How Big Are the Environmental Benefits of High-Speed Rail? A Cost-Benefit Analysis of High-Speed Rail replacing automobile travel in the Georgetown-San Antonio corridor.

By

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An Applied Research Project
(Political Science 5397)
Submitted to the Department of Political Science
Texas State University
In Partial Fulfillment for the Requirements for the Degree of
Masters of Public Administration
Fall 2011

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Abstract

Purpose. The purpose of this study is to determine the environmental impact of a high-speed rail network operating in the Georgetown-San Antonio corridor *Methods.* This research uses a cost-benefit analysis methodology in order to determine whether high-speed rail will reduce the annual carbon dioxide levels produced by automobiles in the Georgetown-San Antonio corridor. The data used for this study derive from existing published studies. The study then compares five types of high-speed rail technologies that are planned for use in the United States to determine which option has the lowest annual output of CO_2 during operation. *Results.* The results show that high-speed rail significantly reduces annual carbon dioxide levels within the corridor due to the cancelling out of annual automobile trips in the Georgetown-San Antonio corridor. The German Intercity Express (ICE) is found to be the appropriate high-speed rail technology to have operating in the corridor, in producing the lowest annual emission cost of carbon dioxide of the five high-speed rail technologies. *Conclusion.* Operation of a German Intercity Express (ICE) high-speed rail network would benefit communities in the Georgetown-San Antonio corridor by reducing the annual amount of automobile carbon dioxide emissions.

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About the Author

Kevin Scott earned his Masters of Public Administration candidate from Texas State University in San Marcos. He completed his undergraduate studies at Texas State University in San Marcos, earning a Bachelor of Applied Arts in Public Administration in 2009. His interest in high-speed rail came from his major focus in Urban and Environmental Planning during graduate and undergraduate studies, along with his time as an intern at the Texas Commission on Environmental Quality. He has lived and worked in the I.H. 35 corridor and during this time observed the population / urban growth and related Environmental, Transportation and Economic impacts. These impacts have influenced his interest in Environmental and Transportation related issues. Mr. Scott Lives in New Braunfels, Texas and can be reached by email at kevin89gloves@gmail.com

Chapter 1: INTRODUCTION

Introduction

The United States Government spends billions of dollars annually on highways and public transit systems, but traffic congestion remains. Rush hour in many cities now lasts all morning and afternoon, reaching far into surrounding suburbs. Traffic tie-ups cost motorists at least $74 billion every year in wasted time and fuel (Hosansky 1999, 729).

Of the 1,700 mile length of Interstate 35 from Mexico to Canada, the section with the highest levels of fatalities, the worst congestion, the slowest average speed per mile, and the highest levels of air pollution is the Georgetown-San Antonio corridor (Austin-San Antonio Commuter Rail District 2003, 1). These problems occur in part due to the population boom along the Georgetown-San Antonio corridor. Experts expect the corridor's population to double almost five million people - the size of the Dallas-Ft. Worth metroplex by the year 2023 (Austin-San Antonio Commuter Rail District 2003, 1). The construction, maintenance and improvement of I-35 required to accommodate current and future traffic will take decades to complete causing further traffic delays. The Texas Department of Transportation's attempt to help divert the amount of traffic on I-35 has been to add toll roads along the Georgetown-San Antonio corridor. The effect has been positive, with freight vehicle traffic now using the State highway 130 toll way; but, the toll ways have had a limited impact on the daily commuter traffic and congestion continues to be a daily problem. Texas Legislature and relevant State and Federal Agencies should review alternative modes of transportation to help alleviate congestion on the Georgetown-San Antonio corridor. One strategy to relieve the traffic burden is a proposed high-speed rail system from Dallas to San Antonio and from Austin to Houston, called the Texas T-plan. The Texas T-plan looks at either using existing Union Pacific lines, or investing new rail lines specifically for high-speed rail use. The Union Pacific rail line is suited to passenger service via high-speed rail and could transport passengers through the Georgetown-San Antonio corridor faster than automobile. High-speed rail could provide services to the region's major destinations—downtown Austin or San Antonio, University of Texas, Texas State University, University of Texas San Antonio, Austin Community College, San Antonio Community College, tourist attractions (Schlitterbahn water parks, 6th street nightlife area, San Antonio Riverwalk), and to major employers in Travis, Hays, Comal, and Bexar counties. Appendix A provides a proposed map of the Lone Star Rail system.

