Cost-Benefit Analysis of Washington-Richmond High-Speed Rail

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Executive Summary

This study conducts a cost-benefit analysis of High Speed Rail (HSR) between Washington, D.C. and Richmond, Va. In particular, the study examines the possibility of a build scenario, in which a third track is constructed and incremental improvements to the existing infrastructure are made. The project represents the educational capstone for its participants, students in the Transportation Policy, Operations and Logistics (TPOL) masters program in the School of Public Policy at George Mason University.

Financial costs that were considered in the study include those associated with rail operations and the addition of new infrastructure in the corridor. There are many benefits that can be expected to result from faster train service between Washington D.C. and Richmond. Those that were included in the analysis include passenger benefits, societal benefits – i.e., reductions in emissions, fuel consumption and road accidents, and ancillary benefits to other users of the transportation system, such as travel time reductions for motorists in the corridor.

The time horizon for the Cost-Benefit Analysis is 2012 to 2035. A 7% discount rate is used to generate the present value of costs and benefits.

Major findings

Rail ridership between Washington, D.C. and Richmond, Va. could nearly double with the addition of high speed rail in the corridor.

Rail users will benefit significantly from high speed rail service. First, current rail passengers will benefit as the travel time between Washington’s Union Station and Richmond’s Main Street Station is reduced from greater average transit speed. Second, motorists who switch to rail will benefit from shorter commutes. The third category of user benefits includes passengers who would otherwise not have traveled between Washington D.C. and Richmond but will now do so because of improved connectivity between the cities. This is referred to as the induced demand from the investment in the rail infrastructure.

High speed rail in the corridor could prevent 10 accidents a year, resulting in an annual average of $1 million in savings. Those savings relate to health and legal costs, market productivity, travel delays, property damage, and other related costs associated with accidents.

The HSR system between Washington, D.C. and Richmond, VA is estimated to attract 4 million new passengers and remove almost 2.3 million vehicles from the I-95 corridor over the period from 2015 to 2035.

The Cost Benefit Analysis shows a net present value of benefits and costs of nearly $500 million. A negative outcome is expected given that the infrastructure costs are significantly greater during the
initial twenty year analysis point and that the full benefits of HSR (e.g., regional economic impact) are not included in the cost-benefit calculations.
1. Introduction

In January 2010, Amtrak and a group of 20 students from George Mason University’s Transportation Policy, Organization and Logistics (TPOL) master’s degree program entered into an agreement to conduct a semester-long study of a High Speed Rail (HSR) line between Washington D.C. and Richmond, Virginia. This report represents the results of that partnership.

Current passenger rail service along this route operates at a maximum speed of 70 miles per hour (mph). According to the Federal Railroad Administration (FRA), in order to qualify as HSR, a passenger train must attain a speed of at least 110 mph. Also imperative to HSR operation is the ability to sustain high speeds over the length of a trip. This is expected to be difficult on the Washington-Richmond corridor due to the lack of additional overtake rail availability and multiple stops in the current route.

Recently, there has been increased interest in establishing HSR service in the United States. President Barack Obama made HSR a transportation priority of his administration. Environmental concerns, increased demand for long distance commuting, and increased congestion fuels public interest in HSR.

There is considerable interest for HSR in the Commonwealth of Virginia. In 2009, Virginia applied for $1.8 billion in federal stimulus money for overall HSR improvements. Virginia commuters have proven to be strong supporters of rail transit with ridership rising in the first four months of 2010 reaching a record average of 17,000 riders per day.1

The current opportunity for HSR in Virginia is expected to be high, especially considering that it has received bipartisan political support. “Virginia doesn’t have the money and other resources to build more roads; the far greater solution is going to have to be rail and transit, and you might as well get used to it” said state Delegate Joe May, R-Leesburg, at a Virginia House meeting in January 2010. “It’s not a choice; it’s just the way it has to be.”2 In a recent study done by Northern Virginia Transportation Alliance on jobs, population and travel trends from 2000-2020, some interesting statistics were revealed about the region that underscore the need for HSR in the state of Virginia.3

- 13% projected increase in highway capacity
- 25% projected in population growth
- 33% projected in increase in jobs (900,000)
- 36% increase in daily trips (6.1 million)
- 43% increase in daily miles travel

This report analyzes if it is cost beneficial for a HSR line to offer passenger service between Washington D.C. and Richmond. The findings are based on issues including expected ridership, fare prices,

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environmental impact, effect on highway traffic, track condition, the possibility of acquiring additional land for more tracks, and other factors. All of these issues have been considered as part of a cost-benefit analysis to make the final assessment. The study also identifies additional areas for future analysis of HSR along the Washington-Richmond corridor that could not be included in this study due to time and scope constraints. This report represents the educational capstone for its participants and our team aims for it to prove to be a useful guide for Amtrak officials and Virginia policymakers.
2. High-Speed Rail Policy

The level of interest in HSR by members of Congress dates back at least to the mid 1960s. With the passage of the High-Speed Ground Transportation (HSGT) Act, this legislation, initially authorized at $90 million, started an effort, at the Federal level, to develop, and demonstrate where possible, contemporary and advanced HSGT technologies. Under the HSGT Act, the Office of High-Speed Ground Transportation of the FRA introduced modern HSGT to America in 1969 by deploying the self-propelled Metroliner cars and the Turbotrain into what would soon become Northeast Corridor revenue service. Simultaneously, the construction of new suburban rail stations at Metropark (Iselin), New Jersey, and Capital Beltway (Lanham), Maryland significantly improved access to this new service. The service improvements, Washington—New York—Boston, represented a private/public partnership between the freight railroad companies, the equipment suppliers, States, localities, and the FRA. The program also included a comprehensive multimodal transportation planning effort focusing on long-term needs in the Northeast Corridor “megalopolis,” as well as a pioneering research and development program in such advanced technologies as tracked air-cushion vehicles, linear electric motors, and magnetic levitation (Maglev) systems.

The Rail Passenger Service Act of 1970 led to the creation of the National Railroad Passenger Corporation (Amtrak) in 1971 as a way of ensuring continued operation of an intercity rail passenger network in the United States.

On May 1, 1971, Amtrak took over the responsibility for operating intercity rail service from the freight railroads in most of the United States. This would also include the Northeast Corridor. As the result of this take over, Amtrak initiated a number of research, planning, development, and demonstration efforts under the HSGT Act to recommend improved HSR in the Northeast Corridor as the optimal response to steadily increasing congestion and decreasing service in the other intercity modes.

While the Metroliners and Turbotrain demonstrated the potential for HSR transportation, the Boston-Washington route infrastructure was still suffering from many years of neglected maintenance. Thus, in 1975, the Congress shifted their focus to upgrading the Northeast Corridor infrastructure to improve the reliability of the service and allow for shorter trip times, particularly between New York City and Washington, D.C. Pursuant to Title VII of the Railroad Revitalization and Regulatory Reform Act of 1976, a total of $3.3 billion was appropriated for the Northeast Corridor Improvement Project (NECIP). This project was a massive engineering and construction effort which was slated to improve major sections of the main line by means of track reconstruction, new signals and control systems, elimination of many highway/railroad grade crossings, construction of maintenance-of-way bases and maintenance-of-

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6 Improved High-Speed Rail in the Northeast Corridor (U.S. Department of Transportation, 1973).
7 Amtrak’s Northeast Corridor: Information on the Status and Cost of Needed Improvements (General Accounting Office, April 13, 1995).
equipment facilities, improvements to stations, and bridge replacement and repair. These improvements would not only pave the way for high-speed intercity passenger rail, it also provided benefits to those commuter rail operators by enhancing operational efficiencies on the corridor. The success of high-speed intercity passenger rail service in the Northeast, between New York City and Washington, D.C., provided the necessary charge for the Federal government to support similar improvements and enhancements along the Northeast corridor between Boston and New York City.

Federal HSGT emphasis in the 1980's shifted to studies of potential HSGT corridors. Among those efforts was a series of reports on “Emerging Corridors,” developed in conjunction with Amtrak, which were issued in 1980 and 1981. In 1984, grants of $4 million were set aside for HSGT corridor studies on the State level under the Passenger Railroad Rebuilding Act of 1980.8

As the Federal involvement in HSR transportation planning continued during the 1980's, State involvement also increased. By 1986, at least six States had formed HSR entities, and ultimately Florida, Ohio, Texas, California, and Nevada awarded franchises to groups of private corporations to build and operate intercity HSR or Maglev systems—although none of the proposals never led to the construction of any of these systems—for a variety of reasons. Learning from such challenges, the State of New York invested heavily in making the necessary upgrades to enhance the Albany portion of the Empire Corridor to 110 mph. These improvements would come with some Federal support. Since that time, more than 15 States have passed enabling legislation that would allow the facilitation of HSR transportation activities.

One significant push by Congress, ensured the safety of new technologies being introduced for HSR travel. To that end, the Rail Safety Improvement Act of 19889 extended the statutory definition of “railroad” in the Federal Railroad Safety Act of 1920 to include “all forms of non-highway ground transportation that runs on rails or electromagnetic guideways,” including “HSR transportation systems that connect metropolitan areas, without regard to whether they use new technologies not associated with traditional railroads.”10

In 1991, the Senate passed a High-Speed Rail Transportation Act11 that encouraged research, development, design, and implementation of Maglev and other HSGT technologies in the United States and would have promoted domestic manufacturing efforts.

In addition, in 1991, the President signed into law the Intermodal Surface Transportation Efficiency Act (ISTEA). This law established a program to fund safety improvements at highway–rail grade crossings on corridors to be “designated” as high-speed intercity passenger rail corridors. However, although this program was established, the maximum funding for the program in most years was about $5 million. Of the 11 authorized high-speed corridor designations, only 10 designations have been made. Since the

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8 Ibid, 96-254
9 49 U.S.C. 20102
10 High Speed Ground Transportation in America (Federal Railroad Administration, September 1997).
11 S.811
days of ISTEA, the Federal government has taken small steps in laying the groundwork for a high-speed intercity passenger rail network—until 2009.

### 2.1 High-Speed Rail Grant Selection by Obama Administration

President Barack Obama’s vision for the future of intercity transportation, envisions development of high-speed intercity passenger rail as a complement to the Nation's highway and aviation system, moved from policy concept to program reality with the enactment of the American Recovery and Reinvestment Act (ARRA) on February 17, 2009. Title XII of ARRA provided the U.S. Department of Transportation (DOT) $8 billion and directed DOT, consistent with the statutory authorizations of grant programs made under sections 301, 302 and 501 of the Passenger Rail Investment and Improvement Act of 2008 (PRIIA), to initiate a program of high-speed intercity passenger rail capital investment.

Consistent with the provisions of ARRA, and with direction from the Secretary of Transportation, the FRA produced a high-speed rail strategic plan, “Vision for High-Speed Rail in America,” in April 2009. Based upon the President’s vision for high-speed rail in America, the initial $8 billion in investment was focused on the following areas that will deliver transportation, economic recovery and other public benefits:

- Building new HSR corridors that will fundamentally expand and improve passenger transportation in the geographic regions they serve
- Upgrading existing intercity passenger rail services
- Laying the groundwork for future high-speed passenger rail services through smaller projects and planning efforts

To that end, the administration, through the FRA, proposed to advance the development of a system of high-speed intercity passenger rail service across the nation. One corridor in particular, the Southeast Corridor, has been planned for over a decade through the coordinated efforts of the States of North Carolina, and Virginia. When these improvements are completed the corridor from Atlanta, Georgia in the south, through Charlotte, Raleigh and Richmond to Washington, D.C. in the north will be served by an integrated network of HSR for passengers that provides intercity connectivity from the Southeast Corridor though the Northeast Corridor. Moreover, the future of HSR in the United States will be contingent upon the continued support from the administration and the Congress. As it stands, the $8 billion investment in HSR corridors is just the beginning. As the program matures, discussions will continue as part of future surface reauthorizations proposals.

“Imagine whisking through towns at speeds over 100 miles an hour, walking only a few steps to public transportation, and ending up just blocks from your destination. Imagine what a great project that would be to rebuild America.”

President Barack Obama (April 16, 2009)
3. Current Conditions

3.1 Existing Study Scope

The existing southeast U.S. rail corridor extends from Miami, FL to Washington D.C. and connects with the Northeast Rail Corridor north to Boston, MA. The entire northeast and southeast corridor assessment assisted in the understanding of the functionality of the system; however, the scope of this report focuses on analyzing the future improvements and impacts of implementing HSR operations between Washington D.C. and Richmond, Virginia. This scope was established to create a manageable study corridor that was conducive to the agreed project timeline and deliverables. Figure 3-1 illustrates the base geographic region of the study corridor.

![Figure 3-1: Study Base Map](image)

Defining the study corridor for purposes of preparing model forecasts, assessing regional demographic patterns, and evaluating a cost-benefit analysis, HSR operations and the service area are explained in the following definitions of HSR and conventional rail. Identifying the general types of HSR describes; the best function and design for the study corridor.

- **HSR – Express:** Frequent, express service between major population centers 200–600 miles apart, with few intermediate stops. Top speeds of at least 150 mph on completely grade-separated, dedicated rights-of-way (with the possible exception of some shared track in terminal areas). It is intended to relieve air travel and highway capacity constraints.

- **HSR – Regional:** Relatively frequent service between major and moderate population centers 100–500 miles apart, with some intermediate stops. Top speeds of 110–150 mph, grade-separated, with
some dedicated and some shared track using positive train control technology. Intended to relieve highway and, to some extent, air travel capacity constraints.

- **Emerging HSR:** Developing corridors of 100–500 miles, with strong potential for future HSR regional and/or express service. Top speeds of up to 90–110 mph on primarily shared track eventually using positive train control technology, with advanced grade crossing protection or separation. Intended to develop the passenger rail market, and provide some relief to other modes.

- **Conventional Rail:** Traditional intercity passenger rail service of more than 100 miles with as few as one to as many as 7–12 daily frequencies; may or may not have strong potential for future HSR service. Top speeds of 79 mph to 90 mph generally on shared track. It is intended to provide travel options and to develop the passenger rail market.

The above definitions evaluate HSR design potential based on population centers and achievable speeds.

Today, the study corridor is described as a conventional and aged rail line that requires many improvements to operate HSR passenger service. As shown in the 2009 population map, Figure 3-2, the study corridor contains city population concentrations within travel distances desired for HSR. The study corridor, is best described as an emerging HSR, especially since the corridor length is approximately 100 miles and design speeds are between 90-110 mph.

![Figure 3-2: 2009 Population Map](image-url)
3.2. Existing Operating Conditions

The study corridor accommodates multiple train operators—Amtrak passenger rail service, CSX freight rail service, and Virginia Railway Express (VRE) commuter rail service. All trains travel at a maximum average speed of 70 mph. The existing operations of each service provider are characterized below.

**CSX:** CSX is a private company that provides service for multiple commodities including natural resources, general merchandise, and intermodal/auto units. CSX owns 25% of railway infrastructure in Virginia, including the track within the study corridor. According to the Virginia Department of Rail and Public Transportation (DRPT), CSX moves an annual total rail tonnage and rail through tonnage of nearly 5-15 million commodity tons within the study corridor and it operates approximately 30 trains per day.

**VRE:** VRE is a public passenger rail system that provides commuter rail service from Fredericksburg and Manassas, VA to Washington, D.C. Along the study corridor, the VRE Fredericksburg Line operates 15 daily trains, northbound during morning peak hours (5:00 AM – 9:00 AM) and southbound during evening peak hours (3:00 PM – 8:30 PM), Monday through Friday. Service is available at 12 stations with headways of 20 – 30 minutes. In FY 2008 - FY 2009 VRE ridership was 3,857,646 passengers with approximately 2,122,000 (55%) using the Fredericksburg Line.

**Amtrak:** Amtrak is privately run, federally owned, passenger rail service that provides regional and long distance service across the U.S. In FY 2008 – FY 2009 Amtrak ridership in Virginia was an estimated 1,037,663 passengers with approximately 705,600 passengers (68%) traveling within the study corridor. Amtrak currently operates 8-10 daily trains (Monday – Friday), 4-5 regional trains and 5 long haul trains in the study corridor, which include:

**Regional Trains**
- Four daily northeast regional routes between Boston, MA and Richmond, VA and Newport News, VA;

**Long-Haul Trains**
- One daily Carolinian route between New York City and Charlotte, NC;
- One daily Palmetto route between Savannah, GA and New York City;
- One daily Silver Star route between Miami/Tampa, FL and New York City;
• One daily Silver Meteor route between Miami FL and New York City;
• One daily Auto Train route between Sanford, FL and Lorton, VA.

Of the four daily northeast regional route trains, two operate within the peak morning period, one operates during the mid-day period, and one operates during the late evening. Northeast regional route trains account for approximately 50% of annual Virginia ridership, and other long haul trains account for nearly 40% of ridership within the study corridor. Other weekend service routes are available within the study corridor; however these routes are not listed or considered in the daily commuter analysis for this report.

