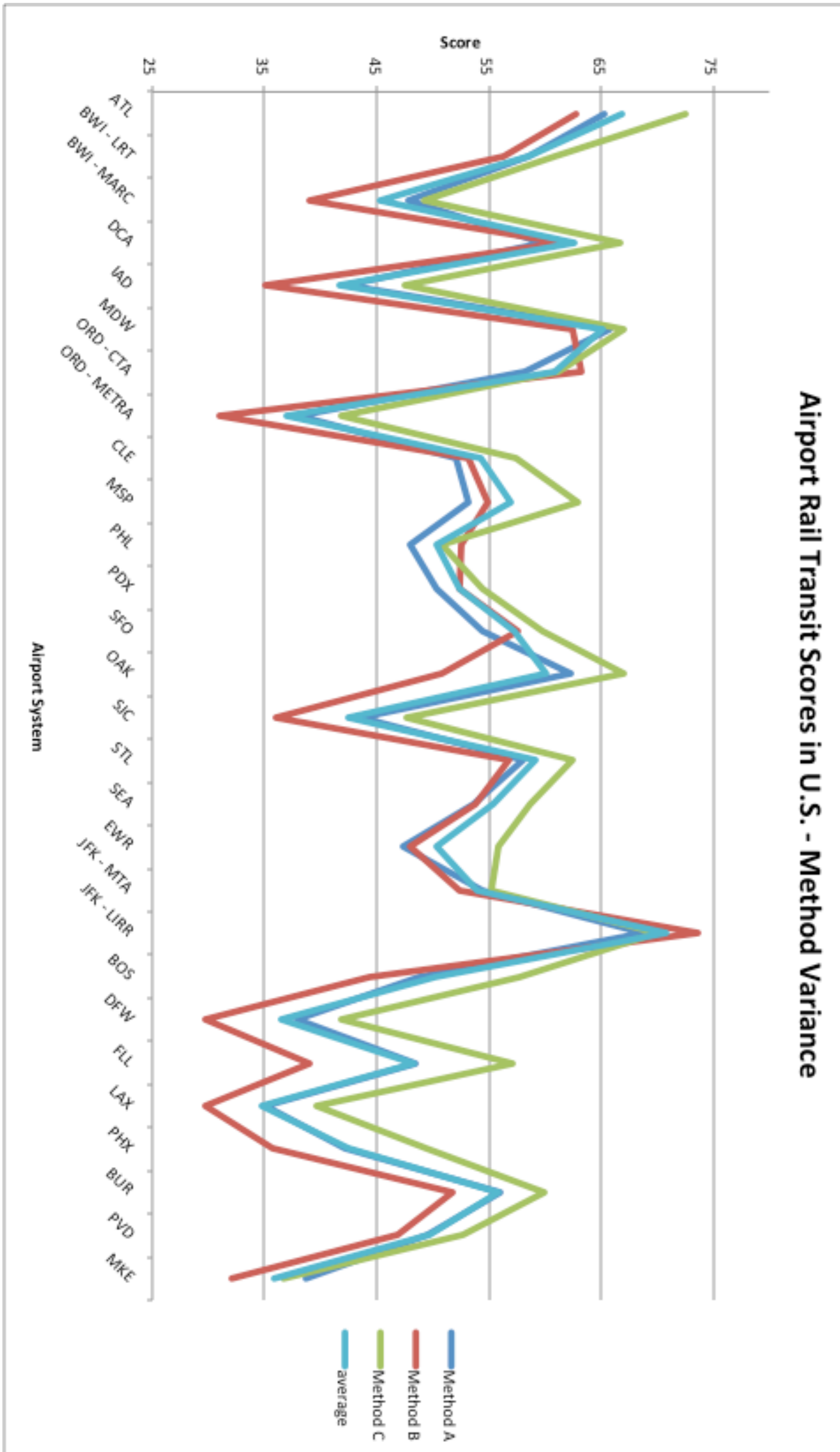

Figure 3. Graph of Method Scores

A statistical analysis is needed to determine if there is a significant difference in the three methods; the Kolmogorov-Smirnov test was used. Three tests were made: A & B, B & C, and A & C. The details of these tests can be found in Appendix F. The test determined that in all three cases there was not a statistically significant difference between the methods being compared. A possible future solution to create methods that are more different from one another is to increase the size of the weights to make service and design characteristics weigh much more heavily than the other characteristics being weighted in that method. For instance, instead of assigning only 25% to the design features in Method B, those features would be assigned weights of 40%. Nevertheless, the three methods and their average will be used to demonstrate the remainder of the procedure [107].

One problem still remains, however, in that airports with multiple transit connections were split up and scored as two different systems. In fact, airports that have two systems should be rewarded for presenting travelers with more options for arriving to or departing from the airport. To account for this, the average scores for airport systems that only represent one-half of that airport's transit options must be increased. The higher-scoring system within the airports with multiple systems (JFK-LIRR, ORD-CTA, and BWI-LRT) will be the starting point for that airport's score. Then, 5 points are added on to that score to represent the lower-scoring system's presence. For example, BWI has two systems, MARC train and light rail. BWI-MARC scored an average 45.4 while BWI-LRT scored an average 58.6. The BWI-LRT score becomes the baseline for BWI's overall score, and an additional 5 points is added to the score to account for the presence of the MARC train as another travel option. This increases BWI's overall score to 63.6.

This 5-point boost is a fair number because it does not artificially inflate the scores, but also does not make having a second transit option meaningless. For instance, the 5-point addition on to ORD pulls it ahead of MDW in the rankings, which is a fair assessment. Both airports serve Chicago, and ORD should receive a higher score since more transit options means more airport passengers can reach it. Less than 5 points, and MDW would score higher than ORD. Furthermore, a 10-point addition would be too much to use, since that would pull BWI ahead in the rankings of ATL. Based on design and service characteristics, BWI is not superior to ATL. Thus, 5 points is a well-rounded amount to use as a score modifier.

6.2 Results

Once the 3 airports with modified score are taken into consideration, the final resulting list is generated and sorted by score in descending order (see Table 5). One method to determine the top airports could be defined by using the standard deviation statistic calculated in Table 4. Using the average column's mean of 52 and standard deviation of approximately 10, it would place 6 of the highest-scoring airports beyond 1 standard deviation from the mean. These top 6 airports could be considered to be the best, however, "Top 6" is not as publicly recognizable or as attention grabbing as "Top 10." Many lists of rankings in wide subject areas narrow top results to 10 because it is a more deliverable and psychologically satisfying figure to the public. Additionally, including only the top 6 airports would make a list that is too small to effectively determine characteristics that represent best practices amongst the airports. Therefore, 10 airports will be highlighted as the best, not 6. These top 10 airports are noted with a box around them in Table 5.

Airport	Score (modified)
JFK	**75.8**
ATL	**66.9**
ORD	**65.9**
MDW	**65.2**
BWI	**63.6**
DCA	**62.6**
OAK	**60.1**
STL	**59.1**
SFO	**57.3**
MSP	**57.0**
BUR	**55.9**
SEA	**55.4**
CLE	**54.3**
PDX	**52.4**
PHL	**51.2**
PVD	**46.7**
EWR	**50.4**
BOS	**50.3**
FLL	**48.2**
PHX	**42.4**
SJC	**42.4**
IAD	**41.7**
MKE	**35.9**
DFW	**36.5**
LAX	**34.8**

Table 5. Scoring Results (modified)