Currently no environmental impact study exists for the Georgetown- San Antonio corridor; however, the TCEQ has initiated an environmental impact study for the entire Texas T-plan corridor. This ARP uses a costs benefit analysis in determining the amount of annual automobile carbon-dioxide emissions savings in the Georgetown-San Antonio corridor due to a forecasted number of commuters switching mode of transportation to using high-speed rail. The second part of the ARP then looks at five high-speed rail technologies (MagLev, German Intercity Express, TGV, IC-3, Shinkansen) that are being considered for use in the United States' high-speed rail network. The ARP compares the five different technologies to determine which of the five provides the best benefit to the corridor in emitting the lowest amount of carbon dioxide annually during operation.

Research Purpose

The purpose of this ARP is to determine the benefits and costs received by the Georgetown-San Antonio corridor as a result of high-speed rail network being in operation. The benefits received by the corridor come in the form of annual weekday vehicle trips canceled within the Georgetown-San Antonio corridor. The next benefit is the amount the daily weekday commuter saves annually in automobile carbon dioxide emissions by opting not to use their automobile. Lastly, the net annual automobile carbon dioxide emissions saved by the corridor as automobile trips are cancelled out. The costs acquired as a result of a high-speed rail network being in operation include the following: What the individual commuter emits in annual CO_2 emissions by using each of the five high-speed rail technologies. The cost being the annual amount of carbon dioxide that each of the five high-speed rails emit into the Georgetown-San Antonio corridor during operation. The ARP then determines out of the five high-speed rail technologies (MagLev, Shinkansen, IC-3, ICE, and TGV) which option has the greatest environmental benefit in emitting the least amount of CO_2 annually.

Chapter Summaries

This study begins with a review of potential benefits the United States would receive in taking part of United States President Barack Obama's vision to incorporate high-speed rail systems into the nation's overburdened transportation system. In chapter two, the research reviews and examines the available literature on high-speed rail transportation and its related benefits. The literature review discusses the benefits of high-speed rail in alleviating highway and airport congestion; reducing pollution and energy use in the transportation sector; promoting economic development; improving transportation safety; providing more options for travelers;

and making transportation more reliable by increasing redundancy in the national transportation system.

Chapter three describes the methodology used to operationalize the environmental benefits and costs associated with a high-speed network in the Georgetown-San Antonio corridor. This paper primarily focuses on the amount of CO_2 saved emitted in the corridor. This chapter discusses how each cost and benefit associated with CO_2 is measured and how the resulting comparison generates meaningful results to support whether to implement a high-speed rail network in the corridor or not.

Chapter four presents the results of the analysis. The results of this study show direct benefits in the form of annual vehicle trip cancellations within the corridor, the amount the commuter saves in annual automobile carbon dioxide emissions, and net annual automobile emissions saved by the corridor due to a high-speed rail network's operation. Also in this chapter, five high-speed rail technologies are analyzed to determine which of the five technologies presents the greatest annual benefit in emitting the lowest annual amount of CO_2 during operation. The only cost incurred by corridor communities is the annual operation of the high-speed rail network, and the CO_2 emitted during its operation.

Chapter five provides a summary of the cost benefit analysis performed on a proposed high-speed rail network operating within the Georgetown-San Antonio corridor. Then recommending which high-speed rail technology will provide the largest benefit to the region by reducing annual automobile CO_2 emission, while emitting the lowest amount of CO_2 annually of the five high-speed rail technologies.