The study rail corridor is utilized by all three service operators. CSX is the sole owner, control operator, and dispatcher of the rail line; therefore, passenger rail service must operate as a complimentary service and not conflict or negatively impact freight rail movement. Common positions taken by the freight rail industry in response to accommodating passenger rail service are:

• Freight railroads should be fully compensated for the use of their property by passenger trains;
• Absent voluntary negotiated agreements, freight railroads should not be forced to give passenger rail operators access to their property;
• Freight railroads should not be expected to subsidize passenger rail; and
• Freight railroads do not want exposure to any liability associated with passenger rail service. At a minimum, freight railroads expect some enforceable limits on liability.

One area with which operators have struggled is balancing on-time performance of all three services. Amtrak and VRE have reported drastic fluctuations in on-time performance related to internal operational problems, but also due to rail line congestion and CSX’s operation hierarchy. Passenger rail must frequently negotiate with freight rail owners to maintain acceptable performance levels as demand of both passenger and freight markets change.

Rail capacity can be measured using many variables, such as topography, load factors, dwell times, operating speeds, train length, and track curvature. For the purpose of this report, a capacity measurement method was borrowed from the 2007 National Rail Freight Infrastructure Capacity and Investment Study, prepared by Cambridge Systematics, Inc. in order to determine capacity. The method calculates a volume-to-capacity ratio for archetypical railway corridors based on the number of tracks, number of daily trains, and operational control type. The following table shows the calculation of existing rail capacity for the study corridor. The method is described in Appendix E.
Based on service timetables and DRPT reports, CSX, VRE, and Amtrak operate approximately 54 daily trains along the study corridor. The study corridor has a practical maximum capacity of 75 trains per day. The existing V/C ratio of the study corridor is calculated dividing current train capacity by maximum train capacity. For the D.C. to Richmond corridor it is 0.72 (54/75), operating at a level of service (LOS) D. This indicates that the rail corridor is moderately congested and operates near full capacity.

### 3.3 Commuting Conditions

#### Origin and Destination

The origin and destination analysis focuses on workers in three areas of residential origin – Northern Virginia/D.C., the middle region, and the Richmond area – and three mode categories by which these residents commute – all modes, single occupant vehicle (SOV), and rail. This analysis reveals potential commuters likely to convert to using HSR, should it become available.

**Northern Virginia and D.C. Region**

This area by far has the most commuters, the majority of which remain in the D.C. Metro area for work. Of the more than 1.6 million workers, 67% drive alone while those using commuter rail and Amtrak are only slightly more than a quarter percent. Commuters in this region are not likely to benefit from HSR in the study corridor because they do not travel distances long enough to warrant its usage. The number of workers commuting by SOV is substantially less than those in the Richmond and middle-regions areas, likely due to the existence of more travel options.

**Middle Region (Stafford, Spotsylvania, Fredericksburg, Caroline, and King George)**

Fredericksburg and the surrounding counties have approximately 120,000 commuters. While many of them remain in the middle region for work, numerous commute to Northern VA and D.C. Of all three regions, this area represents the greatest number of residents that commute by rail, at 1.3%, likely due to the existence of more travel options.

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12 Does not include three year pilot program funded by the Commonwealth of Virginia to operate two new Amtrak trips between Richmond and Washington, D.C. that will begin mid-July 2010.
13 Data used for current commuting conditions was obtained from the Census Transportation Planning Package (CTPP) 2000.
14 See Appendix E for maps of Northern Virginia and DC Region; Middle Region; and, Richmond Region.
to the fact that VRE is a viable option for those desiring time savings compared to commuting alone by personal auto. Current rail users would likely be a captive audience for HSR because they are already comfortable using this mode and would recognize the benefit of additional time savings. SOV data reveals that 76% of middle region residents drive alone, the majority of whom travel north, making them a primary target for HSR.

**Richmond Region (Richmond, Chesterfield, Hanover, Henrico)**

Most Richmond area residents work in the surrounding area; however, some commute to the D.C. metro area. The majority of commuters traveling further north commute alone by car, as transportation options are limited. Two Amtrak trains run northbound in the morning from this region, which is most likely being used by approximately 25 residents, or 0.01%, who indicated they travel by rail to the D.C. area. Of the 86% of SOV commuters, those traveling to the D.C. area would be potential converts to HSR.

Persons working in Metro D.C. who prefer to live further south are most likely to reside in the middle region, as opposed to the Richmond region when considering housing prices and commuting distance. Residents already living in the Richmond region would benefit from HSR because it would make areas north of Richmond more feasible in terms of employment opportunities.

**Existing Congestion**

Figure 3-4: Existing Corridor Congestion

U.S. Interstate 95 and U.S. Route 1 serve as the major thoroughfares for auto trips approximately 107 miles in distance. The majority of the I-95 corridor between Washington, D.C. and Richmond has an LOS of F, indicating heavy congestion and slow moving speeds during peak period travel. A significant stretch of the corridor operates at the slightly improved LOS of D in Caroline County, between Hanover and
Spotsylvania counties. Hanover County is the only jurisdiction with stretches of LOS C, operating at the best level of service along the corridor, although still slightly below free flow speeds. Heading north from Spotsylvania County commuters experience congestion until south of Alexandria City, where there are short stretches of LOS E and then LOS D.

Congestion is costly. The Texas Transportation Institute estimates that congestion costs area residents $2.73 billion, or the equivalent of a new Woodrow Wilson Bridge each year. A breakdown of annual costs attributed to congestion include:

- $2.73 billion congestion cost for the region
- 240 million gallons of fuel wasted
- 160 million hours wasted sitting in traffic
- $925 cost per driver
- $780 cost per person
- 76 hours of delay per driver \(^{15}\)

**Departure time**

Home departure time represents the time that workers leave their homes in the morning to travel to work. The data includes times that workers leave their homes based on 30-minute increments between 5 a.m. and 9 a.m. This information was analyzed to give Amtrak an idea of how to most efficiently schedule trains to meet the demands of commuters. When used in conjunction with the origin-destination and travel time data, it becomes apparent that departure time depends on where a commuter is traveling for work and the length of time it takes to get there.

The majority of commuters in Northern Virginia and D.C. leave their homes between 7:00 and 8:29 a.m. In Manassas, Prince William, and Stafford counties; however, there is a greater number of commuters that depart between 6:00 and 6:29 a.m. Considering these commuters live further from large employment centers, such as D.C. and Fairfax County, it is not surprising that they may be commuting longer distances and using various modes of travel which require more time.

The Richmond region demonstrates a similar pattern of commuters departing between 7:00 and 8:29 a.m. Compared to neighboring counties, Chesterfield County shows a greater number of workers leaving home before 7:29 a.m., which similar to outlying jurisdictions in Northern Virginia, could be due to distance traveling and/or the use of multiple modes to get to work.

In all counties and the District there is a significant decrease in the number of commuters departing during the 8:30 – 8:59 a.m. period, indicating the probability that most workers begin working before 9:00 a.m.

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\(^{15}\) *Transportation Need for the Future of the National Capital Region* (The Greater Washington Board of Trade).
Travel Time

The District of Columbia and counties along the study corridor display a greater number of workers commuting 45 minutes or longer than jurisdictions located further from the corridor.

Jurisdictions with the highest number of commuters traveling 45 minutes or longer are primarily in Northern VA, including D.C., and south to Spotsylvania County, capturing 6,036-121,835 workers. From greatest to least, these jurisdictions in the service area include Fairfax and Prince William counties, the District of Columbia, Loudoun, Stafford, and Arlington counties, Alexandria City, Spotsylvania, Chesterfield, Fauquier, and Henrico counties, and Richmond City.

The middle category of jurisdictions captures from 1,566-6,035 commuters traveling 45 minutes or longer to work. Other than five of the jurisdictions located more closely to the study corridor, they mostly extend further west and east of the corridor. Jurisdictions in this range include, from greatest to least, Manassas, Culpeper, Hanover, Louisa, Powhatan, Caroline, and Orange counties, Fairfax City, Westmoreland County, Manassas Park City, and Goochland, King George, Prince George, and Fredericksburg counties.

The least number of commuters traveling 45 minutes or more reside mainly in jurisdictions that are located furthest east and south of the corridor study area, with the exception of the City of Falls Church in Northern Virginia.

While the aforementioned analysis includes commuters using all modes, a closer look at travel time by individual mode reveals that commuters driving alone for 45 minutes or greater follows a similar pattern to that of all modes. Rail commuters however, demonstrate a major shift in pattern. Jurisdictions south of Spotsylvania County reflect a negligible number of commuters traveling by rail for 45 minutes or longer. In jurisdictions north of Spotsylvania a much greater number of commuters are using rail and traveling for 45 minutes or longer.

Travel Cost

The existing rail market demand within the study corridor is represented by evaluating the cost difference of operating an automobile compared to riding Amtrak. Figure 3-5 shows the counties within the service area where the cost to ride Amtrak is at least 1% less than driving. For example, commuters traveling from Henrico County, VA to Washington, D.C. have a potential cost savings of 10% - 19% when riding Amtrak instead of driving. The gray regions of the map identify the counties where commuters are not likely to save money by riding Amtrak. Figure 3-6 shows the counties where the cost to ride Amtrak is at least 1% less than driving to Richmond, VA.

The average automobile commute calculated for the cost maps is $0.45 per mile, which includes the costs of gasoline, wear and tear per 15,000 annual miles traveled, average insurance, and purchase/loan payment. The cost of using Amtrak rail was calculated based on the average ticket price for traveled distance. Cost effective regions within the service area could expand with the implementation of HSR operations, particularly along the corridor.
Understanding current travel behavior and commuting patterns is essential for identifying potential customers for the HSR line between Richmond and Washington D.C.

According to the data, the greatest potential for Amtrak to attract customers to the HSR service lies in the ability to attract SOV commuters residing in the Fredericksburg and Richmond areas who travel to Northern VA and D.C. Considering congestion on I-95, travel times of 45 minutes and greater, and the early times at which commuters leave their homes, these travelers are likely looking for options. Commuters have various reasons for choosing their travel mode. Amtrak high-speed trains, offered affordably and at times convenient for commuters, would provide a reduction in overall commute time and relief from traffic congestion.
3.4 Environmental Conditions

The National Emissions Inventory (NEI) is developed every three years by EPA. The NEI is a national emissions inventory that includes both stationary and mobile sources that emit hazardous air pollutants (HAPs). Section 112(b) of the Clean Air Act identifies 188 pollutants as HAPs, which are generally defined as pollutants that are known or suspected to cause serious health problems. The NEI contains emission estimates for major sources, nonpoint sources, mobile sources, and other sources which do not fall into these categories.

Onroad mobile sources include "licensed motor vehicles, including automobiles, trucks, buses, and motorcycles."

Figure 3-7: On Road Emissions

The orange and red shading on the onroad emissions map indicates levels that are higher than 691,028 pounds of emissions per year. Counties and cities in the corridor service area that fall into the high emissions category, ranging from highest to lowest are Fairfax, Loudoun, and Prince William counties, Washington D.C., and Chesterfield, Hanover, and Henrico counties.

The middle categories are defined as counties and cities that have moderate levels of onroad emissions, ranging from 127,104 to 691,027. Jurisdictions located in the service area and included in this range from highest to lowest are Richmond City, Arlington and Stafford counties, Alexandria City, Spotsylvania, Fauquier, Westmoreland, Louisa, New Kent counties, Charles City, Essex, Goochland, Culpeper, and King and Queen counties, and Fairfax City.

The jurisdictions showing the lowest amount of onroad emissions located in the corridor study area are Caroline, King William, Powhatan, and King George counties, Falls Church, Manassas, Manassas Park, Fredericksburg, and Colonial Heights cities. These areas have onroad emissions that fall into the range of zero to 127,103 pounds per year.

Looking more closely at the data, onroad emissions as a percent of total emissions tells a different story. While Charles City falls into the moderate category for total onroad emissions, onroad emissions makes up 58% of the county’s total emissions. The counties of Middlesex, Westmoreland, Kind and Queen, and Loudoun range from 45% - 48% onroad emissions as a percent of the total. For jurisdictions that show more than half or nearly half of their onroad emissions as making up total emissions, this could indicate they simply have less nonpoint emissions sources and should not be used as a gauge in obtaining emissions reductions until it is fully understood.
3.5 Future Considerations

For purposes of this report, a third track is assumed to be completed within the study corridor, which would allow for a future practical maximum capacity of 133 trains per day. Increased operations of train operators is unknown, therefore it is assumed that train operation within the future study corridor could increase to approximately 79 trains per day to maintain an operating LOS of D or better.
4. What is a Cost-Benefit Analysis?

A cost-benefit analysis is a term that typically refers to:

- Helping to appraise, or assess, the case for a project or proposal; and
- An informal approach to making economic decisions of any kind.\(^\text{16}\)

In a transportation context, a cost-benefit analysis attempts to measure the dollar value of the benefits and the costs to all the members of society where “society” is all residents of the United States on a net present value basis. The benefits represent a dollar measure to the extent the lives of people are made better by a project. The benefits represent the amount that all the people in society would jointly be willing to pay to carry out the project, and feel as if they had generated enough benefits to justify the project’s costs, accounting for the relative timing of those benefits and costs. In some cases, benefits may be difficult to measure monetarily. Therefore, when preparing a cost-benefit analysis, it is helpful to describe the nature of each major benefit. Benefits should be quantifiable (e.g., in number of users making use of a transportation facility). Lastly, benefits should be measured in dollar terms, or monetized. This allows the benefits to be directly compared to the monetary costs of the project.

Benefits and costs must be estimated for each year of the project after work has begun. These annual benefits and costs must be discounted to the present using an appropriate discount rate so that a present value of the benefits and a present value of the costs is appropriately calculated and compared.

The following provides a simplified example of discounted costs and benefits from a road project that provides travel time savings to local travelers over the course of five years following a one-year period of construction.

### Table 4-1: Cost Benefit Sample

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<thead>
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</tr>
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</tr>
</tbody>
</table>

NPV

- 1. Number of drivers times three minutes a day (3/60 hours) over 260 workdays
- 2. Hours at $13.70 per hour ($2008)
- 3. Includes costs from delays to users during construction

Additional information on cost-benefit analysis preparation can be found in the Office of Management and Budget (OMB) Circulars A-4 and A-94 in preparing their analysis ([http://www.whitehouse.gov/omb/circulars](http://www.whitehouse.gov/omb/circulars)). Circular A-4 also cites textbooks on cost-benefit analysis (e.g., Mishan and Quah).17

#### 4.1 Cost Benefit Analysis vs. Economic Impact Analysis

It is important to recognize that a cost-benefit analysis is not an economic impact analysis. As previously stated, a cost-benefit analysis attempts to measure the dollar value of the benefits and the costs to all the members of society.

Conversely, an economic impact analysis focuses on local benefits rather than national benefits. Some of the benefits that are counted in an economic impact analysis, such as diversion of economic activity from one region of the country to another, represent benefits to one part of the country but costs to another part, so they are not benefits from the standpoint of the nation as a whole.

Moreover, economic impact analyses estimate impacts rather than benefits, and the impacts are normally much larger than the benefits. For example, the total payroll of workers on a project is usually considered one of the impacts in an economic impact analysis. The total payroll is not a measure of the benefits of the project for two reasons. First, a payroll is a cost to whoever pays the employees, at the same time that it is a benefit to the employees, so it is not a net benefit. Second, even for the employees, the employees have to work for their wages, so the amount they are paid is not a net benefit to them — it is a benefit only to the extent that they value their wages more than the cost to them of having to be at work every day.

Economic impact analyses also consider real estate investments to be one of the economic impacts of a project. The full value of such an investment is not a benefit, however, because the benefit of the investments to the community in which they are made is balanced by the cost of the investment to the community.

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investor. Because these investments are a cost as well as a benefit, they are not a net benefit as in a cost-benefit analysis.

There is often an element of benefit in these impacts. A worker who gets a higher paying job as a result of a transportation investment project benefits if he or she works just as hard as he or she did at his or her previous job but is paid more. Such projects produce benefits by increasing the productivity of labor. A transportation investment project that increases the value and productivity of land and thus induces real estate investment can also provide a benefit, but the benefit must be measured net of the cost of making the real estate investment. Measuring these labor productivity effects requires a careful analysis of the local labor market and how that market is changed by the transportation investment. Similarly, measuring the effects of transportation projects on the productivity of land requires careful netting out of increases in land values that are compensated by costs of real estate investment and increases in land values that in effect capitalize other types of benefits that have already been counted, such as time savings.

The benefits that should be reported for transportation projects include:

- Improved condition of existing transportation facilities and systems;
- Long-term growth in employment, production, or other high-value economic activity;
- Improved energy efficiency, reduced dependence on oil and reduced greenhouse gas emissions;
- Reduced adverse impacts of transportation on the natural environment;
- Reduced number, rate and consequences of surface transportation-related crashes, injuries and fatalities;
- Any other benefits claimed in the project’s cost-benefit analysis.