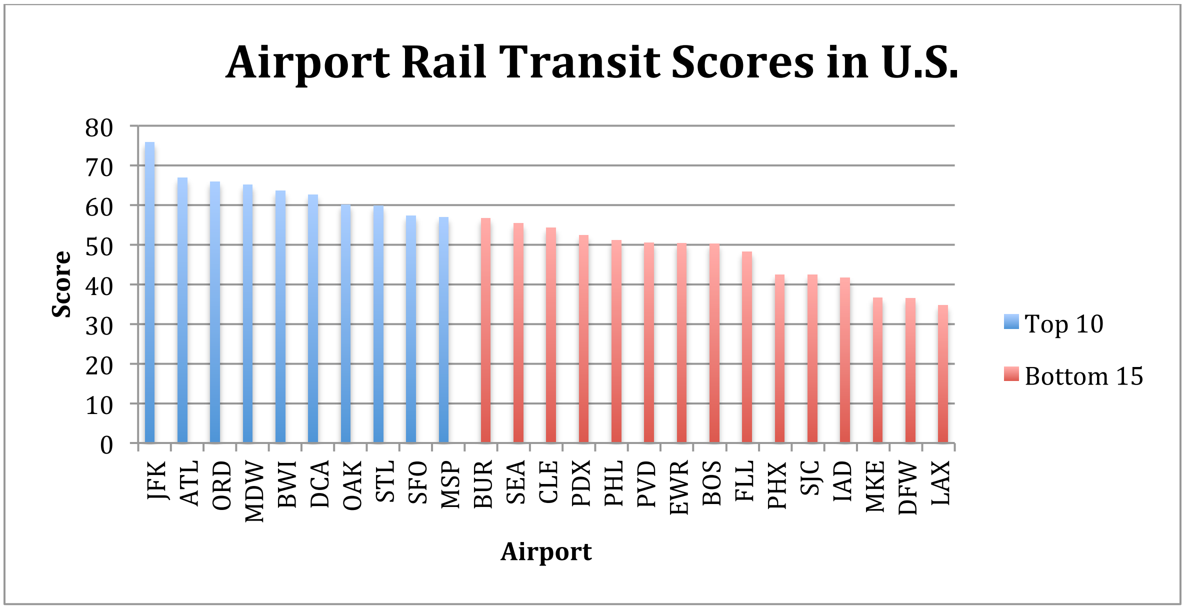

Figure 4. Graph of Scoring Results

Per the new scoring method designed, constructed, and run, these are the "Top 10 Airports to Take Transit To:"

1. JFK (75.8)
2. ATL (66.9)
3. ORD (65.9)
4. MDW (65.2)
5. BWI (63.6)
6. DCA (62.6)
7. OAK (60.1)
8. STL (59.1)
9. SFO (57.3)
10. MSP (57.0)

7. Analysis

The scoring procedure has determined that JFK has the best airport-transit connection, due to its multiple transit options, high frequency of service, efficient AirTrain people mover, and decent time savings when using LIRR from midtown Manhattan. Its relatively high mode share demonstrates this system's popularity with airport travelers.

7.1 Common Factors in High Scoring Airports

The top 10 airports have many factors in common, and to determine the importance of each individual characteristic, the average value across all 25 airports is calculated. This average value will be considered the standard, and any individual airport characteristic value that exceeds the standard will be called out as a best practice. These results can be seen in Table 6.

Of the top 10 airports, 8 of them have stations that are directly in the terminal (score is either a 4 or a 5). This demonstrates that in-terminal access remains a highly desirable design choice for airport transit systems, and is the most typical characteristic of a high scoring airport. The two airports that do not have in-terminal stations (OAK and JFK) accomplish their high scores via high service frequency and large connecting networks.

The average transit time difference across all airports was approximately 10 minutes; meaning transit took on average 10 minutes longer than driving. 8 of the top 10 airports meet or improve upon this average. This demonstrates the need to have a transit trip's duration as close to an automobile's as possible in order to effectively serve passengers and maintain the reputation of the transit system as a highly effective and reliable way to get to the airport. Travelers going to the airport are highly time-sensitive, so this metric remains very important.

The average rush hour frequency across all airports was approximately 21 minutes; however, past research demonstrated the need for airport transit service to have headway of 10 minutes or less, so this will be the standard value instead. 7 of the top 10 airports meet or improve upon this value. This is a highly important metric for time-sensitive airport travelers. Longer wait times for trains will cause travelers to resort to more automobile usage such as a taxicab.

The average network size across all airports was approximately 100 miles. 7 of the 10 airports have systems with over 100 miles of track, demonstrating that a large connecting network is crucial for a high score. While BWI does not have a single system with over 100 miles of track, the two systems (MARC + LRT) combined total over 100 miles. The airports with smaller networks make up by having better cost savings and time savings.

The average mode share across all airports was approximately 5%. 8 of the top 10 airports have a mode share that meet or exceed this standard, adding weight to the argument that these airports are the best in the nation due to the higher than average percentage of travelers using the systems.

The average transit cost savings across all airports was $6.14. 6 of the top 10 airports meet or exceed these savings. In some cases, such as STL, cost savings were so high in relative to other airports that it was able to make up for many of the system's other shortcomings.

It is worth pointing out only 6 out of the top 10 airports met or exceeded the average business traveler percentage, while only 5 out of 10 airports met or exceeded the average low-cost carrier percentage. These weak relationships between high scores and proportion of airports above average indicate that perhaps these factors were not as important as past research has shown. Also possible is the case that these factors need to be accounted for in a different method than the physical and service characteristics.

Table 6 displays these common factors, highlighted in green. It should be noted that while BWI's individual transit systems do not have network sizes of 100 miles each, but the combined network of MARC and light rail is well over. Thus, BWI is highlighted.

	mode share	time savings	cost savings	station type	track miles	rush frequency	business travel	low-cost
JFK - MTA	11	-30	7.18	3	209	7	37	50
JFK - LIRR	11	-3	1.43	3	594	5	37	50
ATL	10	0	6.38	5	48	12	66	14
ORD - CTA	5	-21	14.96	5	224.1	5	50	2
ORD - METRA	5	-20	12.96	1	55.7	60	50	2
MDW	6	-9	7.19	4	224.1	8	37	95
BWI - LRT	1	-10	7.28	5	64	9	45	72
BWI - MARC	3	-15	4.88	2	77	30	45	72
DCA	13	-8	0.78	5	106.3	5	52	2
OAK	14	-10	3.03	2	104	8	50	73
STL	3	-9	11.07	5	46	16	45	45
SFO	9	-14	5.22	5	104	15	41	10
MSP	5	0	5.52	5	12.3	8	32	11
ALL AIRPORT AVERAGE	4.75	-9.96	6.14	4	105	21	45	33

Table 6. Similar Characteristics for Top 10 Airports

7.2 Areas for Improvement/Anomalies

Of the 15 lower scoring airports, 3 are slated for dramatic improvement (IAD, DFW, PHX). These will be examined in the next section. The scoring can be used here to identify areas of low performance. Airport management and/or planners can focus on these areas to improve their overall score.

8 of the 15 lower scoring airports have transit stations that are located off-site and are only accessible by shuttle bus. This remains an unpopular choice for travelers, as the shuttle bus link is seen as not only unreliable, but also burdensome when traveling with

a lot of luggage. Airports that continue to utilize shuttle bus transfers will most likely never score high. OAK is the sole exception in this case, and mysteriously commands the highest mode share of all airports, despite its off-site transit station in addition to a fee-based shuttle bus. The most likely explanation for this is its high frequency BART service in addition to its large proportion of low-cost carriers. The large amount of price-sensitive travelers coming to OAK may be more willing to take a pay shuttle since it is still cheaper than driving or paying for parking.

EWR should have been comparable to JFK, as they both serve the same market, while actually being closer to Manhattan than JFK. However, EWR is the most expensive airport to get to via transit, due to the dual cost of paying a high NJ Transit fare as well as a $5.50 Newark AirTrain fare. Despite a large connecting network, and the fact that it also saves the most amount of time out of all airports, this high cost remains a barrier. Its average 15-minute rush frequency may also be a cause for low scoring. A recommended solution is to remove the cost to use the Newark AirTrain, and make it into a free people mover.

CLE scores points for its in-terminal station and respectable time and money savings, but loses points due to its infrequent (15-min) rush service and small connecting network. Recommended solutions are network expansion and service frequency increase.