Chapter 2: LITERATURE REVIEW

Introduction

The purpose of this chapter is to review and examine available literature on high-speed rail transportation and the accompanying benefits the rail system brings when integrated into a national transportation system. The literature review discusses the benefits provided to other countries utilizing high-speed rail and the role the rail system has played to alleviate highway and airport congestion; reduce pollution and energy use in the transportation sector; promote economic development; improve transportation safety; provide more options for travelers; and make transportation more reliable by increasing redundancy in the national transportation system. Additionally, this literature review assesses the environmental impact of five high-speed rail technologies (Shinkansen, TGV, ICE, IC-3, MagLev) that the United States is looking at using in the nation's high-speed rail network, and each technology's effect on air quality, specifically carbon dioxide (CO_2) emissions during operation.

High speed rail transforming the United States' transportation system

The first United States presidents to introduce the possibility of high-speed rail in the United States were Ronald Reagan and George W. Bush; however, both showed little interest in advanced rail technology, mainly because development of any commercially viable high-speed rail network would require the federal government to underwrite much of the capital costs. The Clinton administration brought a sea of change to government involvement in high-speed rail. President Clinton spoke often about the idea of high-speed rail in the United States during his 1992 Presidential campaign.

“I strongly support the development of high-speed rail because we need to ensure that we possess a transportation system that boosts American productivity and international competitiveness”. “Passenger rail service creates jobs, conserves energy and provides an opportunity to avoid airport expansion” (Worsnop 1993, 2). On April 16, 2009, President Barack Obama, along with Vice President Joe Biden and Secretary of Transportation Ray LaHood announced a new federal push to transform travel in the United States (as presented in image 2.1).

Image 2.1: high-speed intercity passenger rail program

Source: http://www.fra.dot.gov/rpd/downloads/HSIPR_Summary_of_Federal_Investments_070811.pdf

Thus was born a vision to create high-speed rail lines between major cities in the United States. The president held that high-speed rail would benefit the United States as a whole, reducing dependence on cars and planes and spurring economic development and made high-speed rail part of the Recovery and Reinvestment Act. In President Obama's address to the nation describing the Recovery and Reinvestment Act, he outlined the following vision for the incorporation of high-speed rail into the U.S. transportation system.

> Today, our aging system of highways and byways, air routes and rail lines is hindering that growth. Our highways are clogged with traffic, costing us $80 billion a year in lost productivity and wasted fuel. Our airports are choked with increased loads. Some of you flew down here and you know what that was about. We're at the mercy of fluctuating gas prices all too often; we pump too many greenhouse gases into the air. What we need, then, is a smart transportation system equal to the needs of the 21st century. A system that reduces travel times and increases mobility. A system that reduces congestion and boosts productivity. A system that reduces destructive emissions and creates jobs. What we're talking about is a vision for high-speed rail in America. Imagine boarding a train in the center of a city. No racing to an airport and across a terminal, no delays, no sitting on the tarmac, no lost luggage, no taking off your shoes. 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 (U.S. Office of the Press Secretary 2009, 1-4).

President Obama envisions that high-speed rail has the opportunity to be successful in the United States by helping relieve the country's economic depression and reducing the burden on overworked transportation systems. The ability to travel quickly by rail between most major urban centers might not be a problem now, but it will be by 2050 when the U.S population has grown by 130 million people (Peterman, Fritteli, and Mallet 2009, 14).

Peterman, Fritteli, and Mallet believe that future intercity passenger mobility will be dependent on fully utilizing all of the available options (Peterman, Fritteli, and Mallet 2009, 14). The authors cite a number of benefits in support of developing high-speed rail. Benefits include:

the potential role of high-speed rail in alleviating highway and airport congestion; reducing pollution and energy use in the transportation sector; promoting economic development; improving transportation safety; providing more options for travelers; and making transportation more reliable by increasing redundancy within the national transportation system.