### 4.2 Affected Population

Because these improvements are associated with improvements along a passenger rail line, the cost-benefit analysis should clearly identify the population that the project will affect and measure the number of passengers affected by the project. Although the improvements being considered are directly related to passenger rail movements, the rail line being impacted has both passenger and freight movements that need to be addressed as part of the analysis. If possible, passenger and freight traffic should be measured in passenger-miles and freight ton-miles (and possibly value of freight).

### 4.3 Discounting

When preparing the cost-benefit analysis, the analysis should discount future benefits and costs to present values using a real discount rate of seven percent, following guidance provided by the Office of Management and Budget (OMB) in Circulars A–4 and A–94.\(^\text{18,19}\)

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In addition to the 7 percent discount rate, a 3 percent discount rate may be considered as part of the alternative analysis. A 3 percent discount rate should be used when alternative funds that are dedicated to the project would be other public expenditures and not private investment.

The first step, the analysis should present the year-by-year stream of benefits and costs from the project. The analysis should clearly identify when the expected costs and benefits will occur. The beginning point for the year-by-year stream of benefits should be the first year in which the project will start generating costs or benefits. The ending point should be far enough in the future to encompass all of the significant costs and benefits resulting from the project but not to exceed the usable life of the asset without capital improvement.\(^{20}\) In presenting these year-by-year streams, the analysis should measure them in constant or real dollars prior to discounting. The analysis should not add in the effects of inflation to the estimates of future benefits and costs prior to discounting. Once a yearly stream of costs and benefits in constant dollars are generated, the analysis should discount these estimates to arrive at a present value of costs and benefits. The standard formula for the discount factor in any given year is \(1/(1 + r)^t\), where “\(r\)” is the discount rate and “\(t\)” measures the number of years in the future that the costs or benefits will occur. Infrequently, benefits or costs will be the same in constant dollars for all years. In these limited cases, the analysis can calculate the formula for the present value of an ordinary annuity instead of showing a year-by-year calculation.\(^{21}\)

### 4.4 Baselines and Alternatives

The baseline should be an assessment of the way the world would look if the proposed improvements were not implemented. Usually, it is reasonable to forecast that that baseline would resemble the present state. However, it is important to factor in any projected changes (e.g., economic growth, increased traffic volumes, or completion of already planned and funded projects) that would occur even if the proposed project were not carried forward. The benefits and costs in this case should thus be

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\(^{20}\) In some cases the analysis may use a fixed number of years to analyze benefits and costs (e.g., 20 years), even if the project will last longer than that and continue to have benefits and costs in later years. In these cases, the project will retain a “residual value” at the end of the analysis period. For instance, a new bridge may be expected to have a 100-year life, but the analysis period for the cost-benefit analysis might cover only 40 years. In such cases, a residual value can be claimed as a benefit (or cost offset) for the asset at the end of the analysis period. One method to estimate the residual value is to calculate the percentage of the project that will not be depreciated or used up at the end of the analysis period and to multiply this percentage by the original cost of the project. Different components of the project may have different depreciation rates — land typically does not depreciate. The estimated residual value is assigned to the end of the analysis period and should then be discounted to its present value as would any other cost or benefit occurring at that time. Note that a residual value of a project can only be claimed if the project will be kept in operation beyond the end of the analysis period. If the project will be retired at that time, a salvage value (reflecting revenues raised from the decommissioning of the project) can be claimed.

\(^{21}\) See “The Present Value and Future Value of an Annuity Formula,” Bright Hub, http://www.brighthub.com/money/personal-finance/articles/17948.aspx For example, 10.594 is the discount factor that would be multiplied by an annual benefit to get the present value of a constant benefit stream over 20 years at a discount rate of seven percent. If the constant annual benefit is $500,000, then the present value of the benefits is $5.297 million. In these limited cases, the analysis must show the calculation of the discount factor of the ordinary annuity formula.
limited to the marginal benefits (and marginal costs) of having the project completed in a shorter period of time and including the cost of expending resources on the project sooner than otherwise planned.

In preparing a cost-benefit analysis, all costs and benefits of the project should be evaluated, including benefits and costs that fall outside of the immediate area where the project lies. Assuming a baseline scenario in which the owner of the facility performs no maintenance and ignores traffic problems is not realistic and will lead to the overstatement of project benefits.
5. Project Costs

According to Rohit Aggarwala, a member of the New York State Assembly High-Speed Rail Task Force, historically major investments in surface transportation infrastructure have originated from dedicated state funding mechanisms as key drivers. The federal government has historically taken a “wait-and-see” approach to allow states the freedom to develop their own initiatives. Following this, the federal government usually steps in to help organize the various state initiatives into a national network by standardizing successful processes identified by the initial work conducted by the states.

In the current case of HSR development, the federal approach has been augmented by the availability of ARRA funding to allow states with particularly strong rail initiatives a chance to obtain federal support. These projects must meet federal standards, which typically lead to a decrease in the build-time. Currently, there are no dedicated sources of federal funding for HSR. As such, the onus remains on states to fully develop the scopes of their rail investment projects for HSR infrastructure and to establish dedicated sources of funding to ensure their viability.

In “The States, New Modes, and Federal Transportation Policy: Lessons from History for High-Speed Rail,” Dr. Aggarwala suggests that in the first decade of the 21st century we will have entered a period where federal funding has been denied, and states will independently pursue a pattern of development with increasing public support for the successes of these independent projects. Historical development patterns follow the following five steps:

- Failed private attempts;
- Mollification of failed federal bid for dedicated funding with a single unrepeated investment;
- Independent state action;
- Imitation by other states; and
- Adoption of a dedicated federal funding mechanism and national transportation policy.

In the Commonwealth of Virginia two sources of dedicated funding exist, which total $37.5 million annually. The current HSR project designated in the 2009 State Resource Allocation Plan to receive the majority of support from these sources is the D.C. to Richmond Third Track Project. This project entails the construction of approximately 93 miles of track, bridges, stations, signals and curve realignments to

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accommodate maximum speeds of 90 mph, which is 20 mph over the current maximum operating speed.

Virginia is now entering into step three of the HSR Third Track project after having been awarded some federal support. Funding for the $1.4 billion dollar project has been limited to less than 1% of these costs. As such this report assumes that federal funding will play a limited role as part of a public-private consortium dedicated to completing this HSR project. The limited federal support will also lead to an extended build-out period of 17 years which is beyond the seven-year period estimated in Phase I of the 2009 DPRT Statewide Technical Report with full federal support. The following estimates for build-out times, construction costs, and debt service fees thus utilize this historic development pattern in transportation networks and assume limited federal support for the period to follow.

5.1 Background

The estimate of costs must pertain to the same project as the estimate of benefits. The analysis of costs should be equally as rigorous as the analysis of benefits. The lack of a useful analysis of expected project costs may be a basis for questioning the accuracy of the overall analysis. Additional information that should be included is operating, maintenance, and other life-cycle costs of the project, along with capital costs. In addition to construction costs, other direct costs may include design and land acquisition. External costs, such as noise, increased congestion, and environmental pollutants resulting from the use of the facility or related changes in usage on other facilities in the same network, should be considered as costs in the analysis. Additionally, it is appropriate to include costs to users during construction, such as delays and increased vehicle operating costs. The analysis should discount annual costs to arrive at a present value of the project’s cost.

5.2 Infrastructure Cost

For rail infrastructure construction, unit cost categories were used based on the Virginia DRPT 2006 3rd Track Feasibility Study. Unit costs consider many items within a unit price. An example would be the category-track work which includes ballast, ties, fasteners, other track materials, rail material, labor, and equipment needed to complete the work.\(^\text{26}\) Costs include the following categories:

- Track work
- Special track work
- Bridges
- Drainage
- Grade crossings
- Utility relocation (underground piping)
- Communications and signaling
- Right-of-way
- Stations and Buildings

Cost Benefit Analysis of Washington-Richmond High-Speed Rail

- Earthwork
- Environmental and Permitting
- Engineering services
- Construction contingency
- Annual debt service

Due to the release of the 2nd TIER II Environmental Impact Statement (EIS) report in late spring of 2010 and pending priority schedules and engineering reports, several cost components have been relegated to be captured by a construction contingency equal to 30% of the construction costs. These costs have been indexed with the 2012 dollar values and 7.5% annual debt service cost should the current costs need to be adjusted. If it turns out that these additional costs do not materialize, the 30% contingency fee may be reduced based on the current construction timeline as needed.

This report nears the two-year period when the preliminary engineering report for a total-build scenario would need to be undertaken and completed to prioritize the build schedule based on available funding. Since there has been a green light for construction of the Ark-Powell project in 2010, this would shave off 11.4 miles of the 93 mile project and the project could be considered already underway, but to be safe, total project build time starting as of 2012 with 2012 dollar values is assumed to accommodate the estimated reporting time line to complete the preliminary engineering report.

The total estimated cost of construction to complete the third track line between D.C. and Richmond comes to $1.63 billion dollars in 2012 dollar values, which accounts for the contingency construction fee and annual debt service costs over a 17-year period.

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5.3 Operating Costs

The operating costs for HSR systems, according to *The Full Cost of High-speed Rail: an Engineering Approach* by Levinson, et al, can be categorized as follows:

- Sales and administration costs - labor and automated machinery costs for providing tickets and information;
- Shunting cost;
- Train operations costs - labor costs required to service, drive and operate the trains;
- Fuel or energy costs;
- Maintenance of way; and
- Maintenance of equipment.

These are costs that Amtrak would incur to provide additional service as a part of this project.

Considering the proposed technology of the SEHSR system, the most useful method to calculate increased operating and/or maintenance costs was to use the aggregated operating costs that Amtrak releases in their annual and monthly reports. Although possible to use the methods used in previous

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29 The Travel Demand Model used to determine these operating cost figures will be described in a following chapter
30 Ibid., 203.
studies, using Amtrak’s numbers would be the most accurate. The proposed locomotives for the system are modern diesel locomotives that can operate at the intended 110 mph Maximum Authorized Speed (MAS). These locomotives would not have substantially different operating costs than those currently in the Amtrak fleet. Given the similarities between current Amtrak operations and the proposed new trips, this is the most accurate estimate of operating costs for the new service.

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<th>Unit</th>
<th>Unit Cost</th>
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<tr>
<td>Train Mile</td>
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</tr>
<tr>
<td>Passenger Mile</td>
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Table 5-1: Units and Unit Costs for Amtrak Operating Costs

The operating costs can be calculated using both passenger miles traveled and train miles traveled as shown in Table 5-1. The cost per seat mile is equivalent to the cost per train mile because, for the purposes of this study, each train has a constant number of seats. Other studies assume each train has 350 passenger seats. Based on the above figures for seat mile and train mile costs, the average Amtrak train has 295 seats. This corridor is expected to have a higher volume than average, making 350 passenger seats per train a reasonable estimate. To calculate the costs based on passenger mile, the results from the ridership model were used. The difference in ridership from the build and no-build scenarios was multiplied by the miles of travel and by the operating cost per passenger mile. In order to calculate the increased operating costs based on train mile, it was assumed that new trains would be added according to the phases proposed in the DRPT technical report. The exact years the trains would start running was not indicated in the report, but based on the estimated build timeline it was assumed that there would be one additional daily train (round trip) in 2014 as part of a pilot project. It was assumed that this train would continue running until the end of the analysis period. Four additional daily trains (round trip) are anticipated to begin in 2026 just before the proposed build-out completion date. Both of the calculations use a discount rate of 7% which is applied to the cost to account for the increased costs of service. The results of both calculations can be seen below in Table 5-2. The complete table of calculations can be found in Appendix C.

31 Amtrak, “January 2010 Report.”
32 Ibid.
35 Virginia Department of Rail and Public Transportation, “Virginia Department of Rail and Public Transit, Statewide Rail Plan Technical Update,” 11-6
Cost Benefit Analysis of Washington-Richmond High-Speed Rail

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Table 5-2: Increased Operating Costs by Passenger Mile and Train Mile

Fare revenues and expected subsidy were calculated using the additional operating costs based on train miles and fares as projected in the ridership model. Figures 5-2 and 5-3 below, show the comparison for train miles and passenger miles, respectively. The initial subsidy per passenger is estimated to be $218. It should be noted that this subsidy estimate does not include the cost of rolling stock, which would likely be provided by Amtrak. Due to the constraints of this study’s scope, this analysis takes into account only trips between Washington and Richmond. Once the corridor is connected to other HSR corridors it is likely that the ridership and passenger miles traveled will increase. The per-passenger mile operating cost and required subsidy would decrease as the ridership in the corridor increases. It is likely that operating costs would be less if the full ridership, including through traffic, was included in the analysis. Because this additional traffic is not included in the analysis, it might be more useful to calculate the subsidy based on passenger mile. This analysis assumes the system-wide average $0.554 per passenger mile operating cost. If the full ridership data information becomes available it would be beneficial for future studies to address this issue and adjust the passenger mile operating cost rate according to overall ridership.

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36 See Appendix C for the full table of results of this analysis.
Figure 5-2: Increased Operating Costs and Fare Revenue (Based on Train Miles)

Figure 5-3: Increased Operating Costs and Fare Revenue (Based on Passenger Miles)
Key Assumptions

1. No federal or state funding delays for the Ark-Powell project or from REF
2. There will not be any additional Maintenance of Way costs compared with the existing conditions because the improvements will be primarily on existing right of way.
3. Diesel locomotives of comparable efficiency to those currently in operation by Amtrak will be used.
4. There will be one additional daily round trip between Washington and Richmond starting in 2014 and then four additional round trips starting in 2026.

5.4 Rolling Stock

The current agreement CSX has with both VRE and Amtrak limits additional passenger trains on the corridor until phase I is complete (third track infrastructure). Phase I is estimated to be completed by 2026. There is a pilot project that will be authorized under a CSX/DRPT agreement for one additional passenger train between D.C. and Richmond when phase one is initiated. This additional train is expected to be operating by 2014. The costs incorporated into the analysis accounts for a $30 million dollar train in 2012, as authorized by the first train contract, with the four additional authorized trains operating by 2024. The timeline with CSX does not provide for added trains until projects are completed. If construction takes less time than anticipated, it is likely that additional trains could be operating before 2026.

The cost of one new train will be estimated for each additional daily round trip provided. The complete description can be found in the section on operating costs. Based on the phases proposed in the DRPT technical report one train will be provided in 2014 and four trains will be provided in 2026. It is assumed that there is a minimum of two years lead time before the trainset can be manufactured and delivered after the order is placed. Based on a feasibility report of proposed Amtrak service, each trainset has two locomotives for push-pull operation and five passenger cars. The costs are approximately $30,000,000 per trainset in 2012 dollars, as estimated from Table 5-3. Based on these numbers and the years that trains are expected to be added, $30 million is required for one train in 2012 and $270.3 million is required in 2024. These costs include the discount rate.

38 The Virginia Department of Rail and Public Transportation (DRPT) recently partnered with Amtrak to form Amtrak Virginia, which offers new service from Lynchburg to the Northeast Corridor. In summer 2010, Amtrak Virginia will implement additional service between Richmond and the Northeast Corridor. Amtrak Virginia, the first partnership of its kind in Virginia, is funded through a three-year demonstration grant that supports both the capital and operating costs of the new service. While the state has not directly purchased new rolling stock for the service, the capital funds that it provides do support the procurement of new equipment regardless of whether the equipment is used on Amtrak Virginia routes or other Amtrak routes. This equipment is necessary to enable service expansion of the existing Amtrak fleet.
Table 5-3: Estimated Cost per Trainset

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<tbody>
<tr>
<td>Locomotives</td>
<td>2</td>
<td>$5 million</td>
<td>$10 million</td>
</tr>
<tr>
<td>Coach</td>
<td>5</td>
<td>$4 million</td>
<td>$20 million</td>
</tr>
</tbody>
</table>

Key Assumptions

1. No EIS-related delays;
2. No further preliminary engineering delays;
3. No federal or state funding delays for the Ark-Powell project or from REF appropriations;
4. Build time is even and phased projects are not delayed; and
5. Legal agreements for utility relocation and CSX cost-sharing developments will not delay construction.