PHL, despite its large connecting network and in-terminal stations, suffers from highly infrequent (30-min) rush service. Additionally, the cost savings is lower than most other airports, making driving more attractive. The only possible solution is to increase service to 15 minutes or less.

SEA is the newest airport transit system of the group, and despite its in-terminal station, decent rush service (7.5 min) and high cost savings, it suffers from a small network and longer than average travel time difference compared to other airports. As this network continues to expand, it is possible its score may increase. No other solutions are possible right now.

BOS has solved its own shuttle bus transfer problem by introducing the Silver Line BRT system. This service has slowly been eroding the ridership of the Blue Line off-terminal station. LAX has taken a similar approach by directing marketing towards its FlyAway bus, connecting Union Station to the airport via a BRT-like system.

Airports with 1% mode share or less are unlikely to make any rail transit system improvements, as the large capital cost necessary for improvements is unlikely to impact a large enough share of their daily passengers to warrant the expense. These airports are SJC, FLL, LAX, BUR, PVD, and MKE.

8. Future Airport Transit

Currently, 6 airports are in the process of improving their airport transit connections. 4 of these airports have been scored already by this thesis for their existing systems, while the other 2 are brand new airport transit connections. Unfortunately, since these systems are not yet completed and all characteristic data is not fully known, they are unable to have an accurate score assigned to them, and will not affect the rest of the scoring system. It would be worthwhile to revisit these systems when they are complete and operational data is known.

8.1 Washington – Dulles (IAD)

IAD's market characteristics remain the same (see section 5.4).

8.1.1 Service

WMATA is currently in the process of creating a new line of Metro service, currently dubbed the Silver Line, which will run from downtown DC out to Dulles Airport without transfers. The Silver Line connection will also certainly improve upon the Washington Flyer's current 30-min headways. This project is expected to be completed in 2016 [(103)].

8.1.2 Physical Characteristics

Total network length will be increased from 106.3 to 129.3 miles. The airport station will not be directly within the terminal, but will require a 600 foot walk [(103)]. Washington Flyer bus transfer will not be required anymore. The elimination of the need to transfer to the Washington Flyer Bus at West Falls Church station will not only save money, but also reduce the hassle and uncertainty of a bus transfer.

8.1.3 Time/Cost

Rush hour frequencies as well as differences between travel time and cost are not yet known, as the fare structure and published schedule have not yet been determined. However, predictions can be made based on an Environmental Impact Statement (EIS). See Section 8.8 for more details.

Elimination of Washington Flyer bus will save $10 one-way, or $18 round trip.

8.2 Salt Lake City (SLC)

Salt Lake City International Airport is located 5 miles west of downtown Salt Lake City. Currently, 16% of flights are with a low-cost carrier [33]. In 2010, 10,258,950 passengers enplaned at SLC [9].

8.2.1 Service

Salt Lake City is served by Utah Transit Authority's (UTA) TRAX light rail. The new line will extend 6 miles from the current downtown Central Station, opening up new neighborhoods as well as the airport to light rail access. Train frequency is predicted to be 15 minutes at rush hour [71].

8.2.2 Physical Characteristics

SLC will be served by TRAX via an in-terminal station. Many other TRAX expansions are happening as well, and by the time everything has been completed, total TRAX network length will be increased from 19.6 miles to 44.8 miles. The airport extension is due to open in 2013, with the full expansion completed in 2015 [71].

8.2.3 Time/Cost

Transit time savings can not yet be determined, as a train schedule has not yet been determined.

Driving cost to SLC from downtown Salt Lake City is $7.92 while transit cost is $2.35 [71], assuming that the TRAX flat fares remain in effect, a savings of $5.57.

8.3 Denver (DEN)

Denver International Airport is located 18.5 miles northeast of downtown Denver. Currently, 16% of flights are with a low-cost carrier [16]. In 2010, 25,241,962 passengers enplaned at DEN [9].

8.3.1 Service

Plans are underway for a new commuter rail line to connect DEN with downtown Denver, as part of the larger Regional Transportation District (RTD) FasTracks project. SkyRide buses, which currently serve DEN, provide express service between the airport and downtown. This bus system has a 3.5% market share currently, so it is reasonable to expect these passengers will shift to the new commuter rail line. Expected completion is in 2016 [48].

8.3.2 Physical Characteristics

Aside from the new 22.8 commuter rail airport line, there will also be 17.7 miles of extensions to the current 39.4-mile RTD light rail system. DEN will be served by commuter rail via an in-terminal station, possibly similar to PHL's [48].

8.3.3 Time/Cost

Transit time and cost savings cannot yet be determined, as neither a train schedule nor a fare structure has been determined.

8.4 Oakland (OAK)

OAK's market characteristics remain the same (see section 5.12).

8.4.1 Service

OAK's current AirBART shuttle bus service is being replaced by an elevated rail people mover called the Oakland Airport Connector (OAC). This will directly connect OAK's main terminal with the Coliseum/Airport BART station via rail transit. Expected completion of this project is in 2014 [(58)].

8.4.2 Physical Characteristics

The OAC will most likely be accessible directly from the BART platform, similar to EWR and JFK's people movers. This elevated line will parallel the existing AirBART route, all while avoiding congestion and traffic signals. The exact station placement is unknown, but will most likely be right outside or physically connected to the existing terminal [(58)].

8.4.3 Time/Cost

Travel times between OAK and the BART station currently take between 15 and 30 minutes on the AirBART bus service, while the OAC will reduce trip times to 8.5 minutes [(58)].

Cost of this service is undetermined as of now, but is likely to be the same $3 fare as the AirBART bus.

8.5 Dallas – Fort Worth (DFW)

DFW's market characteristics remain the same (see section 5.19).

8.5.1 Service

Access to DFW will no longer only be served by the TRE commuter rail + shuttle bus service. Dallas Area Rapid Transit's (DART) Orange Line light rail is currently under construction to directly connect downtown Dallas with DFW's main terminals. This direct connection to DFW will most certainly boost the mode share rail transit currently commands, and will solve many issues with current rail transit access. Future Orange Line train frequencies are unknown at this point, but will most likely be comparable to the current 15-minute frequencies, a vast improvement over TRE's current 30-60 minute headways. In addition, airport users will gain transit service to DFW on Sundays, since there is no current TRE service. This project is due to be completed in 2014 [50].

8.5.2 Physical Characteristics

The Orange Line expansion will add 14 miles to the existing DART light rail network, for a grand total of 90 miles, currently the largest light-rail network in the U.S. The DFW Airport Station on the Orange Line will most likely be a direct in-terminal station, with no transfer required. Despite the fact that DFW has multiple terminals, there will most likely be one single DART station, which connects to the intra-airport people mover system

[58]. This will be a great advantage over the current system's requirement that 2 shuttle buses be taken from the train station to access the airport.

8.5.3 Time/Cost

Transit time savings can not yet be determined, as a train schedule has not yet been determined.

Driving cost to DFW from downtown Dallas is $17.76 while transit cost is $1.75 [58], which represent a savings of $16.01 assuming that the DART flat fares remain in effect.

8.6 Miami (MIA)

Miami International Airport is located 5.5 miles west of downtown Miami. Currently, 35% of travelers through MIA are business travelers [42], and 0.3% of flights are with a low-cost carrier [24]. In 2010, 17,017,654 passengers enplaned at MIA [9].

8.6.1 Service

In summer 2012, Miami-Dade transit will open their MIA airport connection, bringing Miami Metro directly to the airport for the first time. The MIA Airport station will create a new northern terminus of a newly created Orange Line, representing service between southern terminus Dadeland South station and MIA. Newly created Green Line trains will run parallel service from Dadeland South but instead bypass MIA and continue to the original northern terminus of Palmetto. Service frequency will most likely be every 10 minutes during rush hour [104].

8.6.2 Physical Characteristics

This 2.4-mile extension will expand Miami Metro's 22.4-mile system to 24.9 miles. The Miami Metro Airport station will not be directly at the airport, but will instead be located in the new Miami Central Station multimodal station. This station consolidates Tri-Rail, Amtrak, local buses, Metro, and rental cars all within the same complex. This complex connects to the MIA terminals via a free people mover called the MIA Mover [(104)].

8.6.3 Time/Cost

Driving time to downtown Miami is 16 minutes, while taking Metro will be approximately 15 minutes plus a 5 minute MIA mover transfer between Miami Central Station and the terminals [(104)].

Driving cost is $6.11 while the transit cost is $2.00, a savings of $4.11.

8.7 Phoenix (PHX)

PHX's market characteristics remain the same (see section 5.23).

8.7.1 Service

PHX will replace its current shuttle bus service between the METRO station and the terminals with a new elevated people mover system called SkyTrain. This project will be done in 3 phases. The first phase, due to be complete in 2013, will connect the 44th St. METRO station with Terminal 4 (the busiest terminal). The next stage, to be completed in 2015, will expand the SkyTrain to the remaining terminals, while the final stage, completed in 2020, will finish the line out to the Rental Car Center. This people mover will provide 3-minute headways to the METRO station, a vast improvement over the current shuttle buses [62,63].

8.7.2 Physical Characteristics

The SkyTrain station on the METRO side will be across Washington St, the current bus bays, and the Grand Canal, connecting via an elevated moving walkway. The route will then pass through a long term parking area, before arriving at Terminal 4, and then continuing westbound through Terminals 2 and 3, and eventually to the Rental Car Center [62,63].

8.7.3 Time/Cost

Since this is just replacing the shuttle bus service, these characteristics remain the same as before (see section 5.23.3). The SkyTrain people mover will be free.

8.8 Predictions of Success

While it is impossible to perfectly score these 6 new airport transit connections due to the fact they are still under construction and all physical and service characteristics are not fully known, predictions can still be made based upon prior scores. One airport, IAD, will be assigned a new score since its current characteristics are arguably undergoing the most radical change. Additionally, there is a great deal of information available on the future IAD service from the Final Environmental Impact Statement that was completed by the Metropolitan Washington Airports Authority (MWAA) in 2004 [108].

IAD’s Metro Silver line will most likely command a higher mode share than the current Washington Flyer Bus Service due to the fact that a transfer is eliminated. It has been predicted to generate a 5% mode share. However, it will need to have attractive travel times to be able to compete with driving. The Silver Line route deviates from the main roadway to service 4 stations in Tysons Corner, which will make the transit time difference quite large. The travel time from Metro Center station in the city center to Dulles Airport station has been predicted to be 50 minutes. The closest comparisons to existing service are either ATL’s MARTA service or ORD’s CTA service.

The characteristics for both current and future IAD systems are displayed in Table 7. While the trip is estimated to have 3 minutes more of travel time, this comes at the advantage of a no-transfer ride. Cost savings will be increased as the $10 Washington Flyer bus is cut out. Metro cost to Dulles was estimated to be 5% greater than the current maximum of $5.75, to adjust for inflation. It is possible the cost to take Metro to Dulles may be higher than this estimation. Rush hour frequency estimates coincide with the current rush frequencies of trains from DC’s current furthest from downtown station, Shady Grove. Business travel percentage and low-cost percentage are assumed to be unchanged.

	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost
IAD-current	1	-12	11.60	1	106.3	30	51	13
IAD-future	5	-15	19.49	5	129.3	7	51	13

Table 7. IAD Characteristics (present vs. future)

The normalizing and weighting process was repeated in the same manner as prior score calculations, and new scores were generated. In the end, the new system characteristics impact IAD's score greatly across all three methods. These new scores can be found in Table 8.

	Method A	Method B	Method C	average
IAD-current	42.4	35.1	47.5	41.7
IAD-future	60.5	62.1	65.4	**62.7**

Table 8. IAD Scores (present vs. future)

The new Metro Silver Line service to IAD will be able to raise IAD's score by more than 20 points. This increase would place IAD in the top 10 airport systems, with a score almost exactly the same as DCA's and slightly less than BWI. If that were to happen, all three of the Washington/Baltimore region's airports would be in the top 10, at spots 5,6, and 7. This would be a great boon to the Washington/Baltimore airport passengers and planners, and would make for great publicity by bringing awareness to the excellence of the region's airports. This illustrates that the methodology is useful and can accurately reflect incremental improvements in service.

SLC's TRAX Green Line extension will be comparable to other moderate-size light rail connections such as BWI or PDX, with multiple lines to connect to as well as an in-station terminal. SLC will need to make sure transit time to downtown be competitive with driving.

DEN's commuter rail connection will be comparable in design and operation to PHL's commuter rail line, both of which are electric powered rather than diesel. DEN needs to make sure and not repeat the major flaw with PHL's airport transit by ensuring that headways are no more than 15 minutes.

OAK's Oakland Airport Connector will most certainly be successful, assuming that the current high ridership of the AirBART service shifts to the OAC once it opens. OAK has the highest rail transit mode share of any airport, and the OAC will only increase it, due to the OAC's faster travel times between the BART station and OAK's terminals.

DFW's DART Orange Line extension will be similar in nature to SLC's TRAX airport extension. Both will have similar headways and large connecting networks. The only possible flaw with this extension is a large travel time difference that will discourage travelers from Dallas to use it.

MIA's Metro extension to the airport will be successful only if airport passengers can overcome several limitations of the Metro system. Not only is the connecting network quite small for such a large city, but travelers will also need to transfer to the MIA Mover to get between the Metro airport station and the MIA terminals. Travel time differences to get to downtown are comparable, but in a region where much traffic is headed towards South Beach rather than downtown Miami, this system may struggle to attract riders.

PHX's SkyTrain people mover will most certainly accomplish its goal of facilitating the transfer between Valley METRO and the PHX terminals. The current ridership of METRO to the airport station is quite low, so it seems that it can only increase with an improved connection system.

9. Conclusions

This thesis developed a procedure that can be used to assign airport-transit connections a numerical score on a scale of 0-100, with 100 being the best. This procedure used system and market factors, representing supply and demand respectively, as the basis of the score of 25 airports and their rail transit connections. The procedure was used to predict an improved score for an airport that was undergoing major transit upgrades, which further illustrates the utility of the procedure.

With this information, two results can be achieved. First, if travelers in cities with high-scoring airports see the score, they may be more inclined to take transit if they had not already before, as now there is strong evidence that the transit system will effectively and efficiently get them to the airport, and they need not worry about reliability factors such as on-time trains or hassle-free terminal connections. An outcome of these rankings would be if travelers in St. Louis may not have realized how effective their MetroLink system was, and would feel more secure in using the service next time they go to the airport. Second, while cities with low-scoring airports and transit systems will most likely not immediately win the favor of airport travelers anytime soon, this can be used as incentive to the airport planners and transit operators to improve service where possible in an attempt to move up a few spots on the list and convince more airport travelers to try transit. An example of this action would be considering an increase in rush hour headways or creation of express trains to decrease the trip length. These factors are relatively easy to change, whereas design factors such as connection type may not be as simple.

JFK airport in New York City was found to be the highest scoring airport, with a score of 75.8, while Los Angeles International scored the lowest with a 34.8. This tells people that while cities and transit systems like JFK airport and the NYC transit system are doing a great job connecting people in the city core with the airport, cities at the lower end of the scale such as Los Angeles have much more work to do.

The thesis goal was not only to establish numerical rankings, but also to raise awareness of rail transit connections and study how to improve new and existing systems by following some key requirements. This is an important first step in realizing the underutilized value of current airport-transit connections, and this procedure can be seen as a proof-of-concept in creating a standardized model that can be used in the future to predict scores on the fly, without being dependent on all the other airports' criteria data.