5.5 Additional Items of Note

Right of Way Improvements

In addition to third track development costs, costs associated with necessary infrastructure improvements to support HSR, which includes eradicating curvature, were also calculated. The cost is expected to be $58 million when averaged out over 93 miles of track.40

Financial Debt Service Costs and Considerations

Because of the support of Virginia’s REF, the Ark-Powell project will not incur debt service costs based on the availability of federal funding within one year of the start of the project.41 If there is any delay in federal funding beyond this first year, debt service costs will be incurred. This report moves in another direction from current federal funding prospects and assumes that the Commonwealth of Virginia will receive limited federal support. Because major federal support is not expected, it is assumed that the majority of funds (up to 70%) will originate from the commonwealth to back a bond for construction of rail infrastructure for a total build cost scenario with construction slated to begin in 2012. It assumes that financial debt service fees will be incurred for the majority of the construction costs and that these debt service fees will be supported with Virginia’s rail investment funding sources, which include:

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40 Virginia Department of Rail and Public Transportation, “Virginia Department of Rail and Public Transit, Statewide Rail Plan Technical Update,” 11-4
41 Virginia Department of Rail and Public Transportation, “Arkendale to Powell’s Creek Third Track Project: Financial Plan.,” 10
• The Rail Enhancement Fund - $25 million in annual funding;
• Capital Project Bonds (CPB) - $113 million in capital project bond proceeds; and
• 2007 Acts of the Assembly General Fund Appropriations - $65 million for specific I-95 corridor projects.\(^{42}\)

In Florida, during the initial attempt in the 1990s to build HSR between Tampa and Miami, $70 million were appropriated annually for a similar rail investment fund, which was set up to support an infrastructure bond equal to $2.146 billion dollars.\(^{43}\) It is assumed that, in a similar fashion, Virginia could use the dedicated annual $12.9 million in CPB funds, and $25 million annual REF to float a construction bond equal to $1.2 billion dollars, which is enough to cover the 70% match\(^{44}\). In California, debt service costs followed the market interest rates for major infrastructure projects of 7.5% annually to service a bond that covers a total build scenario for HSR infrastructure improvements for the entire Los Angeles-San Francisco corridor.\(^{45}\) Both of these figures were used to estimate total construction cost debt incurred and debt service costs on a yearly basis for the length of the D.C.-Richmond project assuming limited federal support. These costs were separated out from the mandatory 30% contribution of public and private partners (VRE, Amtrak, CSX, the federal government, and local jurisdictions), which is required by the Commonwealth of Virginia to qualify for use of its REF and CPB funds. No further analysis was conducted to estimate the likely breakdown of contributions on the part of individual agencies within this consortium; however, it was included in a lump sum in a separate column in the infrastructure costs table.

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\(^{42}\) Virginia Department of Rail and Public Transportation, “Virginia Department of Rail and Public Transit, Statewide Rail Plan Technical Update,” 8-4 - 8-8

\(^{43}\) Anthony Pearl, *New Departures: Rethinking Rail Passenger Policy in the Twenty-First Century* (Lexington, KY: The University Press of Kentucky, 2002), 71

\(^{44}\) Virginia Department of Rail and Public Transportation, “Virginia Department of Rail and Public Transit, Statewide Rail Plan Technical Update,” 8-1 - 8-4

6. Travel Demand Model

6.1 Forecasting Background

Cost-benefit analyses of transportation projects almost always depend on forecasts of projected levels of usage. When using forecasts to generate benefit estimates, it is important to assess their reliability. In order to assure the reliability of the forecasts used in this analysis, a careful review of outside forecasts was completed. When using previously prepared forecasts, it is important to match forecasts of affected population to the appropriate time period. For example, using projected traffic levels for 2030 to generate benefits for all the earlier years is incorrect. For more information on forecasting, refer to the forecasting section of FHWA’s Economic Analysis Primer\(^\text{46}\).

6.2 Ridership Forecasts

Passenger ridership is one of the most critical components used in calculating the costs and benefits of a major public transportation project. Before additional analysis could be conducted, it was necessary to calculate estimated passenger rail ridership between Washington, D.C. and Richmond, VA for each year of the analysis period, 2015-2035. The gravity model was used in this study to estimate ridership because it is one of the most widely used and most commonly accepted forms of a travel demand model. The gravity model is based on Isaac Newton’s Law of Gravitation where the size and population of a location may be appealing (gravitate) to other locations due to size, proximity, and other factors\(^\text{47}\). Several iterations of the model were run using different variables. Ultimately, a model based on population, trip fare, and travel time by train provided the most accurate results when fully calibrated. The passenger ridership results of the travel demand model for the analysis period can be seen in Figure 6-1 below. For complete results, including I-95 corridor average vehicle miles traveled (AVMT) estimates for the build and no-build scenarios, see Appendix B.

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The model shows a ridership increase in the build scenario of 189% compared to the no-build scenario for the forecasted years of 2015, 2025 and 2035, assuming a 8% increase to 2035 (Table 4). The no-build scenario would take an additional 25 years before reaching the forecasted levels of the 2015 build ridership forecast.

The difference in ridership between the build and no-build scenarios is used in the analysis to calculate some of the costs and benefits of the project. The projected ridership will also be used to calculate the build scenario AVMT on the I-95 corridor. These two measures form the basis for the majority of the estimates for costs and benefits including the operating costs, external costs, external benefits and travel time benefits. For the complete process used to set up the model and calculate projected ridership and AVMT, see Appendix B.

### 6.3 Data Sources and Methodology

Various techniques and models have been developed to predict the levels of use (i.e., ridership). One simple method uses past trends and applies them to the future. Other methods predict yearly ridership solely on one variable, such as the population. The gravity model incorporates observation-based variables and interactions between them to predict future interactions. The use of this model anticipates ridership in the build scenario between city pairs randomly selected in the HSR Northeast Corridor. The gravity model, compounded by other methods of analysis, provides a more comprehensive predictive model that result in a higher confidence of ridership forecasts. The results from this model provide key elements of knowledge, such as amount and type of demand, about resource requirements for future management planning and are a critical factor in the decision-making and design process.
To obtain ridership forecasts for the build and no-build scenarios, population, trip fare, and travel time by train were used in the model. Although rail stations are often associated with economic development and population growth in the regions they are located, it is assumed that population remains the same in both scenarios because an analysis of increasing rates is beyond the scope of this study. To predict future population, U.S. Census data was analyzed using the trend line tool in Microsoft Excel. Average trip fare was estimated to be $0.35 per mile based on the “Bay Area/California High-Speed Rail Ridership and Revenue Forecasting Study Interregional Model System Development” report prepared by Cambridge Systematics, Inc.; it was assumed that the trip fare will increase 7% annually. Travel time in the no-build scenario is equal to current conditions. In the build scenario, it is assumed that travel time equals the distance between Washington, D.C and Richmond divided by the average operation speed of HSR in the corridor.

As depicted in the correlation chart, travel time by auto and travel time by train are highly correlated\(^{48}\). From the chart, it is clear that the number of transit lines available in a particular city has a strong relationship with the population of that city. Since demographic features are considered a critical feature of the gravity model, population was kept as an independent variable and transit lines left out.

**City Selection**

Based on the scope the study, only the cities where Amtrak stations are located were used. Thirty cities were randomly selected from the Amtrak website on the northeast and southeast corridors.\(^{49}\) This also included the cities specific to the scope of the study.\(^{50}\) Several models were attempted. The ridership model with the best fit includes the variables fare, rail travel time, and population. This is the last model in Appendix B.

In the model selected, population is used instead of population density due to difficulties in interpreting density. Specifically, high density is not necessarily equated with large population. For example, a city with one million people and 100 square miles has the same density as a city with two million people and 200 square miles. The scope of rail service area in the two cities may be different.

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\(^{48}\) See Appendix B, table B-4

\(^{49}\) See Appendix B

\(^{50}\) See Appendix B
7. Benefits

The Washington-Richmond corridor will continue to be a major economic force in the nation, it is expected that the population growth in the region will increase significantly and by 2030, 2 million new jobs will be created.\textsuperscript{5152} To accommodate this increase in population and employment, the region needs transportation solutions beyond the Interstate 95 highway. Rail transportation is becoming an increasingly popular mode of transit in the United States. In its January 2010 report, Amtrak indicated that there had been a 9% increase in ridership as compared to one year ago. Amtrak expects ridership to increase if travel time is reduced. Evidently, this is a positive sign that shows the importance of rail as an important mode of transportation.

A recent feasibility study conducted by the North Carolina Department of Transportation (NCDOT) on the proposed SEHSR corridor concluded that there are a number of benefits associated with the installation of HSR. Benefits included the propensity to decrease travel time in conjunction to having reliable service and convenience operation. These could be user benefits; the report also cited some non-user benefits such as, environmental, highway operation and management savings. It also pointed out that there are travel time benefits for passengers of other modes as well.

This section will show the benefits of a HSR network in the specific context of the Washington-Richmond corridor. Passengers will gain more transportation options and should expect shorter commute times as well as less congestion on the highways. By emphasizing rail transportation over automobile usage, the region will experience a reduction of 213 million pounds of CO2 emitted into the atmosphere, and will save an estimated $679,741.90 during the system’s first twenty years. During the same period, the I-95 highway will experience an estimated reduction of 227 automobile collisions involving serious injuries. As a result, the region will save an estimated $24.1 million due to decreased hospital and highway cleanup costs. A HSR system will also further connect and unify the region encouraging economic development and increasing the region’s economic competitiveness on a global level.

The Washington D.C. – Richmond region is a thriving region. To fully take advantage of the population and job growth, significant transportation improvements are necessary. This section will detail the passenger, safety, environmental, and economic benefits of a HSR system between the two cities. Our data forecasts the regional benefits of HSR over a twenty year period, but of course such an important piece of infrastructure will continue to reap benefits for the region for decades to come.


\textsuperscript{52} “Socioeconomic Data Report, 2000 and 2031” (Richmond Regional Planning District Comittion, November 8, 2007), http://www.richmondregional.org/Publications/Reports_and_Documents/Socioeconomic_Rep_Approved_11-08-07.pdf
7.1 Passenger Benefits

There are many benefits that will result from faster train service between Washington D.C. and Richmond. These benefits include passenger benefits to the users of the rail service, social benefits, and ancillary benefits to other users of the transportation system, including motorists who continue to drive.

Passenger benefits are one of the most significant improvements resulting from faster rail service between Washington D.C. and Richmond. Within the passenger benefits category, there are three main subgroups of users who will see economic welfare gains with faster rail service.

First, current rail passengers will benefit as the travel time between Washington’s Union Station and Richmond’s Main Street Station is reduced with passenger rail services with an average speed of 70 miles per hour. Currently, the trip takes approximately 2 hours 45 minutes (165 minutes) with the current service which averages just over 40 miles per hour. With 70 mile per hour average speed, the length of the trip is reduced by nearly 70 minutes to a total trip time of 93 minutes. The travel time savings for current rail passengers who would benefit from 70 mph rail service is $32.2 million for the period between 2015 and 2035.

Second, with faster train service, some travelers who currently drive will be convinced to take rail instead, as this mode promises more attractive travel between these destinations than both current rail service or with congestion on I-95. These passengers who switch from automobiles to rail will benefit from both reduced travel time and foregone vehicle operating costs. It is approximately 109 miles from Washington’s Union Station to Richmond’s Main Street Station, as shown in Figure 7-1. According to trip times provided by Google, this trip takes two hours by automobile without traffic and 2 hours 20 minutes with congestion. To estimate average trip time, we averaged the driving times for congested and un-congested auto travel, weighing each one fifty percent. This is a reasonable assumption since the D.C./Northern Virginia metropolitan region is a highly congested area and it is likely that congestion occurs on I-95 on more than fifty percent of vehicle trips. The travel time savings for passengers who switch modes from auto to rail is $20.1 million between 2015 and 2035.

According to the Bureau of Transportation Statistics (BTS) data, the average variable cost of operating a passenger vehicle in 2008 was 15.4 cents per mile. This includes the cost of gas, maintenance, and tire wear and tear; this assumes a motorist who drives an average of 15,000 miles per year. To calculate savings for vehicle operating costs, we divided the number of new rail passengers with the build scenario (minus the induced demand) by the average vehicle occupancy of 1.5. The Virginia Department of Transportation (VDOT) provided estimates of average vehicle occupancy ranging from 1.22 to 1.92, depending on the section of I-95/395, time of day, and the location of High Occupancy Vehicle Lanes.

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53 The total cost of operating a vehicle includes the cost of vehicle ownership which is currently 54 cents per mile (BTS 2008 data). For the Washington-Richmond corridor, it was appropriate to take the average vehicle operating costs which is currently 15.4 cents per mile provided by (BTS). This figure more accurately reflects the costs users would forego with the introduction of HSR to the corridor. Until more transit options are introduced within the local communities, the likely users will not go carless based on the accessibility to HSR alone.
The cumulative reduction in vehicle operating expenses for the 2015-2035 timeframe amounts to $16.4 million\textsuperscript{54}.

Since Virginia is implementing High Occupancy Toll lanes which would be free for vehicles with three or more passengers but would cost other cars a significant amount of money depending on the level of congestion, we have preformed a sensitivity analysis of vehicle operating cost savings assuming an average vehicle occupancy rate of 2.25 passengers per vehicle. With the higher average vehicle occupancy rate, the reduced foregone vehicle operating costs drop to $16.2 million for the period of analysis.

The third category of user benefits is passengers who would otherwise not have traveled between Washington D.C. and Richmond but will now do so because of improved connectivity between the cities. This is referred to as the induced demand from the investment in the rail infrastructure. Because faster service between the two cities will reduce the costs of making the trip (reduced travel time), some marginal passengers will now travel who otherwise would not have taken the trip. This user group does not experience social welfare benefits since these passengers did not previously travel with the current 40 mph average service and, as a result, do not experience any travel time reductions from the improvement of that service compared with the 70 mph average service. The economic benefits from this category of user are most likely captured through expanded economic output and greater regional integration that HSR encourages.

The value of passenger time is based on the economic theory of opportunity costs. If the passenger was not traveling, he/she could use that amount of time for some other combination of work/leisure activity. Generally, business travel is valued at a higher rate than personal or leisure travel. For intercity surface transportation, the U.S. DOT recommends an hourly rate of $14.80 per hour for personal travel and $21.20 for business travel. This rate values travel time for business travel at 100 percent of the total annual average household wage rate and values personal travel at 70 percent of the total annual average household wage rate. The value of personal time for intercity travel for surface modes is more than for intracity surface modes because a greater share of the intracity trips are discretionary than that between cities. All of the aforementioned values use a national average of hourly income from 2000.

Because this data is now a decade old and the Washington D.C. metropolitan region is significantly more affluent than the national average, we have decided to adjust this using a weighted average of the hourly wage rates from the Washington D.C. and Richmond metropolitan regions. Additionally, since it is beyond the scope of this study to determine the motivations for taking the trips between D.C. (which

\textsuperscript{54} Since Virginia is implementing High Occupancy Toll lanes which would be free for vehicles with three or more passengers but would cost other cars a significant amount of money depending on the level of congestion, we have preformed a sensitivity analysis of vehicle operating cost savings assuming an average vehicle occupancy rate of 2.25 passengers per vehicle. With the higher average vehicle occupancy rate, the reduced foregone vehicle operating costs drop to $16.2 million for the period of analysis.
is a significant employment and tourism center) and Richmond, it is assumed that 50 percent of the travel is for business and 50 percent is leisure travel.

For this analysis, we calculated the passenger value of time using 2009 population estimates from the U.S. Census and 2007 wage data from the Bureau of Economic Analysis\(^5\). The last full year of data available for wages for specific metropolitan regions was released in 2007. According to the Census data, the Washington, D.C. region had nearly 5.5 million residents, while Richmond had over 1.2 million residents, giving this region a population exceeding 6.7 million inhabitants. Alternatively, the D.C. region, with its higher annual per capita personal income ($54,971) has approximately 80 percent of the corridor’s inhabitants—important for calculating the weighted average per capita personal income for the corridor. The value for an hour of work time was determined to be $26.13, while an hour of leisure time is $18.29. The blended average value of time (assuming a 50-50 split between work and leisure travel) equals $22.21 per hour.

**Key Assumptions**

1. Passenger value of time: $22.21/hour
2. Vehicle operating costs: 15.42 cents per mile
3. Value of life: $6.1 million
4. Value of carbon: $22/ton

### 7.2 Safety Benefits

Building a HSR system will improve travel safety in the region by reducing the number of highway fatalities and accidents on the I-95 Corridor. From 2015 to 2035 the HSR system is estimated to remove 2.3 million vehicles from the corridor. Removing these vehicles will result in 223 fewer non-fatal accidents and prevent 4 fatal accidents during the twenty year period, as shown in Figure 7-2. These safety benefits correlate into savings of over $24.1 million.

While the implementation of a HSR system between Washington and Richmond will result in a reduction of less than 1% of accidents on the I-95 corridor over the twenty year period, it will generate on average $1 million a year in savings and prevent 10 accidents a year. These savings relate to health and legal costs, market productivity, travel delays, property damage, and other related costs associated with accidents.

Without implementation of a HSR system the traffic on the I-95 corridor will experience an estimated 1,858 fatal highway accidents and 112,813 non-fatal highway accidents from 2015-2035. By implementing HSR the region will experience $6.5 million in savings from reduced fatal accidents and $17.6 million from reduced non-fatal accidents. These safety benefits correlate into a total savings of over $24.1 million from 2015-2035, as shown in Figure 7-3.

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7.3 Social Costs

As in other studies, in our study we can assume no risk of accident: Although the cost will be enormous in the case of an accident, the likelihood of it happening is almost zero\(^{56}\). It will also be very difficult to try to monetize different magnitudes of accidents since, in case of an accident, the costs will be specific to each particular event depending on the track section it happened, the kind of trains involved, and the hour of the day (traffic) among other variables to consider. The variance in the value of the accident will be so enormous; there will be no tangible use in trying to obtain such an estimate. For that reason it is not useful to try to forecast the cost of an accident. This does not mean there are no costs associated with safety, but it is more appropriate to consider them in infrastructure costs (i.e. signaling, elimination of grade crossing and shunting).

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>17.15</td>
<td>16.80</td>
<td>16.70</td>
<td>18.45</td>
</tr>
<tr>
<td>Actual</td>
<td>18.03</td>
<td>17.42</td>
<td>16.56</td>
<td>15.74</td>
</tr>
</tbody>
</table>

**Table 7-1: Rail-related Accidents and Incidents per million train miles\(^{57}\)**

There have been some good efforts to try to evaluate noise pollution. In most of those cases it involves noise levels in cities and in industrial areas, where noise is constant. Nevertheless we want to mention some of the results made by Hanson and Levinson for high speed train:

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\(^{56}\) There are 18.45 train related accidents per million train miles travelled, Source: (http://www.dot.gov/par/2008/SSG.htm)

Cost Benefit Analysis of Washington-Richmond High-Speed Rail

- Hanson makes a calculation with very high speed train (180 mph) where the corridor has to be 146 meters in order to maintain noise levels unchanged for the residential areas next to them.

- Levinson’s model calculates Ordinary Least Squares to determine the proposed width of the corridor to offset the noise. The model measures the damage comparing the noise levels before and after the track improvements are done, therefore only calculating them once the project has been put into work.

- Levinson also proposes to measure noise pollution per passenger kilometer, as a conclusion of the model he found that At 200 kph, is $0.0025/pkt; and at 320 kph it is $ 0.0043/pkt, assuming 5 trains per hour, though clearly these costs depend on local conditions as described above. In the case of the Washington-Richmond corridor this cost should be much lower as trainsets are smaller, are slower and the trips are much shorter.

As in the case of air pollution, noise generated by the Washington-Richmond corridor is only marginally increased by the number of high speed trains.

The proposed speed for the Washington-Richmond corridor is much lower (110 mph) than that calculated by Levinson, and the configuration of the land is already set, so our conclusion is that, this too, has a little impact on the regions overall noise pollution.

### 7.4 Congestion Reduction

The Virginia Transportation Research Council did a report on congestion on the I-95 and I-66 corridors. While this report dealt with the investigation of solutions to recurring congestions on the freeways, it did not consider HSR as a mitigating option. However, it is obvious that congestion possesses a significant challenge to the region and HSR can be a vital mechanism in alleviating that traffic congestion dilemma. Northern Virginia is plagued with 2 of the top 18 worst congested highways in the nation.

Each year, billions of gallons of wasted fuel, vehicle hours of delay, and dollars in lost productivity are wasted due to congestion. For example I-66 and I-95 heading into and out of the Washington, D.C., area handle roughly 196,000 and 267,000 vehicles per day, respectively, during peak periods bottlenecks on these segments of highway reduce capacity and increase travel times during peak periods. A bottleneck can be anything from a physical feature of the highway, such as an entrance ramp with merging traffic, to a reduction in the number of lanes. A bottleneck subsequently causes drivers to brake, which in turn creates a disturbance in the traffic flow, resulting in vehicle queues. The impact of bottlenecks and the resulting congestion on Northern Virginia can be potentially mitigated by applying operational changes to I-95.

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58 For a complete description go to (Levinson, 1997).
The research findings show that reducing congestion through better managed freeways has numerous documented benefits, including “reducing travel times, smoothing the travel flow, increasing average fuel economy and reducing vehicle queuing.” However, our study on HSR from Washington to Richmond will show that all the mentioned benefits will be realized with the implementation of HSR, as a potential countermeasure to congestion on the Washington-Richmond corridor.

Traffic congestion is a widely recognized transportation cost. Several methods can be used to quantify and monetize this cost, which can provide different results, as shown in Table 7-2. The most appropriate approach for many applications, although difficult to perform, is to calculate the marginal delay caused by an additional vehicle entering the traffic stream, taking into account the speed-flow relationship of each road segment. Another approach is to determine the user fee needed to reduce demand to design capacity, based on travelers’ willingness-to-pay for road use. A third approach is to calculate unit costs of current expenditures on congestion reduction projects. In theory these three methods should produce similar values, assuming that roadway capacity is expanded based on vehicle delay costs as reflected in vehicle users’ willingness to pay, but in practice they often provide different results.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Costs</th>
<th>Cost Value</th>
<th>2007 USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delucchi (1997)</td>
<td>Total US in 1991</td>
<td>$34-146 billion</td>
<td>$52-222 billion</td>
</tr>
<tr>
<td></td>
<td>Per urban peak mile</td>
<td>$0.07-0.32</td>
<td>$0.11-0.49/mile</td>
</tr>
<tr>
<td>TRB (1994)</td>
<td>Delay costs based on willingness to pay</td>
<td>$12 billion</td>
<td>$14 billion</td>
</tr>
<tr>
<td>Texas Transportation Institute (2007)</td>
<td>Congested urban roads per vehicle mile</td>
<td>average of $0.10 to 0.15*</td>
<td>$0.14-0.21/mile</td>
</tr>
<tr>
<td>Land Transport New Zealand (2005).</td>
<td>Benefits of TDM mode shift per Km</td>
<td>$1.27 - Auckland, $0.98 - Wellington, $0.09 - Christchurch (NZS 2002 / km)</td>
<td>$1.09 / mile, $0.84 / mile, $0.08 / mile</td>
</tr>
<tr>
<td>FHWA (1997)</td>
<td>Urban Highway Car Bus</td>
<td>$0.062 / VMT 6</td>
<td>$0.08 / mile</td>
</tr>
<tr>
<td>M. Maibach, et al (2008)</td>
<td>Urban collectors in European centres over 2</td>
<td>0.5 €/km 2000</td>
<td>$0.89 / mile</td>
</tr>
</tbody>
</table>

This table summarizes key congestion cost studies. These estimates range widely since they have been produced using different methods for different purposes. More detailed descriptions of these studies

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61 Miller and Li, “Investigation of the Costs of Roadway Traffic Congestion” (California PATH, 1994)
are found below. Values are converted to 2007 U.S. dollars using the Consumer Price Index. * Indicates the currency year is assumed to be the same as the publication year\textsuperscript{64}.

### 7.5 Environmental

Legislation mandates that transportation projects have an environmental impact assessment. This assessment has to comply with regional standards in order to preserve or improve their quality of life. When the projects include environmental impacts in their evaluation, costs are internalized in the construction of infrastructure and will get passed on through the price of the service\textsuperscript{65}, in this case the high speed rail price of the ticket.

The benefits from the decrease in fuel used in the highway, mainly in I-95 will largely offset the social cost of air pollution (in our estimates an average of 290 cars will be taken out of I-95 annually).

In weighting the impacts of environmental benefits and costs, the benefits outweigh the cost by 2 to 1 (see the chart below). At the maturity of the project savings in emissions will be close to 50 thousand dollars a year, while costs will be approximately 18 thousand dollars a year, as shown in Figure 7-4.

![Figure 7-4: Savings and Costs of Emissions (2010 dollars)](chart)

This could be achieved without affecting ridership (and thus mobility) as the increase in HSR ridership (433.4 million passenger miles) is matched by the decrease in car use (404.6 million passenger miles), with a slight positive effect in overall mobility, as shown in Figure 7-5.

\textsuperscript{64} Note that CPI is not the only way to adjust for inflation and results can vary significantly with different methods, see Samuel Williamson, “Ways to Compute the Relative Value of a U.S. Dollar Amount, 1790 to Present,” \textit{Measuring Worth}, www.measuringworth.com

\textsuperscript{65} Ibid
Benefits

The implementation of a HSR system between Washington, D.C. and Richmond, VA will result in environment benefits throughout the region by reducing emissions and energy consumption. The HSR system between Washington, D.C. and Richmond, VA is estimated to attract 4 million new passengers and remove almost 2.3 million vehicles from the I-95 corridor over the period from 2015 to 2035. By diverting travelers away from using the highway, the HSR system is estimated to cut greenhouse gases (CO2) by 213 million pounds over the 20 year period and reduce the consumption of gas by almost 11 million gallons. These environmental benefits correlate into savings of $679,741.90 over the 20 year period.

Without implementation of a HSR system the environmental costs of the I-95 Corridor are expected to exceed $448 million dollars and produce over 106 billion pounds of CO2 over the time span. By implementing a HSR system on this corridor it will reduce CO2 by an average of 10 million pounds a year which is an average of $30,681 a year in savings.

Overall the total environmental benefits are estimated to be $679,741.90 over the 20 year period. However, it should be noted that this is a very limited estimate of the environmental benefits as this study only took into account the largest pollutant, carbon dioxide, emitted from vehicles. A reduction in other emissions, such as carbon monoxide (CO), nitrogen oxides (NOx), and other major air pollutants will need additional study.
Figure 7-7: Total CO₂ Emission Saving in Cost

Figure 7-8: Total CO₂ Emission Saving in Tons
8. Cost-Benefit Analysis

The cost-benefit analysis utilized an annual discount of 7% to calculate benefits and costs. The cost-benefit analysis incorporates operating costs and infrastructure costs and travel time, economic, safety, environmental benefits to establish the likely grant or subsidy amount Amtrak will require to provide HSR service in the Washington-Richmond corridor. The discount rate was used to assess the project in terms of present day monetary value. The CBA does not include alternate costs for a no-build scenario whereby highway infrastructure may be expanded.

Financial analysis was used to determine the subsidy, which was compared to the CBA to obtain the net present value of benefits. The analysis used the estimated 17-year incremental build-out period to establish the no-build versus build operating costs and no-build versus build fare revenue.

The CBA shows that the total benefits for a build minus no-build scenario of HSR in the Washington-Richmond corridor as $29,520,273. The total cost for a build minus no-build scenario in the Washington-Richmond corridor is $1,294,475,440. The total fare revenue for a build scenario minus a no-build fare revenue projection over an incremental build-out time period of 17 years is $771,330,709.

The present value of net benefits for the Washington-Richmond HSR corridor improvements and expanded service results in a negative value of $493,623,458.
9. Financial Analysis

9.1 Regional Economic Benefits

It is expected that an HSR system would generate economic growth in the Washington D.C., and Richmond, Virginia, regions by providing faster and more efficient transportation. The system will likely also provide stimulate transit-oriented development along the rail line and immediately surrounding the train stations.

The primary economic benefit of HSR is that it reduces commute time, expanding a region’s employment opportunities. Reducing commute time improves residents’ access to more distant employment centers. Additionally, employers benefit from access to a wider, potentially richer, pool of candidates.

HSR creates opportunities for relatively long distant trips for business or leisure travelers. Face-to-face interaction is often preferred to video and teleconferences. With HSR, business travelers could meet with clients in other cities faster than they could with automobiles and without the added cost, security delays, and necessary transportation to downtown locations associated with air travel.

While multi-lane freeways take up much space and contribute to suburban sprawl, HSR consumes less space and train stations can become developmental focal points of communities. Transit-oriented-development (TOD) can be incorporated in these communities to create greater community awareness as well as more efficient mixed use of real estate. An HSR system will have a profound economic impact with the potential of generating employment due to redistribution and creation of new businesses. Kim Scheeler, president of the Greater Richmond Chamber of Commerce, eagerly anticipates the economic benefits of HSR saying, “High-speed rail has the potential to be a game changer for the Richmond Region. It can spur economic development and create greater efficiencies for companies that have to do business in D.C., but would prefer to locate here for economic and quality of life reasons.”

Increased rail ridership offers the opportunity for communities with rail stations to further develop economically viable and pleasant residential and commercial facilities in the proximity of those stations, with resulting environmental benefits to the affected communities. Train stations close to new housing and commercial developments will help minimize urban sprawl, making HSR more visible and viable. To most effectively utilize the rail system, these stations should have safe and reliable access to all modes of travel to increase transportation system connectivity and reduce the need for vehicular driving and parking.

The unifying effects HSR can have on a region can make the region’s airports, universities, and other major installations more efficient and competitive on a national and global level as they become more

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accessible to a larger population. The region will also be able to more effectively attract tourists if travel times can be reduced between locations. “With over 5.7 million visitors to the Richmond region each year,” stated Jack Berry, president of the Richmond Metropolitan Convention and Visitors Bureau, “we need to continue to ensure that we have a world class transportation system that includes HSR. Tourism equals jobs, and with a travel time of less than five hours to New York City, HSR has the potential to create a lot of tourism.”

HSR has numerous benefits, many of which are unquantifiable. Like the interstate highway system, the benefits of HSR are incalculable before construction, but will be very noticeable upon completion. In a report about the history of the interstate highway system, for which construction began in 1956, the Transportation Research Board describes the difficulty of capturing the full economic impact of such a massive transportation advancement using conventional models. Introduction of the highway system “fundamentally altered relationships between time, cost, and space in a manner which allowed new economic opportunities to emerge that would never have emerged under previous technologies.” Today, HSR may have the right characteristics to help facilitate another wave of productivity-driven economic growth. HSR will spur development in the region, especially dense, mixed-use transit-oriented development adjacent to the train stations, but it is impossible to predict the full extent of this development.

Northern Virginia needs transportation solutions. The region consistently ranks high among southeastern coastal cities in annual hours of delay per traveler, and in the nation in congestion costs. The region is expected to grow in population with the bulk of the jobs and population growth trending westward away from Washington D.C.

The Washington–Richmond corridor seems primed for HSR. The region has supported public transportation more than most other regions in the nation. The region is densely populated and highly educated, which typically are qualities which lend themselves to HSR usage.

There are several clear benefits to HSR. The current Obama administration is encouraging its implementation in the nation’s more populous regions. In order to remain competitive domestically and globally, the Washington-Richmond corridor must have improved transportation infrastructure. HSR provides a modern, efficient, and cost-effective solution.

68 Ibid. 2009
71 Ibid
9.2 Revenue Generation

The fares for Amtrak’s California Capitol Corridor service were examined to estimate fares for the improved Washington-Richmond service. The Bay Area-Sacramento corridor has approximately 8.3 million residents and the Washington-Richmond corridor has approximately 6.7 million residents. The distance between Union Station in D.C. and It is 109 miles between Union Station and Main Street station in Richmond is 109 miles, while it is 118 miles between Sacramento and San Jose. According to the Capitol Corridor's 2009 Performance Report, "The average cost of a full-fare Capitol Corridor ticket is about $0.35 per mile traveled, and can be as low as $0.14 per mile with a multi-ride ticket." At $0.35 per mile, a one-way ticket costs $41.30. The average fare listed on Amtrak’s website is $34, with a low of $27 and a high of $45. For the Washington-Richmond corridor this price may be discounted by a certain percent since a certain number of the passengers will be regular commuters with multi-ride tickets.

9.3 Salvage Value

The capital costs of the trainsets needs to be reduced by the residual value of the passenger cars and locomotives. This equipment will retain value beyond the analysis period, 2035. Guidance provided in 1996 by the Office of Management and Budget lists locomotives as having a useful life of 29 years and passenger rail cars as having a useful life of 40 years. The salvage value of locomotives is approximately 16.5% of the original purchase price, while the salvage value for passenger rail cars is 10.2% of the original purchase price. For the analysis, it was assumed that Amtrak would purchase two locomotives and four passenger rail cars in 2012, at a cost of $5 million and $4 million, respectively for each piece of equipment. Amtrak will purchase eight locomotives and twenty passenger cars in 2024 to augment its service to accommodate expected growth.

The residual values of the rail vehicles and locomotives are subtracted from the purchase cost to reflect the remaining value after the analysis period. The residual value of the 2012 trainsets is $1.973 million and the residual value of the 2024 trainsets is $35.573 million.

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10. Conclusions & Recommendations

10.1 Recommendations

Sole investment in the Washington-Richmond corridor is not financially feasible – The cost-benefit analysis indicates that HSR on the Washington-Richmond corridor alone does not provide net positive benefits. Substantial benefits can be expected during the incremental build-out phase; however, infrastructure costs are expected to be significantly greater during the initial twenty year analysis period.

Incorporate federal capital subsidy as part of feasible build-scenarios – HSR requires massive upfront capital investment, including both time and resources. Without complete federal funding, build-out for the entire corridor is estimated to take 17 years and $1.63 billion. Conversely, complete federal funding could provide a shortened build-out period, allowing the full benefits of a build scenario to be realized in as few as seven years. Since HSR on this corridor is not cost-effective, it would be feasible with a substantial federal subsidy. Additionally, current operating revenue projections are not expected to cover operating costs. Given passenger rail’s current operating ratio and profitability characteristics, this is not surprising. Amtrak already operates with a substantial federal subsidy because it is viewed as providing an important transportation service to users. Amtrak and the federal government should expect that the value proposition for HSR will include a subsidy. Amtrak should expect to receive state and federal grants to alleviate the capital cost burden on their general capital budget.