As airports continue to expand, an increased desire to minimize roadway network impact will arise. Airport transit systems will need to continually better themselves in order to keep up with increased travel demand. Holding the cities and airports accountable by assigning a numerical score for all to see and critique is an effective method that will hopefully become a standard evaluation tool. For many travelers, airports are the main gateway to the city. These airports are not complete without good access to public rail transit lines to best serve the needs of the people.

10. Future Work

This thesis has developed a scoring system with regard to airport rail transit access, but future work is needed in order to refine this process. It is important to note the limitations of this analysis; that this was just a scoping analysis on a small scale as a proof-of-concept, using a scoring system that was additive and linear in nature. Future full-fledged modeling work should be done on this topic on a much larger scale using non-linear techniques and more sophisticated methods. One such technique can be done in MATLAB by using an Artificial Neural Network.

For this study, scores were linear, meaning that the difference between a 50 and a 60 was the same as the difference between a 60 and a 70. Recently, the creators of Walk Score, an online tool for determining how easy it is to walk around a given address or city by assigning a 0-100 score, released a new online scoring system called "Transit Score," which utilizes the same 0-100 scale to determine how accessible public transit is for cities. They created a "Top 12" list using similar methods to the airport scoring system created here. Transit Score's scores, however, are not linear, so raising a city's score from 70 to 80 takes much more work than raising it from 60 to 70. But the creation of weightings of different factors and the concept of a two-digit score on a 0-100 scale, with a top score of 81 for New York City has many parallels to the airport transit scoring system. The existence of the Transit Score tool adds validity to the newly created airport transit score procedure, proving that it is worthwhile and in demand to create these scoring systems [105,106].

In this thesis, the individual system characteristics were treated as independent variables, with each characteristic not affecting others in any way. Other methodologies may be examined that account for relationships between the variables, treating them as variables that depend on each other more. The addition of other market characteristics may be investigated such as population density, census data, and traffic flows. The market characteristics chosen for this procedure did not appear to have a direct impact on an airport's score, though it is possible they need to be scored in a separate manner from the system characteristics.

This thesis only looked at airport passengers using transit, while ignoring employee usage. In many systems, employee usage surpasses that of passenger usage, and it would be useful to determine and account for this breakdown.

Airport parking costs were deliberately left out of the analysis due to the difficulty in accounting for variable prices among airports as well as the unknown duration of stay. However, a more robust model may be able to work parking costs into the cost characteristics.

It would also be useful to redo these scores in the future to account for any service pattern or price changes to the existing systems. Additionally, any airport transit systems that are currently under construction but open in the future should be added into the scoring matrix.

Finally, a few airports in this study had a record of transit passenger mode share data that was outdated. Updating all mode share data values to the absolute most recent values may alter the scores.

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12. Appendix

Appendix A: Normalized Values

	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost
ATL	0.714	0.833	0.547	1.0	0.081	0.900	1.000	0.147
BWI - LRT	0.071	0.556	0.588	1.0	0.108	0.925	0.682	0.758
BWI - MARC	0.214	0.417	0.480	0.4	0.130	0.750	0.682	0.758
DCA	0.929	0.611	0.295	1.0	0.179	0.958	0.788	0.021
IAD	0.071	0.500	0.782	0.2	0.179	0.750	0.773	0.137
MDW	0.429	0.583	0.583	0.8	0.377	0.933	0.561	1.000
ORD - CTA	0.357	0.250	0.933	1.0	0.377	0.958	0.758	0.021
ORD - METRA	0.357	0.278	0.843	0.2	0.094	0.500	0.758	0.021
CLE	0.143	0.556	0.658	1.0	0.062	0.875	0.758	0.116
MSP	0.357	0.833	0.509	1.0	0.021	0.933	0.485	0.116
PHL	0.214	0.528	0.329	1.0	0.210	0.750	0.667	0.137
PDX	0.429	0.361	0.452	1.0	0.088	0.875	0.545	0.274
SFO	0.643	0.444	0.495	1.0	0.175	0.875	0.621	0.105
OAK	1.000	0.556	0.397	0.4	0.175	0.933	0.758	0.768
SJC	0.071	0.472	0.345	0.4	0.071	0.942	0.727	0.453
STL	0.214	0.583	0.758	1.0	0.077	0.867	0.667	0.474
SEA	0.357	0.361	0.686	1.0	0.029	0.938	0.818	0.105
EWR	0.429	1.000	0.000	0.6	0.274	0.875	0.576	0.032
JFK - MTA	0.786	0.000	0.583	0.6	0.352	0.942	0.561	0.526
JFK - LIRR	0.786	0.750	0.325	0.6	1.000	0.958	0.561	0.526
BOS	0.429	0.861	0.270	0.4	0.215	0.958	0.500	0.263
DFW	0.071	0.167	0.902	0.2	0.057	0.750	0.864	0.020
FLL	0.071	0.750	1.000	0.2	0.119	0.833	0.348	0.558
LAX	0.071	0.028	0.742	0.2	0.133	0.958	0.500	0.168
PHX	0.071	0.667	0.406	0.4	0.034	0.900	0.545	0.347
BUR	0.071	0.889	0.475	0.8	0.119	0.750	0.667	0.716
PVD	0.071	0.917	0.385	0.8	0.086	0.500	0.667	0.537
MKE	0.071	0.833	0.248	0.4	0.145	0.000	0.667	0.737

Appendix B: Method A weightings

Airport	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost	FINAL SCORE
ATL	8.929	10.417	6.840	12.500	1.010	11.250	12.500	1.842	65.288
BWI - LRT	0.893	6.944	7.346	12.500	1.347	11.563	8.523	9.474	58.589
BWI - MARC	2.679	5.208	5.997	5.000	1.620	9.375	8.523	9.474	47.876
DCA	11.607	7.639	3.693	12.500	2.237	11.979	9.848	0.263	59.766
IAD	0.893	6.250	9.774	2.500	2.237	9.375	9.659	1.711	42.398
MDW	5.357	7.292	7.293	10.000	4.716	11.667	7.008	12.500	65.832
ORD - CTA	4.464	3.125	11.663	12.500	4.716	11.979	9.470	0.263	58.180
ORD - METRA	4.464	3.472	10.538	2.500	1.172	6.250	9.470	0.263	38.130
CLE	1.786	6.944	8.228	12.500	0.779	10.938	9.470	1.447	52.092
MSP	4.464	10.417	6.357	12.500	0.259	11.667	6.061	1.447	53.171
PHL	2.679	6.597	4.109	12.500	2.625	9.375	8.338	1.711	46.964
PDX	5.357	4.514	5.649	12.500	1.103	10.938	6.818	3.421	50.299
SFO	8.036	5.556	6.188	12.500	2.189	10.938	7.765	1.316	54.486
OAK	12.500	6.944	4.957	5.000	2.189	11.667	9.470	9.605	62.332
SJC	0.893	5.903	4.314	5.000	0.888	11.771	9.091	5.658	43.517
STL	2.679	7.292	9.476	12.500	0.968	10.833	8.338	5.921	59.139
SEA	4.464	4.514	8.571	12.500	0.364	11.719	10.227	1.316	53.675
EWR	5.357	12.500	0.000	7.500	3.424	10.938	7.197	0.395	47.310
JFK - MTA	9.821	0.000	7.290	7.500	4.398	11.771	7.008	6.579	54.367
JFK - LIRR	9.821	9.375	4.058	7.500	12.500	11.979	7.008	6.579	68.820
BOS	5.357	10.764	3.378	5.000	2.694	11.979	6.250	3.289	48.711
DFW	0.893	2.083	11.269	2.500	0.715	9.375	10.795	0.250	37.881
FLL	0.893	9.375	12.500	2.500	1.492	10.417	4.356	6.974	48.506
LAX	0.893	0.347	9.274	2.500	1.665	11.979	6.250	2.105	35.013
PHX	0.893	8.333	5.078	5.000	0.421	11.250	6.818	4.342	42.135
BUR	0.893	11.111	5.935	10.000	1.492	9.375	8.338	8.947	57.223
PVD	0.893	11.458	4.811	10.000	1.077	6.250	8.338	6.711	50.670
MKE	0.893	10.417	3.094	5.000	1.810	0.000	8.338	9.211	39.894

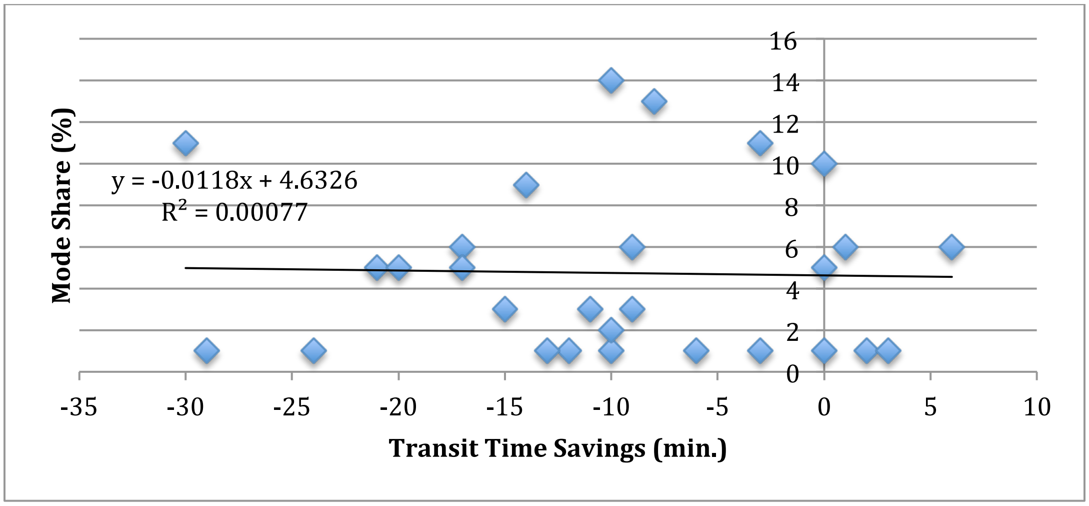
Appendix C: Method B weightings

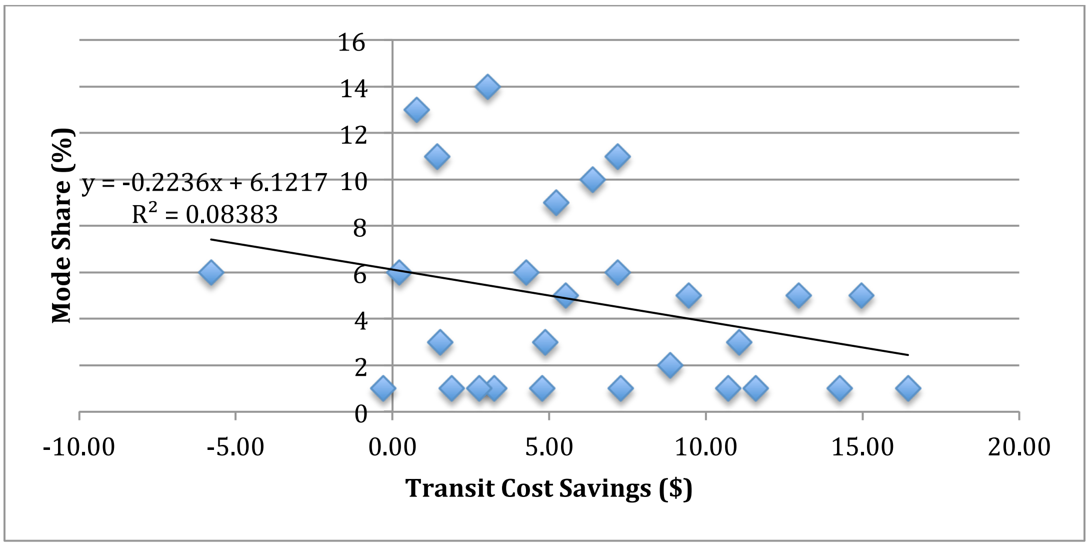
Airport	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost	FINAL SCORE
ATL	7.143	8.333	5.472	25.000	2.020	9.000	5.000	0.737	62.705
BWI - LRT	0.714	5.556	5.877	25.000	2.694	9.250	3.409	3.789	56.289
BWI - MARC	2.143	4.167	4.798	10.000	3.241	7.500	3.409	3.789	39.046
DCA	9.286	6.111	2.954	25.000	4.474	9.583	3.939	0.105	61.453
IAD	0.714	5.000	7.819	5.000	4.474	7.500	3.864	0.684	35.055
MDW	4.286	5.833	5.834	20.000	9.432	9.333	2.803	5.000	62.521
ORD - CTA	3.571	2.500	9.330	25.000	9.432	9.583	3.788	0.105	63.310
ORD - METRA	3.571	2.778	8.431	5.000	2.344	5.000	3.788	0.105	31.017
CLE	1.429	5.556	6.583	25.000	1.557	8.750	3.788	0.579	53.241
MSP	3.571	8.333	5.085	25.000	0.518	9.333	2.424	0.579	54.844
PHL	2.143	5.278	3.287	25.000	5.250	7.500	3.335	0.684	48.728
PDX	4.286	3.611	4.519	25.000	2.205	8.750	2.727	1.368	52.467
SFO	6.429	4.444	4.951	25.000	4.377	8.750	3.106	0.526	57.583
OAK	10.000	5.556	3.966	10.000	4.377	9.333	3.788	3.842	50.862
SJC	0.714	4.722	3.451	10.000	1.776	9.417	3.636	2.263	35.980
STL	2.143	5.833	7.581	25.000	1.936	8.667	3.335	2.368	57.316
SEA	3.571	3.611	6.857	25.000	0.728	9.375	4.091	0.526	53.760
EWR	4.286	10.000	0.000	15.000	6.848	8.750	2.879	0.158	47.920
JFK - MTA	7.857	0.000	5.832	15.000	8.796	9.417	2.803	2.632	52.337
JFK - LIRR	7.857	7.500	3.246	15.000	25.000	9.583	2.803	2.632	73.621
BOS	4.286	8.611	2.702	10.000	5.387	9.583	2.500	1.316	44.385
DFW	0.714	1.667	9.015	5.000	1.431	7.500	4.318	0.100	29.745
FLL	0.714	7.500	10.000	5.000	2.984	8.333	1.742	2.789	39.064
LAX	0.714	0.278	7.419	5.000	3.329	9.583	2.500	0.842	29.666
PHX	0.714	6.667	4.063	10.000	0.842	9.000	2.727	1.737	35.749
BUR	0.714	8.889	4.748	20.000	2.984	7.500	3.335	3.579	52.202
PVD	0.714	9.167	3.849	20.000	2.155	5.000	3.335	2.684	47.357
MKE	0.714	8.333	2.475	10.000	3.620	0.000	3.335	3.684	32.615