Leverage HSR’s highly visible benefits as part of a broad marketing strategy – Though profitability will be difficult to attain with HSR, the public’s generally positive view of HSR’s substantial social benefits of clean, safe, and rapid intercity transportation, may assist with support and usage. Compared to automobile travel, passenger miles traveled by rail produce substantially less environmental impact, including lower particulate and carbon emissions. Rail is also significantly safer than passenger automobile travel, with accidents occurring at a much lower rate. For journeys of 100-300 miles, HSR also provides significant travel time savings compared to other modes. Ensuring these benefits are highly visible through effective marketing strategies may prove helpful for encouraging investment in HSR.

Develop HSR market for customers looking for fast and convenient service – HSR on the Washington-Richmond corridor is estimated to provide travel time savings of 22-33% compared to current estimated drive time, and a travel time savings of 19-31% compared to current rail service. HSR has the potential to provide passengers with fast and convenient service, which should induce demand through mode change. Amtrak’s Acela service in the Northeast Corridor provides a successful example of how to develop additional markets for HSR.

Utilize HSR as an important tool in alleviating congestion – Roadway infrastructure, including I-95 between Washington and Richmond, is at capacity and will continue to increase, especially during peak
periods. While it may be possible to build additional highway capacity, even proponents admit that it is not realistic to think congestion can be resolved solely through roadway construction. Any additional capacity gains must also be met with programs that seek to reduce demand as well as improve the efficiency of current operations on existing infrastructure. Improving rail networks, especially HSR, can serve as an effective tool to encourage mode shifting from automobile to rail, decreasing demand of roadway infrastructure. Policymakers and Amtrak should cooperate to determine how HSR can play an effective role in congestion reduction.

10.2 Areas for Further Study

Additional forecasting – This study was conducted based on the data available to George Mason students during the spring 2010 semester. Data was collected from a variety of sources including Amtrak, VDOT, and the U.S. Census Bureau. Much of it was limited in terms of scope and timeframe. For example, Amtrak was unable to share proprietary station-to-station ridership data for the study, which would have provided a more accurate ridership forecast. Furthermore, current and projected population data for the catchment areas was based on data extrapolated from the 2000 Census. The available datasets provided only for a reliable forecast period of 20 years. Estimates for an extended forecast (e.g., 50 years) may provide a more accurate cost-benefit ratio and more proficient analysis because benefits will be realized over a longer period of time and capital costs, which require a large upfront investment, will already have been expended. Furthermore, 2010 Census data should provide for a more accurate estimate of future population.

Economic growth analysis – A complete analysis is expected to show that HSR has the potential to produce significant benefits related to economic growth. While an HSR connection will likely provide positive local economic impacts, including additional jobs and economic stimulation, HSR has the potential to do more than transfer national or regional wealth to the Washington-Richmond corridor. By improving transportation for business and leisure travelers, HSR has the ability to stimulate the economy, benefiting the entire nation. George Mason students were limited by schedule and resources, which prevented a more comprehensive study. Future research is likely to demonstrate that economic growth will be a significant and measurable impact of the HSR value proposition.
Appendix A: Terms & Acronyms

**Acronyms**

- ARRA- American Recovery and Reinvestment Act
- BTS- Bureau of Transportation Statistics
- CO- Carbon Monoxide
- CO2- Carbon Dioxide
- DOT- U.S. Department of Transportation
- DRPT- Virginia Department of Rail and Public Transportation
- EIS- Environmental Impact Statement
- EPS- Environmental Protection Agency
- FRA- Federal Railroad Administration
- GIS- Geographic Information System
- HSGT- High Speed Ground Transportation
- HSR- High Speed Rail
- ISTEAt- Intermodal Surface Transportation Efficiency Act
- LOS- Level of Service
- MAS- Maximized Authorized Speed
- NCDOT- North Carolina Department of Transportation
- NEI- National Emissions Inventory
- NECIP- Northeast Corridor Improvement Project
- NOx- Nitrous Oxide
- OMB- Office of Management and Budget
- SEHSR- Southeast High-Speed Rail
- SOV- Single Occupancy Vehicle
- TOD- Transit Orientated Development
- VDOT- Virginia Department of Transportation
- VRE- Virginia Railway Express

**Highway Engineering Terms and Concepts**

- **Traffic congestion** consists of the incremental delay resulting from interference between vehicles in the traffic stream
- Traffic congestion can be **recurrent** (occurring regularly on a daily, weekly or annual cycle, making it easier to manage) or **non-recurrent** (due to accidents, special events or road closures)
- **Capacity** refers to the number of people or vehicles that could be accommodated. Load factor refers to the portion of capacity actually used. For example, a load factor of 0.85 indicates that 85% of the maximum capacity is occupied
- **Design vehicle** refers to the largest and heaviest vehicle a roadway is designed to accommodate.
- **Passenger Car Equivalents (PCE)** indicate the traffic impacts of larger vehicles compared with a typical car
- A **queue** is a line of waiting vehicles (for example, at an intersection)
- A **platoon** is group of vehicles moving together (such as after traffic signals turn green)\(^74\)

\(^74\) Transportation Cost and Benefit Analysis II – Congestion Costs Victoria Transport Policy Institute ([www.vtpi.org](http://www.vtpi.org))
Appendix B: Modeling

Data Source and Methodology

In determining ridership, a basic gravity model was used which was expressed as follows:

\[
\text{Ridership} = \alpha + \beta_1 \text{Population Density} + \beta_2 \text{Income Level} + \beta_3 \text{Trip Fare} + \beta_4 \text{Travel Time by Auto} + \\
\beta_5 \text{Travel Time by Train} + \beta_6 \text{Travel Frequency} + \beta_7 \text{Transit Lines} + \beta_8 \text{TCongestion Status}
\]

Where \( \alpha, \beta_{1-8} \): Coefficients of variables.

Table B1 shows the results from the first run of the model.

Table B-1: Preliminary Modeling Results

<table>
<thead>
<tr>
<th>SUMMARY OUTPUT</th>
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<td>Regression Statistics</td>
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<td>Standard Error</td>
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<td>Residual</td>
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<td>Total</td>
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| Coefficients | Standard Error | t Stat | P-value | Lower 95% |
|----------------|
| Intercept | -302888.0981 | 174425.793 | -1.73649 | 0.097127 | -665626.3907 |
| Transit lines (A) | 12786.38161 | 15990.71371 | 0.799613 | 0.432887 | -20468.12788 |
| Population 2009 (A) | 0.013913919 | 0.048192611 | 0.288715 | 0.77563 | -0.086308103 |
| Transit lines (B) | -1430.179237 | 10901.05742 | -0.1312 | 0.896869 | -24100.16909 |
| Population 2009 (B) | 0.041366657 | 0.028402305 | 1.456454 | 0.160057 | -0.017699169 |
| Trip time (train) | 50.36981722 | 1259.000779 | 0.040008 | 0.968465 | -2567.865623 |
| Trip time (auto) | -165.0871146 | 1419.845003 | -0.11627 | 0.908542 | -3117.816428 |
| Trip Fare (adult) | 795.8446271 | 2984.463018 | 0.266663 | 0.79233 | -5410.68596 |
| Travel Freq(annually) | 298.1122713 | 226.0098302 | 1.319023 | 0.201364 | -171.9008989 |

In order to derive the coefficient, several regressions were run in Microsoft Excel. The regressions were run using the raw data, with the datasets then converted to logarithms. With further analysis of the results were derived from both methods and the best fit outcome was chosen.
Dependent Variable

Ridership was chose for the dependent variable since the aim was to forecast the ridership of the Amtrak service from Washington D.C. to Richmond. The ridership for each city pair was identified based on

Independent Variable

To determine the factors that influence ridership, several variables were identified based on the premise they were in some way associated rail ridership. The following variables were considered for the model; Population Density, Income Level, Trip Fare, Travel Time by Auto, Travel Time by Train, Travel Frequency, Transit Lines, and Congestion Status on the Highways. The assumptions were that:

- **Population Density**: If the population density in a certain Amtrak service area increases, there will be more customers utilizing HSR if the market shares of Amtrak remains the same or increases.

- **Income Level**: The income level is an indicator of how many people will be able to afford the HSR service. Here, we used the documented median household income level rather than, individual income level, because the children in a family may also become an HSR customer, even though the member of the family does not have any income.

- **Trip Fare**: The cost of a trip is very important to a commuter, with overall fare price having a large impact on mode choice.

- **Travel Time by Auto and by Train**: Travel time is another important variable. Since shorter travels times are more desirable, they will attract more consumers. If the driving time is nearly equal to the time by train or less than it, it is less likely for people to choose rail service.

- **Travel Frequency**: This refers to the number of trains that are scheduled on particular days from an origin to a destination. The travel frequency will attract commuters if they have the option to choose from flexible times within the routine schedule. This will also imply that high frequency shows more people are willing to choose Amtrak.

- **Transit Lines**: Transit lines are bus routes, metro lines, and coach services that link with the rail station. Such feeder lines can offer convenient transportation services for potential rail passengers.

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76 US Census Bureau, CBA-2008 Poverty and Median Income Estimates
77 Ibid
78 Ibid.
79 Ibid
80 Ibid
• **Congestion Status on the Highways:** People who choose HSR as their travel pattern may avoid congestions on the highways which are quite time-consuming. The indicator for this variable was congestion time on highways between every two cities.

• **Congested Travel Time:** Travel time by car under congested conditions between the Origin and Destination pairs was considered as an additional input variable for the ridership demand model. However, due to the inconsistency of available data, it was not possible to obtain the peak hour congested travel time between all of the city pairs. The commercially available data covers trips within metropolitan areas but not between metropolitan areas. Rather than compute the model based on an incomplete data set it was decided that the other factors used would be sufficient. Future studies may be able to incorporate the congested travel time as data becomes more readily available due to the incorporation of real time road traffic monitoring into intelligent transportation systems.

• **Vehicle Miles of Travel (VMT):** VMT estimates include the distance traveled element, which provides a measure of highway vehicle travel usage over a geographic area, such as a county, state, or highway system. The model results for the build scenario include incremental travel time improvements over the construction cycle of the project. An equal time reduction for each year was assumed until the project was complete and the final travel time was met. The projected VMT spreadsheet also shows a reduction in vehicles for each “Build and No Build” scenario.

In order to calculate the relationships between every two variables and decide which ones would be utilized a correlation check was run after the first model, which was unsatisfactory. In the Correlation chart, we found that Travel Time by Auto and Travel Time by Train were highly correlated as shown in Table B4. Given the scope of study of the Amtrak HSR service, the variable of Travel Time by Auto was dropped. Another observation was that the number of transit lines in a certain city has a strong relationship with the population of that city. Since demographic features are considered critical data in the gravity model, the population was kept as an independent variable. The Travel Frequency was equally dropped from the model because it was found to be highly correlated with the other four independent variables.

Travel time by car under congested conditions between the Origin and Destination pairs was also considered an important additional input variable for the ridership demand model. However, due to the inconsistency of available data it was not possible to obtain the peak hour congested travel time between all of the city pairs. The commercially available data covers trips within metropolitan areas but not between metropolitan areas. Rather than compute the model based on an incomplete data set it was decided that the other factors used would be sufficient. Future studies may be able to incorporate the congested travel time as data becomes more readily available due to the incorporation of real time road traffic monitoring into intelligent transportation systems.
Cost Benefit Analysis of Washington-Richmond High-Speed Rail

Regression Analysis

By and large, there are three criteria which can be used to show how well a model fits. This can be established if there is a high R square, low P-value, specifically, below 0.05, and the rationality of coefficients. In the first regression analysis run, Income Level was excluded from the model, due to the lack of data. With six initially selected independent variables, the R Square of the model was approximately 0.6, which meant this model could be narrowly accepted. But some of the P-values of coefficients were quite high and the coefficient of Trip Fare was a positive one. The positive coefficient implied that the higher the fare is, the more ridership we will have. This is not reasonable in terms of certain city pairs, for instance, Tampa, FL to Orlando, FL. The number of passengers between Tampa and Orlando is unlikely to go up if the trip fare increases. The results remained the same when we used logarithmic numbers for dependent variable, independent variables, or all of them.

Another observation of this run was Trip Fares were higher in large cities while at the same time, the Travel Frequencies of those ones were also higher. Therefore, we believed that the Income Level might be a contributor in the analysis. It was also suggested that we should separate the fares of Acela trains, and following the suggestion, we attempted several approaches using Median Household Income Level. First, we separated the Acela portion of the Ridership and Trip Fare, because if we only separated Trip Fares, the Ridership data and Trip Fare data would not match with each other. Second, we used a dummy variable to indicate if there are Acela trains running through the area. Third, we used the interaction of dummy variable and Trip Fare. All the methods led to worse results. In the next stage, we ran 16 possible models as shown Table B2.

The final data sets used included Population at Station A, Population at Station B, Travel time by rail between A and B and Fare to travel between A and B. The 16 models in total were run with four different kinds of data sets. Washington, D.C to New York City corridor was identified as an outlier and the first data sets were those that had the outlier (D.C.-Richmond) removed with the inclusion of the intercept included.

Finally, we decided to use the last model of No. 4, because it has elasticity of price, travel time and population with respect to ridership, and the R Square was within acceptable limits. These results are shown in Table B3. Below are several of our results and the interpreted influence each has on ridership:

- A 1% increase in population around station A will increase ridership between A and B by 0.58%
- A 1% increase in population around station B will increase ridership between A and B by 0.29%
- A 1% increase in travel time (by rail) between A and B will decrease ridership between A and B by 1.169%
- A 1% increase in fare between A and B will increase ridership between A and B by 1.03%

The equation is shown below:

\[
\text{Lg(Ridership)} = 0.06515707 + \text{Lg(Population (A))} * 0.589624048 + \text{Lg(Population (B))} * 0.291360812 - \\
\text{Lg(Travel Time by Rail)} * 1.169310317 + \text{Lg(Trip Fare)} * 1.030540476.
\]
### Table B-2: Model Breakdown

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<th>Models</th>
<th>Dependent Log</th>
<th>Dependent No log</th>
<th>Independent Log</th>
<th>Independent No log</th>
<th>Without Outlier</th>
<th>With Outlier</th>
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Richmond Hill of Washington
### Table B-3: Demand Model Results

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<tr>
<th>Year</th>
<th>Projected Ridership- No Build Scenario</th>
<th>Projected Ridership- Incremental Build Scenario</th>
<th>Projected Ridership Increase</th>
<th>No Build Scenario I-95 AVMT</th>
<th>Incremental Build Scenario I-95 AVMT</th>
<th>Projected AVMT Decrease</th>
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<td>53,891</td>
<td>86,812</td>
<td>32,920</td>
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<td>97,192</td>
<td>38,837</td>
<td>5,427,052,072</td>
<td>5,424,681,485</td>
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<td>5,516,679,896</td>
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## Table B-4: Correlation Table

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<th>Transit Lines (B)</th>
<th>Population 2009 (B)</th>
<th>Travel Time (Train)</th>
<th>Travel Time (Auto)</th>
<th>Trip Fare (adult)</th>
<th>Travel Frequency (annually)</th>
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</table>
Appendix C: Cost

Infrastructure Cost Methodology

The current incremental approach to developing HSR in the Washington-Richmond Corridor is phased construction of a third track between the Alexandria Station and the Richmond Main Street Station.\(^8^1\) The most recent federally-funded HSR D.C.-Richmond project is the construction of a 3\(^{rd}\) track on an 11.4 mile stretch of track between Arkendale and Powell Creek. This project has received approximately $75 million dollars in ARRA federal funds and is supported with the backing of an annual $25 million dollar state-based rail enhancement fund (REF) from the state of Virginia.

A total build cost scenario was developed for the entire 3\(^{rd}\) track between D.C.-Richmond using average per mile times extrapolated from the Ark-Powell project. The Arkendale-Powell Creek project (Ark-Powell) is slated for completion in two years which works out to an average build-out time of 5.5 miles per year on a project with complete funding.\(^8^2\) It has been selected as a result of its identification as a stretch of track that poses a significant bottleneck in the Washington-Richmond corridor that can deliver the most travel time savings compared to the cost associated with its improvement. This scenario assumes that project funding will originate primarily from the state of Virginia and a consortium of private and public agencies (Amtrak, VRE, CSX).\(^8^3\) It assumes that this funding will be readily available and that there are no further time delays from additional environmental impact requests and preliminary engineering reports beyond a two year period (2010-2012).\(^8^4\)

\(^8^1\) Virginia Department of Rail and Public Transportation, “Arkendale to Powell’s Creek Third Track Project: Financial Plan,” 1
\(^8^2\) Ibid., 3
\(^8^3\) Virginia Department of Rail and Public Transportation, “Virginia Department of Rail and Public Transit, Statewide Rail Plan Technical Update,” 11-8
Based on the 5.5 miles per year average, and the total track distance of 92.7 miles between the Alexandria and Richmond Main Street Stations, the total build-out time would come to approximately 17 years. This figure does not include improvements to Richmond Main Street and ACCA rail yard as there are several preliminary reports pending that could significantly alter these costs which range between $71-$256 million dollars. Additionally, there is a pending cost study to routing tracks either thru the town of Ashland or around it that are still undecided which were not included in the report.