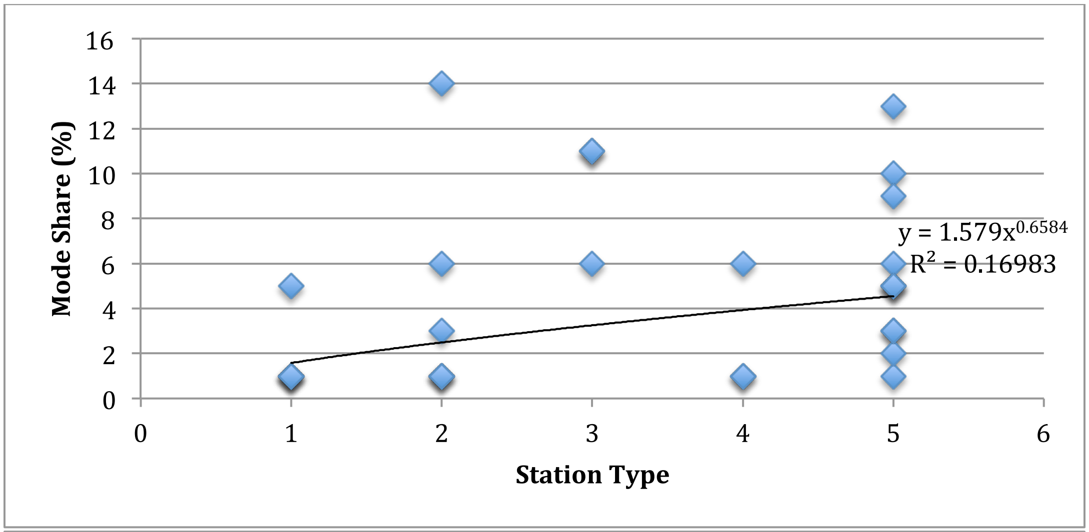
Appendix D: Method C weightings

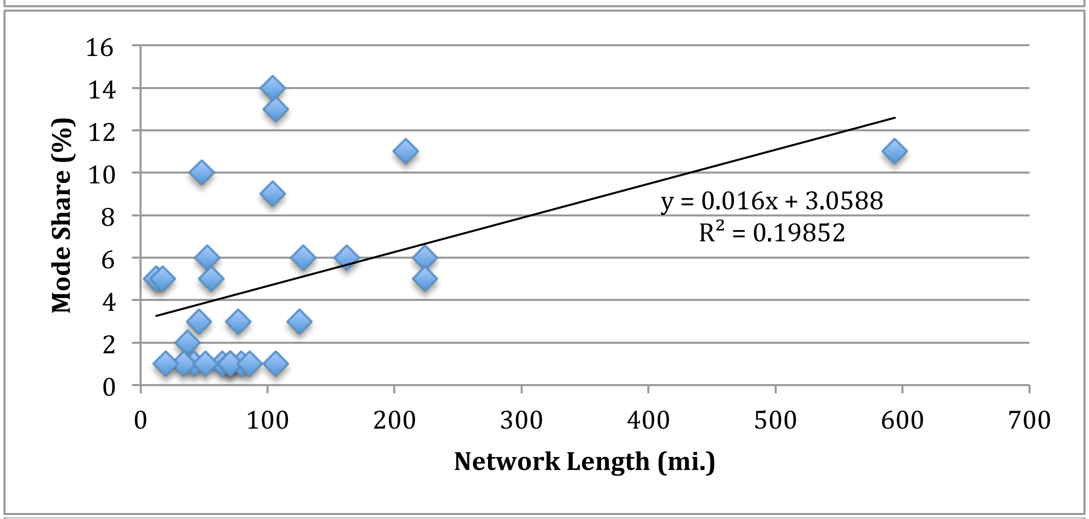
Airport	mode share	transit time savings	transit cost savings	station type	track miles	rush frequency	business travel	low-cost	FINAL SCORE
ATL	10.714	16.667	8.208	10.000	0.404	18.000	7.500	1.105	72.598
BWI - LRT	1.071	11.111	8.815	10.000	0.539	18.500	5.114	5.684	60.834
BWI - MARC	3.214	8.333	7.196	4.000	0.648	15.000	5.114	5.684	49.190
DCA	13.929	12.222	4.431	10.000	0.895	19.167	5.909	0.158	66.710
IAD	1.071	10.000	11.729	2.000	0.895	15.000	5.795	1.026	47.517
MDW	6.429	11.667	8.751	8.000	1.886	18.667	4.205	7.500	67.104
ORD - CTA	5.357	5.000	13.995	10.000	1.886	19.167	5.682	0.158	61.245
ORD - METRA	5.357	5.556	12.646	2.000	0.469	10.000	5.682	0.158	41.867
CLE	2.143	11.111	9.874	10.000	0.311	17.500	5.682	0.868	57.490
MSP	5.357	16.667	7.628	10.000	0.104	18.667	3.636	0.868	62.927
PHL	3.214	10.556	4.930	10.000	1.050	15.000	5.003	1.026	50.618
PDX	6.429	7.222	6.778	10.000	0.441	17.500	4.091	2.053	54.514
SFO	9.643	8.889	7.426	10.000	0.875	17.500	4.659	0.789	59.782
OAK	15.000	11.111	5.949	4.000	0.875	18.667	5.682	5.763	67.047
SJC	1.071	9.444	5.176	4.000	0.355	18.833	5.455	3.395	47.730
STL	3.214	11.667	11.371	10.000	0.387	17.333	5.003	3.553	63.207
SEA	5.357	7.222	10.286	10.000	0.146	18.750	6.136	0.789	58.686
EWR	6.429	20.000	0.000	6.000	1.370	17.500	4.318	0.237	55.853
JFK - MTA	11.786	0.000	8.748	6.000	1.759	18.833	4.205	3.947	55.278
JFK - LIRR	11.786	15.000	4.870	6.000	5.000	19.167	4.205	3.947	69.974
BOS	6.429	17.222	4.054	4.000	1.077	19.167	3.750	1.974	57.672
DFW	1.071	3.333	13.523	2.000	0.286	15.000	6.477	0.150	41.841
FLL	1.071	15.000	15.000	2.000	0.597	16.667	2.614	4.184	57.133
LAX	1.071	0.556	11.129	2.000	0.666	19.167	3.750	1.263	39.601
PHX	1.071	13.333	6.094	4.000	0.168	18.000	4.091	2.605	49.363
BUR	1.071	17.778	7.122	8.000	0.597	15.000	5.003	5.368	60.619
PVD	1.071	18.333	5.773	8.000	0.431	10.000	5.003	4.026	53.317
MKE	1.071	16.667	3.713	4.000	0.724	0.000	5.003	5.526	37.383

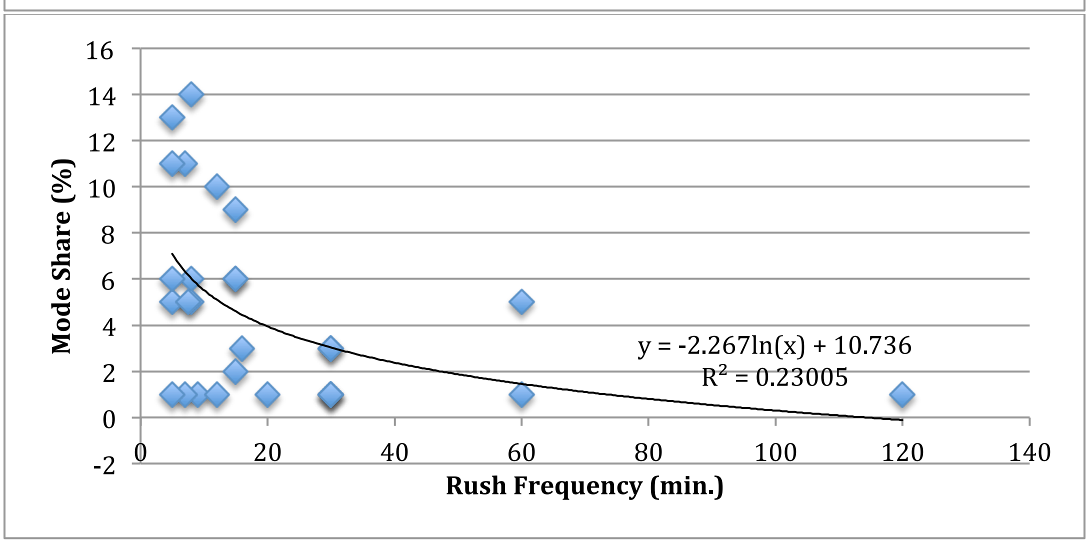
Appendix E: Criteria/Mode Share Correlations

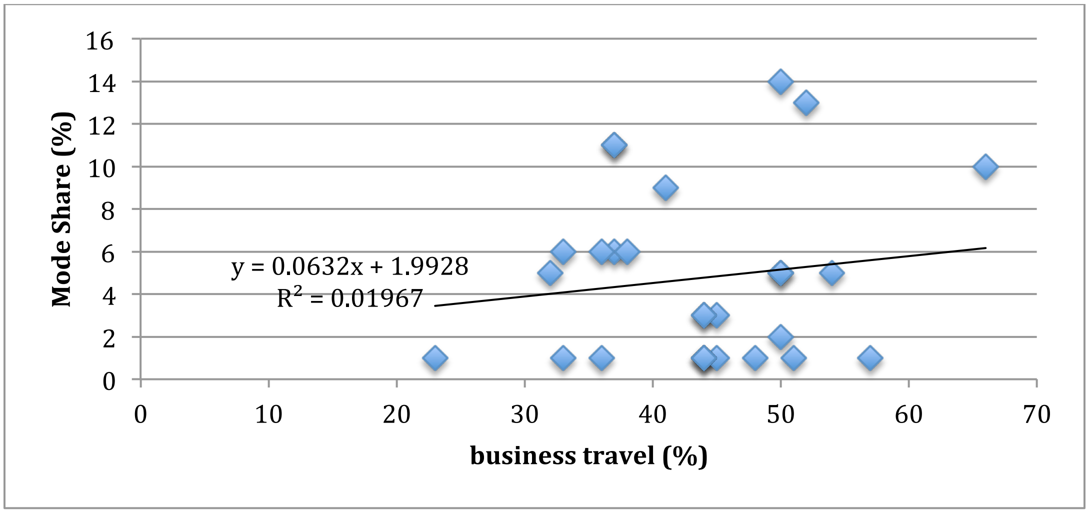




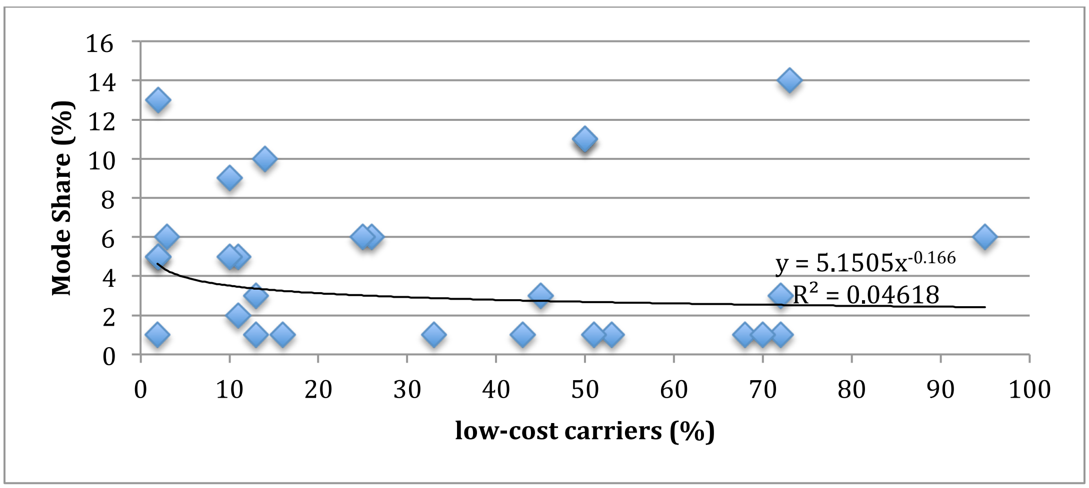

Mode Share (%)
Station Type
y = 1.579x^0.6584
R² = 0.16983


Mode Share (%)
Network Length (mi.)
y = 0.016x + 3.0588
R² = 0.19852


Mode Share (%)
Rush Frequency (min.)
y = -2.267ln(x) + 10.736
R² = 0.23005



16
14
12
10
8
6
4
2
0
Mode Share (%)
y = 0.0632x + 1.9928
R² = 0.01967
0
10
20
30
40
50
60
70
business travel (%)



16
14
12
10
8
6
4
2
0
Mode Share (%)
y = 5.1505x^-0.166
R² = 0.04618
0
10
20
30
40
50
60
70
80
90
100
low-cost carriers (%)

Appendix F: Kolmogorov-Smirnov Tests

Method A (scores)

<30		30-40		41-50		51-60		61-70		>70	
		LAX	35	PHX	42.1	CLE	52.1	OAK	62.3		
		DFW	37.9	IAD	42.4	MSP	53.2	ATL	65.3		
		ORD-METRA	38.1	SJC	43.5	SEA	53.7	MDW	65.8		
		MKE	38.8	EWR	47.3	JFK - MTA	54.4	JFK - LIRR	68.8		
				BWI - MARC	47.9	SFO	54.5				
				PHL	47.9	BUR	56.1				
				FLL	48.5	STL	58.0				
				BOS	48.7	ORD - CTA	58.2				
				PVD	49.5	BWI - LRT	58.6				
				PDX	50.3	DCA	59.8				
#	0		4		10		10		4		0
%	0		0.143		0.357		0.357		0.143		0
Cum %	0		0.143		0.500		0.857		1.000		1.000

Method B (scores)

<30		30-40		41-50		51-60		61-70		>70	
LAX	29.7	ORD - METRA	31.0	BOS	44.4	BUR	51.7	DCA	61.5	JFK - LIRR	73.6
DFW	29.7	MKE	32.2	PVD	46.9	JFK - MTA	52.3	MDW	62.5		
		IAD	35.1	EWR	47.9	PDX	52.5	ATL	62.7		
		PHX	35.7	OAK	50.9	PHL	52.5	ORD - CTA	63.3		
		SJC	36.0			CLE	53.2				
		BWI - MARC	39.0			SEA	53.8				
		FLL	39.1			MSP	54.8				
						BWI - LRT	56.3				
						STL	56.9				
						SFO	57.6				
#	2		7		4		10		4		1
%	0.071		0.250		0.143		0.357		0.143		0.036
Cum %	0.071		0.321		0.464		0.821		0.964		1.000

Method C (scores)

<30		30-40		41-50		51-60		61-70		>70	
		MKE	36.7	DFW	41.8	PVD	52.6	ORD - CTA	61.2	ATL	72.6
		LAX	39.6	ORD - METRA	41.9	PDX	54.5	STL	62.5		
				IAD	47.5	JFK - MTA	55.3	MSP	62.9		
				SJC	47.7	EWR	55.9	DCA	66.7		
				BWI - MARC	49.2	FLL	57.1	OAK	67.0		
				PHX	49.4	CLE	57.5	MDW	67.1		
				PHL	50.8	BOS	57.7	JFK - LIRR	70.0		
						SEA	58.7				
						SFO	59.8				
						BUR	59.9				
						BWI - LRT	60.8				
#	0		2		7		11		7		1
%	0		0.071		0.250		0.393		0.250		0.036
Cum %	0		0.071		0.321		0.714		0.964		1.000

A vs. B	<30	30-40	41-50	51-60	61-70	>70
A	0	0.143	0.5	0.857	1	1
B	0.071	0.321	0.464	0.821	0.964	1
abs. value D	0.071	0.178	0.036	0.036	0.036	0
		max D				

theoretical D 0.363

For A vs. B, theoretical D is greater than max D, so not significant at α = .05 level

A vs. C	<30	30-40	41-50	51-60	61-70	>70
A	0	0.143	0.5	0.857	1	1
C	0	0.071	0.321	0.714	0.964	1
abs. value D	0	0.072	0.179	0.143	0.036	0
			max D			

theoretical D 0.363

For A vs. C, theoretical D is greater than max D, so not significant at α = .05 level

B vs. C	<30	30-40	41-50	51-60	61-70	>70
B	0.071	0.321	0.464	0.821	0.964	1
C	0	0.071	0.321	0.714	0.964	1
abs. value D	0.071	0.25	0.143	0.107	0	0
			max D			

theoretical D 0.363

For B vs. C, theoretical D is greater than max D, so not significant at α = .05 level