Operating Cost Methodology

Studies to calculate the operating costs typically follow one of two methods. The first method is to itemize the costs into categories similar to those utilized by Levinson for the Los Angeles-San Francisco corridor. The second method typically used to calculate the operating costs is to aggregate all of the costs based on previously built high speed rail systems.

The primary difference between the Californian HSR system in the study and the system proposed for the SEHSR (Southeast High Speed Rail) corridor is that the California system is proposed to travel at 300 kph while the SEHSR system will be limited to 110 mph (177 kph). The SEHSR system will be a diesel powered system while the California system is electrified. The calculations used in the study incorporated costs from the Shinkansen from Japan and Trains à Grande Vitesse (TGV) from France which are both more similar in speed and technology to the proposed LA-SF corridor HSR than to the

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85 Virginia Department of Rail and Public Transportation, “Washington, D.C. to Richmond Third Track Feasibility Study.”, pg. ES-16
SEHSR system. These are important distinctions to be made because the differences affect the maintenance of equipment, energy, and train operating costs.

The affect of different factors on the cost can be modeled using a regression analysis or other method. The cost then can be estimated on a per train, train-km or passenger-km basis. The study that was considered as an example for this calculation method is an empirical analysis of the results of a U.S.DOT commercial feasibility study of HSGT\textsuperscript{86}. Eight different technologies (categorized by MAS) of HSGT systems were analyzed on nine corridors. In the study, a formula was derived based on six parameters that explained 98.9\% of the variability in the operations and maintenance cost (not including Maintenance of Way) for the corridors included in the study. The six parameters are as follows:

1. MAS for the system
2. Corridor length in route-miles (RM)
3. Passenger-traffic density (PTD) – the ratio of corridor passenger miles to route-miles
4. Annual revenue seat-miles (RSM)
5. Annual revenue seat-hours (RSH)
6. Specific trip length (STL) – the ratio of average passenger trip length to the corridor route length.

With all six of these parameters, the formula from the study could be used to calculate the operations and maintenance costs. However, with this method it is not possible to obtain itemized costs.

Both of the studies mentioned are from 1997, so the costs would need to be converted to a present day value before we can use our inflation factors, and results from the modeling group to forecast the operations costs. One way to do this would be to use the Railroad Cost Recovery (RCR) Index. The RCR is a price index that measures changes in the price level of inputs to railroad operations: labor, fuel, materials & supplies, and other operating expenses. 7\% has been used as the discount rate for the costs in this analysis and it will be used for the operating cost analysis as well.

### Table C-1: Carrier Operating and Capital Costs for Los Angeles-San Francisco Network

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<th>Quantity</th>
<th>Cost</th>
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\textsuperscript{86} TRB Study
Cost Benefit Analysis of Washington-Richmond High-Speed Rail

Social Cost Methodology

After defining infrastructure and operational costs, now we have to include the social costs of HSR in the Washington-Richmond corridor. To do this we are going to proceed with the social costs defined by in the document of David Levinson et al87 that include a complete formula and some references to calculate such costs for HSR in California. We have to realize that in practice those definitions were used in 1997 for an electrified track, but the model can proof beneficial for our analysis as well.

The equation is:

$$ FC = ICC + IOC + CCC + COC + CT + UCC + UOC + UT + UTC + UD.C. + SEC + SNC + SAC $$

Social Costs

The equation above includes all costs. The first 9 terms on the right side of the equation refer to infrastructure and operation costs. The last three terms refer to emissions, noise and accident/safety costs.

In our study we have to assess the impact of air pollutions generated mainly from the increase in the use of diesel (from new trainsets), the increase in noise, and finally the possible increase in train accidents.

In our model we have some situations that can mitigate those costs as the main lay down of tracks has already taken place: the main track is already constructed and it is used for passengers and cargo. So the impact on noise, air pollution and the environment will only be marginal to the new operations of HSR.

Moreover, in calculating the social benefits of the project we can find that the same elements are considered but in a positive way, like noise reduction, less air pollution and less highway accidents due to the reduction of traffic in the I-95 segment between Washington D.C. and Richmond. In weighting the impacts of social costs and benefits just by the broad numbers

One alternative to measure the social cost has been to quantify the change of property values. This has been done in specific situations with noise pollution in neighborhoods close to airports, which is somehow easy to identify. In the case of noise and vibration by the HSR, as people price it negatively, home values in the proximities will likely decrease. Nevertheless this alternative is more difficult to evaluate since there are many other variables affecting the price of housing in positive and negative ways along a rail track than only noise pollution.

Finally, we want to mention that legislation mandates that transportation projects have an environmental impact assessment. This assessment has to comply with regional standards in order to preserve or improve their quality of life. When the projects include environmental impacts in their evaluation, costs are internalized in the construction of infrastructure and will pass through the price of the service88, in this case the HSR price of the ticket.

87 Levinson et al., “The Full Cost of High-Speed Rail : An Engineering Approach.,” 189-215
88 Ibid
We want to do a comparison between the HSR project in California and the project for the Washington-Richmond corridor to have a better understanding on how to calculate social costs, focusing only in air pollution, accidents/safety, and noise

**Operating and Cost Tables**
## Table C-2: Operating Costs Data #1

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### Table C-3: Operating Costs Data #2

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Appendix D: Benefits

Congestion Methodology

Our model forecasts that as of 2015 there will be a reduction of 18,435 vehicles on the corridor between Washington and Richmond, which constitutes to be approximately 50.50 vehicle reduction per day. The model also indicates that by 2035 this region will have seen a reduction of 566,213 vehicles on the corridor. Assuming that this reduction number of vehicles were part of congestion that would ultimately have a positive impact on reducing congestion.

To quantify our findings, we can use this formula to calculate the cost of congestion.

\[
\text{Congestion} = \text{quantity} \times \text{price} \times \text{distance}
\]

- Congestion cost = 0.38 per mile (FHWA)
- Total miles of corridor = 107 (distance)
- Number of vehicle reduction = 566,213 (quantity)

\[
566,213 \times 0.38 \times 107 = 23,022,227 \times 2 = 46,044,454 \text{ (total cost due to vehicle reduction) for both northbound and southbound trip on the corridor.}
\]

There are certain inherent limitations about this finding because we did not account for an inflation rate percentage which could be as high as 7%. That means that the true congestion cost would be much greater. Another point of importance is that congestion is not uniform but rather some road segments are more affected than others. Nevertheless, this illustrates that this region is a heavily congested one and HSR can play an integral role in congestion mitigation.

Environment Methodology

Environmental Benefits Methodology

The positive environmental effects of the high speed rail system come from the number of carbon dioxide emitting automobiles removed from the highways. In addition, by reducing the number vehicles traveling it will also decrease the region’s energy consumption. The environmental benefits calculated are limited to CO2 emissions due to the complexity of calculating other air pollutants. Benefits are calculated over a twenty year period from 2015-2035.
Analytical Steps:

- Forecasted Annual Vehicle Miles Traveled (VMT) on I-95 Corridor during both a build and no-build scenario. During this calculation a 16% induced demand was taking into account as well as an average 1.5 vehicle occupancy rate.\(^8\)
- Calculated the annual gallons of gas used on the I-95s Corridor during both a build and no-build scenario by using the forecasted AVMT and an average vehicle fuel efficiency of 23.9 mpg.\(^9\)
- Used the calculated annual gallons of gas used and a standard of 19.4 lbs of CO2 produced per gallon of gas to estimate the CO2 emitted during both a build and not build scenario.\(^10\)
- Determined the cost of CO2 emitted over a 20 year period for both a build and no-build scenario by using the $22 value per ton of CO2.
- Identified the reduction in CO2 emitted and cost savings from building a high speed rail system by taking the difference between the build and no build scenario calculations. (See Table) shows the reduction in CO2 emissions as well as the monetary savings associated with these environmental benefits from 2015-2035.

Environmental Costs Methodology

Analytical Steps for Cost of CO2

- Forecasted the increase in Annual Passenger Miles Traveled on the Washington-Richmond Corridor during both a build and no-build scenario.
- Multiplied the increase in “Annual Passenger Miles Traveled” (variable x) by the “pounds of CO2 per passenger mile” for similar kind of trains (variable y) to obtain the “total pounds per passenger miles of CO2 per year” in the segment. According to the Center for Clean Air Policy\(^9\) the average emissions passenger mile of CO2 is .26 pounds.
- Multiplied the “total pounds of CO2 per year” by the “cost per pound” (variable z) to obtain the total cost of CO2 cost. (x * y * z = total pounds of CO2 per year). According to the Environmental Protection Agency the cost per ton of CO2 is $22.05 (or 1 cent per pound).
- Calculated every year, then discount the yearly results by a factor of 7% to obtain 2010 dollar estimates.

\(^8\)The 16% figure was taken from the estimated induced demand generated from the high speed rail system proposed in Florida servicing Orlando to Tampa. It was thought that this would be a comparable figure for calculating induced demand on the Washington, D.C. to Richmond, VA system. See: Government Accountability Office, “Surface Infrastructure: High Speed Rail Projects in the United States,” 1999
\(^10\)Ibid.
Safety Methodology

Safety benefits are generated by diverting passengers from traveling in their vehicles and onto the high speed rail system. This ultimately results in fewer vehicles on the road which limits the rate of fatal and non-fatal accidents. To calculate the safety benefits a basic assumption that I-95 would be the main vehicle travel route from Washington, D.C. to Richmond, VA was used. Thus safety benefits were focused exclusively on this corridor during calculations.

Analytical Steps:

- Forecasted Annual Vehicle Miles Traveled (AVMT) on I-95 Corridor over a 20 year period during both a build and no-build scenario. During this calculation a 16% induced demand was taking into account as well as an average 1.5 vehicle occupancy rate.  

- Calculated the estimated number of fatal and non-fatal accidents on I-95 Corridor over a 20 year period for both a build and no build scenario using the 2007 U.S. Department of Transportation Bureau of Transportation Statistics motor vehicle accident rates of 1.4 fatal accidents per 100 million miles and 85 non-fatal accidents per 100 million miles.  

- Determined the cost of the calculated fatal and non-fatal accidents over a 20 year period for both the build and no build scenario by using a 2008 U.S. Department of Transportation Guidance Memorandum on valuing accident fatalities and injuries, which recommends a cost of $6.1 million per fatality and $271,780 per moderate injury (MAIS 2).  

- Identified accident reductions and cost savings from building a high speed rail system by taking the difference between the build and no build scenario calculations. (See Table) shows the reduction in fatal and non-fatal accidents as well as the monetary savings associated with these safety benefits from 2015-2035.

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93 The 16% figure was taken from the estimated induced demand generated from the high speed rail system proposed in Florida servicing Orlando to Tampa. It was thought that this would be a comparable figure for calculating induced demand on the Washington, D.C. to Richmond, VA system. See: Government Accountability Office, “Surface Infrastructure: High Speed Rail Projects in the United States.”

94 Bureau of Transportation Statistics, “National Transportation Statistics, U.S. Department of Transportation’s Bureau of Transportation Statistics, Table 2-17.”

Appendix E: GIS

Analysis Background

On a basic level Geographic Information Systems, or GIS, is the use of a map. As technology evolved, maps could become more than two-dimensional pieces of paper. Using computer databases, maps could be expanded to illustrate multiple layers of information, allowing for a multi-faceted viewer experience. For example road and rail network of a particular state can be separated by county, with a color gradient to reveal the populations of various cities. GIS can be utilized to develop complex model with many layers of information; arranging these models according to spatial relationship gives a different perspective than data in formulas and charts. When building the GIS database behind a model, the user’s decision of which data to use on the map determines the story related to the viewer. In this way, GIS tools can help guide policy makers visualize complex decisions for transportation planning. Though GIS applications are complex, in the context of transportation, they have three facets:

1. Provides a synchronized way of collecting data based on procedures to guide input selection
2. Allows for compiling and observation of spatially oriented information
3. Helps policy makers decide transportation planning issues

Each of these dimensions can further be elaborated on, but nothing tells a story like the final product. A GIS map is an invaluable aid in visually representing complicated planning issues.

For our study, we used a GIS application to plot the relationships between the route of the proposed HSR corridor between Washington and Richmond. GIS allowed us to use officially obtained data sources such as Amtrak, Virginia Department of Transportation, Environmental Protection Agency, National Transportation Atlas Database, and the Census Transportation Planning Package to develop a series of maps that show what current corridor conditions and how future conditions according to future forecasting models. Since an examination of all proposed HSR projects in the U.S. is beyond our scope, we have focused on the proposed HSR line in Washington and Virginia.

As a supplement to our study, we have created a database of GIS information for our partners at Amtrak to use and study. The data we present is a snapshot of a very short section of the envisioned Southern HSR corridor that would connect states all the way to Florida to the Northeast Corridor, a section of the country that already has HSR. Nonetheless, this data will be a useful tool for transportation planners in Virginia, Amtrak, CSX, as well as the D.C. metropolitan area, to see how a short section of HSR, can change a region.

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Datasets Used

Census Transportation Planning Package (CTPP) 2000

The Census Transportation Planning Package (CTPP) is a collection of summary tables that have been generated from the census long form data collected in year 2000. It is the only source of information with summary tabulations available for traffic analysis zones (TAZs) that have been defined by state and regional transportation agencies. These summary tables contain three sets of tabulations: Part I - PLACE OF RESIDENCE, Part II - PLACE OF WORK, and Part III - JOURNEY-TO-WORK.

To better understand the commute patterns of persons living and working along the corridor study area, and for the purposes of analysis, the following datasets were used. County-level data was used for Virginia and the District of Columbia.

A. Means of transportation to work and travel time to work - P1-022 (Part1 Table 022)

Modes used for analysis are:

1. All workers, who drove alone
2. All workers, who travel to work by 2-person carpool
3. All workers, who travel to work by streetcar, trolley car, subway, or elevated
4. All workers, who travel to work by railroad or ferryboat

Developing maps of mode usage graphically displayed the amount of time commuters were spending traveling to work and provided a greater understanding of commuter behavior. Additionally, these maps will assist in determining where the best opportunities might lie to shift more persons to the HSR Amtrak service.

For the purpose of our analysis, we captured commuters using the aforementioned modes who spend 45 minutes or more commuting. To capture commuters traveling 45 minutes and greater, for each mode listed above, we downloaded the six travel time categories beginning with 45-49 minutes. Using field calculator in ArcGIS, we totaled the categories to determine the number of commuters in each county traveling by the specified mode for 45 minutes or more. The attribute categories for travel time ranged from less than 5 minutes up to 90 or more minutes, broken out by four-minute increments through 55-59 minutes and then by 14-minute increments through 89 minutes.

B. Time leaving home to go to work - P1-001 (Part1 Table 001)

The various fields under this table are a cross tabulation of one or more variables. The tabulations under the table consist of departure times beginning at 5:00 a.m. and are broken out into 14-minute increments, for example 5:00 a.m. – 5:14 a.m., 5:15 a.m. – 5:29 a.m., etc. To capture leave time, we decided to focus on half-hour increments between 5:00 a.m. and 8:59 a.m.

1. 5:00 – 5:29 a.m.
2. 5:30 – 5:59 a.m.
3. 6:00 – 6:29 a.m.
4. 6:30 – 6:59 a.m.
5. 7:00 – 7:29 a.m.
6. 7:30 – 7:59 a.m.
7. 8:00 – 8:29 a.m.
8. 8:30 – 8:59 a.m.

Selecting these half-hour increments provides an opportunity to extrapolate potential scheduling of HSR service that can attract the greatest number of commuters. Using the field calculator function in ArcGIS, two columns were combined to create each category to be used in the map. A total of 16 time periods were combined to create the final eight categories used for mapping.

C. Journey-to-Work - P3-001 (Part3 Table 001)

In order to understand the origin-destination travel patterns of commuters, we used the CTPP Journey-to-Work data. The census asks workers to indicate the last location at which they worked. Using this information we are able to determine work flow travel patterns. For the purpose of this study, we looked at regions along the corridor based on residential location. The regions are:

1. Northern VA/D.C. region
   a. District of Columbia
   b. City of Alexandria
   c. Arlington County
   d. Fairfax County
   e. City of Fairfax
   f. Prince William County
   g. Manassas
   h. Manassas Park
   i. City of Falls Church

2. Middle region
   a. Stafford County
   b. Spotsylvania County
   c. Fredericksburg County
   d. Caroline County
   e. King George County

3. Richmond region
   a. Richmond County
   b. Chesterfield County
   c. Hanover County
   d. Henrico County

The data table is based on the state or Metropolitan Planning Organization, (MPO) for which the information was tabulated. Although the data was for both Virginia and D.C., residence location was occasionally listed as being outside of Virginia and D.C. For this reason, we removed all of the states and counties for those workers who did not list residence as being in one of the Virginia counties being analyzed, or D.C. This was done using state and county Federal Information Processing Standard (FIPS) codes, which is what is used in the data table. The STATE 3 column contains residential state FIPS codes; the COUNTY column contains residential county FIPS codes. The table was sorted to include only residential state FIPS codes of 51 (VA) and 11 (D.C.). It was then sorted by county FIPS code to only include the counties identified above. Once the sorting for each table was complete, the tables were
combined into one spreadsheet to include VA counties and D.C. The next step was to combine all of the counties and cities according into regions as indicated above. The table was sorted to include only the counties and cities listed in each region. That means we now have one table for each region – Northern VA/D.C., the Middle Region, and the Richmond Region.

Next is to identify the work locations. Respondents can indicate any state and county throughout the country for their work location, and many do. For the purposes of this study, we decided identify residents from each of the regions who work in counties in VA or MD or in D.C. To consolidate the data based on a work county or city, each of the corresponding resident rows needed to be added together to make up the total from the region destined for that particular municipality for work. For example, all of the workers who are a part of the Northern VA/D.C. region that identified their work state as Virginia and their work county as Winchester, needed to added together to determine all workers going to Winchester for work. Each county chosen as a work destination for analysis will need to be totaled.

National Transportation Atlas Database


1. Railway Network - Region 3 (D.C., DE, MD, PA, VA, and WV)
2. Amtrak Stations

Railway Network – This is a polyline shapefile representing rail lines. Once the shapefile was loaded into ArcGIS, it was apparent that it included all rail lines and not just those on which Amtrak operates. In order to show only the Amtrak routes, the data needed to be filtered using the selection tool. The column entitled TRKRGHTS1 included Amtrak as an entity having rights to the usage of the track. Additionally, the column entitled RROWNER1 included Amtrak, so the Amtrak filter was also applied to this column. After that, we needed to select the Amtrak routes that pertained only to VA and D.C. Again, using the selection tool, the criteria were set to select the Amtrak rail lines in VA and D.C.

Amtrak Stations – This is a point shapefile representing all of the Amtrak stations throughout the country. Not only does it include rail stations, but also Amtrak bus stations. Once the shapefile was added to ArcGIS, it was necessary first to select only rail stations. Second, the selection criteria were set to include only rail stations in VA and D.C.

Census

For state and county polygon shapefiles, the Census 2000 County Subdivisions in ArcView were used. Virginia, the District of Columbia, and Maryland were used. The information was downloaded from the Census webpage for cartographic boundary files – [http://www.census.gov/geo/www/cob/cs2000.html](http://www.census.gov/geo/www/cob/cs2000.html)

Emissions

The data used to create this map was collected from the Environmental Protection Agency’s County Emissions Report on the EPA web site - [http://www.epa.gov/air/data/help/hntisumm.html](http://www.epa.gov/air/data/help/hntisumm.html) "Information
for this report comes from an extract of EPA’s National Emission Inventory (NEI) database.” Using the Hazardous Air Pollutants (HAPs) report, all 188 HAPs for onroad emissions were downloaded for 2002. Table attributes included Total Emissions, Onroad Emissions, Percent of Total Emissions, and Percent of Onroad Emissions for the District of Columbia and county/city in Virginia. Onroad emissions sources include “licensed motor vehicles, including automobiles, trucks, buses, and motorcycles.” The output table included the state and county codes, which could be used for joining to the geospatial table in ArcGIS.

Level of Service

LOS data was provided by the Virginia Department of Transportation. The geodatabase was uploaded into ArcGIS in order to specifically represent LOS data for the Interstate 95 corridor which runs north and south, parallel to the project Amtrak rail corridor. Using the Selection tool, the database was queried to select from the Route attribute all records containing 95

Methodology

Station to Station Ridership Calculations

A major component needed to develop the transportation model was preparing annual ridership (arrivals & departures) totals for station-to-station pairs along the existing Amtrak northeast and southeast systems. Ridership totals were calculated using 2009 Station Passenger Fact Sheets, published by “National Association of Railroad Passengers”, and provided to the practicum team by Amtrak. Four sets of passenger statistics were analyzed from each station fact sheet in order to calculate the annual number of passengers traveling between two Amtrak stations.

The passenger statistic categories used are:

1. Total station ridership
2. Passenger trips by distance
3. Amtrak presence at station
4. Top city pairs by ridership and revenue

To best explain the calculation method used to develop ridership totals between stations a sample calculation is expressed in the table below.
Cost Benefit Analysis of Washington-Richmond High-Speed Rail

Figure E-1: Union Station Ridership

Union Station Ridership Table Overview: The following table depicts the calculation steps used to estimate total annual ridership traveling to and from Washington, D.C. and between 13 other top cities within the northeast and southeast rail system. Each station fact sheet provides an overall travel pattern of passengers based on a scale of passenger distance traveled and a list of other top cities being travel to and from. Eight station fact sheets were used to estimate the annual ridership between a total of 92 station pairs; calculation tables and fact sheets are provided in Appendix #. The sample data analysis tool provided in Microsoft Excel 2007 software package was used to determine a random sample of 30 station pairs. This sample was then used within the transportation model to assist with forecasting future station ridership.

Five main steps were performed to estimate station-to-station ridership.

1) As seen in section A, determine total ridership and total regional and long-haul ridership split using the passenger statistics listed on the fact sheet within sections entitled, “Quick Recap, 2009 (arrivals and departures)” and “Amtrak Presence at this Station”. It is imperative to determine the split of regional and long-haul passenger totals, because the station-to-station ridership is based on passenger distance traveled.

2) As seen in section A and B, determine the corresponding distance split of regional and long-haul trips by closely matching the passenger totals in section A with the percentage splits in section B. This step uses the section of the fact sheet entitled, “Trips by Distance, 2009”, which provides the distribution of total station passengers based on distance traveled. The fact sheet does not...
break out regional and long-haul totals; therefore, the passenger percentages must be adjusted to estimate the split based on passenger totals established in step 1. Notice in section B, the blue area indicates that at the Washington, D.C. Amtrak Station regional trips are within 0-399 miles and account for 92% of total ridership; and the red area shows long-haul trips as anything 400+ miles and accounting for 8% of total ridership.

3) Using the list of top city pairs shown in the fact sheet sections entitled, “Top City Pairs by Ridership / Revenue, 2009”, first determine which city corresponds to the regional and long-haul splits estimated in steps 1 and 2, and input the class in section C of the table. Once cities are classified based on distance, then passenger splits in section C and be calculated.

4) Distribution rates must be calculated based on total 2009 ridership at each city station and applied to the passenger split calculation. Distribution rates were calculated using all 92 stations and are shown in the appendix.

5) As seen in section C, Annual Ridership and Passenger Splits for each city pair are calculated using classification of trips, distributions rates, and passenger percentages in section B. For example, to calculate annual passengers traveling to and from Washington, D.C. between Baltimore, MD; first determine the distance and classification of trip (41 miles and regional); next identify distance parameter and corresponding percentage of total ridership (0-99 miles and 9.9%). If other station pairs exist within 99 miles of Washington, D.C., then the Baltimore station won’t account for the total 9.9% of ridership and a distribution rate must be applied to passenger split (9.9 x 0.6 = 6.0). Last, calculate Annual Ridership (6.0 x 4,151,457 = 247,037 passengers).

**GIS Network Analyst Process for Service Area Catchment**

The study service area was calculated using the Network Analyst Extension Tools provided in ArcGIS 9.3 software. Figure E-2, shown below is the process model used to calculate the study service area for the railroad corridor between Union Station, Washington, D.C. and Staple Mills Road Station, Richmond, Virginia. The following is a description of each model step:

1) **Convert NTAD Shape File to a Network Dataset**: The 2009 Highway planning shapefile, downloaded from National Transportation Atlas Database, was used to create a network data set file in order to perform the net work analysis in ArcGIS. ArcCatalog was used to convert the shape file into a network dataset file.

2) **Upload Network Dataset (ND) File**: The ND file was then uploaded into ArcMap using the add data function under the layers button. Once uploaded there should be three visible layers, the road network, stop nodes, and junction nodes.

3) **Create Service Area Layer**: The service area layer is created using the “Create Service Area” tool in the Network Analyst Extension of ArcMap. When this layer is first created it loads as a blank layer, so nothing in the map view window will appear until you run a simulation.

4) **Create Facility Layer**: A facility layer is created using ArcCatalog by saving an existing shapefile as a layer file. For this analysis, Amtrak stations shape file was saved as a layer file, and then loaded into the service area layer as facilities. These locations will represent our facilities in the simulation.

5) **Set Analysis Parameters**: Analysis Parameters are set within the service area layer to guide the simulation to produce the desired result. For this analysis, limits of 20 and 40 miles are set to project service rings based on the existing network dataset of major highways. Once all parameters are set then the simulation is run by clicking the “solve” button in the Network Analyst toolbar.
The results of the service area analysis shows all regions that have access to study Amtrak stations using a major highway network from a maximum 40 miles away from each station. The reason for preparing this analysis is to capture a more accurate estimation of the population areas served within the study corridor, then by simply projecting a service area buffer ring from each station.

![Process Model](image)

**Figure E-2: Process Model**

**Railway Capacity Analysis**

**Railway:** For the purpose of this report, the capacity measurements outlined in the following two tables provide a viable method for estimating railway capacity within the study rail corridor. Rail capacity can be measured using many variable factors, such as topography, load factors, dwell times, operating speeds, train length, track curvature, etc. The capacity measurement borrowed from the following calculates capacity for archetypical railway corridors based on the number of tracks, number of trains, and control type.

Table E-1 provides the maximum number of trains per day that can operate under practical conditions based on number of tracks and control type for archetypical corridors. The existing study rail corridor between Richmond, VA and Washington, D.C., operates CSX freight trains, VRE passenger trains, and Amtrak passenger trains on two (2) tracks using Centralized Traffic Control (CTC).

Table E-2 shows the parameters for estimating the Level of Service (LOS) of archetypical railway corridors based on the calculation of a volume-to-capacity (V/C) ratio expressed as (# of Trains Per Day / Practical Maximum # of Trains Per Day). This LOS calculation is similar to the HCM method of measuring LOS for highways based on V/C ratios.
Table E-3 shows the calculation of the existing capacity for the study rail corridor. Based on general timetable and public information of CSX, VRE, and Amtrak daily operations, approximately 54 trains operate daily along the study corridor. According to table E-2 a corridor with 2 tracks that operates using CTC has a practical maximum capacity of 75 trains per day. Therefore, the existing V/C ratio of the study corridor is 0.72 (54/75) and the corridor operates at an LOS D, near capacity. For purposes of this report, a third track is assumed to be completed within the study corridor, which would allow for a future practical maximum capacity of 133 trains per day to operate. Increased operations of train operators is unknown, therefore it is only appropriate to assume that train operation within the future study corridor will increase no more than (133 – 54) 79 trains per day to maintain an operating LOS of D or better.
**Cost Benefit Analysis of Washington-Richmond High-Speed Rail**

**Table E-1: Average Capacities of Archetypical Rail Corridors (Trains per Day)**

<table>
<thead>
<tr>
<th>Number of Tracks</th>
<th>Type of Control</th>
<th>Practical Maximum If Multiple Train Types Use Corridor*</th>
<th>Practical Maximum If Single Train Type Uses Corridor**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N/S or TWC</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>ABS</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>N/S or TWC</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>CTC or TCS</td>
<td>30</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>CTC or TCS</td>
<td>53</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>CTC or TCS</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>CTC or TCS</td>
<td>133</td>
<td>163</td>
</tr>
<tr>
<td>5</td>
<td>CTC or TCS</td>
<td>173</td>
<td>230</td>
</tr>
<tr>
<td>6</td>
<td>CTC or TCS</td>
<td>248</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td></td>
<td>360</td>
<td>415</td>
</tr>
</tbody>
</table>

Key:  
N/S-TWC – No Signal/Track Warrant Control.  
ABS – Automatic Block Signaling.  
CTC-TCS – Centralized Traffic Control/Traffic Control System.

Notes:  
* For example, a mix of merchandise, intermodal, and passenger trains.  
** For example, all intermodal trains.

Source:  
Class I railroads’ data aggregated by Cambridge Systematics, Inc.

Table E-1 provides the maximum number of trains per day that can operate under practical conditions based on number of tracks and control type for archetype corridors. The existing study rail corridor between Richmond, VA and Washington, D.C., operates CSX freight trains, VRE passenger trains, and Amtrak passenger trains on two (2) tracks using Centralized Traffic Control (CTC).
Table E-2: Volume-to-Capacity Ratios and Level of Service Grades

<table>
<thead>
<tr>
<th>LOS Grade</th>
<th>Description</th>
<th>Volume/Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Below Capacity</td>
<td>Low to moderate train flows with capacity to accommodate maintenance and recover from incidents</td>
</tr>
<tr>
<td>B</td>
<td>Below Capacity</td>
<td>0.2 to 0.4</td>
</tr>
<tr>
<td>C</td>
<td>Below Capacity</td>
<td>0.4 to 0.7</td>
</tr>
<tr>
<td>D</td>
<td>Near Capacity</td>
<td>Heavy train flow with moderate capacity to accommodate maintenance and recover from incidents</td>
</tr>
<tr>
<td>E</td>
<td>At Capacity</td>
<td>Very heavy train flow with very limited capacity to accommodate maintenance and recover from incidents</td>
</tr>
<tr>
<td>F</td>
<td>Above Capacity</td>
<td>Unstable flows, service breakdown conditions</td>
</tr>
</tbody>
</table>

Source: Cambridge Systematics, Inc.

Table E-2 shows the parameters for estimating the Level of Service (LOS) of archetypical railway corridors based on the calculation of a volume-to-capacity (V/C) ratio expressed as (# of Trains Per Day / Practical Maximum # of Trains Per Day). This LOS calculation is similar to the HCM method of measuring LOS for highways based on V/C ratios.
Supplemental Maps

Figure E-3: Home Departure Time (Map 1)

Home departure time represents the time that workers leave their homes in the morning to travel to work. This map shows the time that workers leave their homes in 30-minute increments from 5 a.m. - 9 a.m. This data was analyzed to give Amtrak an idea of how to best schedule trains to meet the demands of commuters. This map is best understood when the analysis is combined with the origin-destination maps and the travel time maps as departure time will depend on to where a commuter is traveling for work and the length of time it takes to get there.

Looking solely at this map, it can be seen that the majority of commuters in Northern Virginia and D.C. leave their homes 7:00 and 8:29 a.m. In Manassas, Prince William, and Stafford counties; however, there is a greater number of commuters that depart between 6:00 and 6:29 a.m. Considering these commuters live further from large employment centers, such as D.C. and Fairfax County, it is not surprising that they may be commuting longer distances and using various modes of travel which require more time.

The Richmond region demonstrates a similar pattern of commuters departing between 7:00 and 8:29 a.m. Compared to neighboring counties, Chesterfield County shows a greater number of workers leaving home before 7:29 a.m., which similar to outlying jurisdictions in Northern Virginia, could be due to distance traveling and/or the use of multiple modes to get to work.

In all counties and the District there is a significant decrease in the number of commuters departing during the 8:30 – 8:59 a.m. period, indicating the probability that most workers begin working before 9:00 a.m.
Group A: Northern Virginia and District of Columbia Residents Work Locations

Travel via SOV (Map 2)

Travel via Rail (Map 3)

Travel via All Modes (Map 4)
Group B: Middle Region Work Residents Work Locations

Travel via SOV (Map 5)

Travel via Rail (Map 6)

Travel via All Modes (Map 7)
Group C: Richmond Region Residents Work Locations

Travel via SOV (Map 8)

Travel via Rail (Map 9)

Travel via All Modes (Map 10)
45+ Minutes Travel Time

All Modes (Map 11)

SOV (Map 12)

Rail (Map 13)
The 2030 population growth map depicts the estimated population growth of service area counties and cities. Population growth was calculated using an annual compounded growth rate of 1 percent applied to all counties and cities. This growth percentage is consistent with typical long range plans of Metropolitan Planning Organizations within the service area; however it is simply a growth rate applied equally to all counties and does not account for general growth pattern shift affected by important variables, such as economic and land use changes. An annual 1 percent growth rate applied to the entire service area results in a 15.8 percent total growth in population over 30 years for each city and county. Assuming that each county will follow this growth trend, then the region would also experience a proportionate increase in probably ridership and HSR would be a great benefit for the region. Historically, Virginia has experienced a population trend of decentralization in major cities, but this is not reflected in the estimate growth calculated for this report.
Appendix F: Works Cited

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