High-speed rail- traffic congestion and its costs

The government spends billions of dollars annually on highways and public transit systems but traffic congestion seems worse than ever. Rush hour in many cities now lasts all morning and afternoon and reaches far into the surrounding suburbs. Traffic congestion caused urban Americans to spend 4.8 billion additional travelling hours and to purchase an extra 3.9 billion gallons of fuel for a combined cost of $115 billion (Schrank, Lomax, Turner 2010, 1). As planners search for ways to modernize the nation's overburdened transportation network, they are increasingly looking ―back to the future." They see the humble railroad train, which helped shaped the Industrial Revolution 200 years ago, transforming life in the 21st century. But the sleek trains the planners envision are barely related to their smoke-belching forebares (Hosansky 1999, 742).

High-speed rail operating in Europe and Asia

High-speed rail has been in commercial service in Europe and Japan for decades. Japan's famed ―bullet" trains began operating in 1964, just before the start of the Olympic Games in Tokyo. Train à Grande Vitesse (TGV), France's high-speed trains began regular passenger runs in 1981 (Hosansky 1999, 742). Transportation officials in the United States hope new trains will lure hurried travelers from congested roadways and air corridors in the Northeast. High-speed rail could be the option that relives those exhausted modes of transportation because it ―is a heck of a lot cheaper than the never ending business of widening highways and expanding airports," says Amtrak spokesman John Wolf (Hosansky 1996, 743).

Vuchic and Casello (2002, 34) also recognize the need for high-speed rail in the United States. The authors believe wasted time and fuel plague those using the nation's highway transportation system. Thus, the need for high-speed ground transportation systems has intensified in recent decades as congestion in major cities continues to be a problem due to rising populations. All industrialized countries have faced two serious transportation problems in urbanized regions and in major intercity corridors, as a result of increasing transportation congestion. First, highway and street congestion become a chronic problem, causing longer travel times, economic inefficiencies, and deterioration of the environment and quality of life. Secondly, the same congestion problems are occurring at airports, as seen by overcrowding of people and flights in the terminals. These two problems were addressed by the April 16, 2009 vision for high-speed rail in America speech given by President Obama, who stated investing in a high-speed rail will ―loosen the congestion suffocating our highways and skyways" (Tanaka & Monji 2010, 7).

An example of congestion relief to a country's transportation system is evidenced by the post-assessment of the Japanese high-speed rail train Kyushu Shinkansen, carried out by the Japanese railway construction, transport, and technology agency. The post-assessment results support President Obama's claim that high-speed rail will ease the amount of congestion on other modes of transportation by decreasing the yearly total number of users on highways and skyways. Since the commencement of the Kyushu Shinkansen train system in March, 2004, results of annual ridership data have shown the share of travel using high-speed rail in the corridor between Fukuoka and Kagoshima increased from 41 percent to 71 percent and the share of travel by air decreased from 42 percent to 12 percent. Although the number of bus users increased, the total share of transportation by bus fell from 18 percent to 17 percent and the number of high-speed rail users increased substantially. As for the transportation share in the corridor between Kumamoto and Kagoshima, the share of travel by high-speed rail rose from 88 percent to 99.5 percent, whereas, the share by bus fell from 12 percent to 0.5 percent, due to the termination of the Highway express bus services (Tanaka & Monji 2010, 7).

Shinkansen high-speed rail post-assessment

A questionnaire survey targeted Shinkansen users and questioned the mode of transportation the participants used before the operational start of Shinkansen. Findings indicate that 20 percent of all Shinkansen users changed from air travel to Shinkansen, and 25 percent switched from driving a car to riding Shinkansen. Evaluation of the purpose of trip showed that 33 percent of the Shinkansen business users switched from air to Shinkansen; whereas, approximately 35 percent of users traveling for leisure and recreation changed from the automobile to the Shinkanen service (Tanaka & Monji 2010, 7). With the operation of Kyushu Shinkansen, travel times fell, and the use of the railway for work and school commuting from Izumi City and Satsuma Sendai City to Kagoshima City and other cities increased significantly. In the second year of the Kyushu Shinkansen service, and ever since, commuter numbers have increased. As of January 31, 2007, the number of commuters using the railway was 1,100 a day, approximately eleven times the number before the launch of Shinkansen in January, 2004 (Tanaka & Monji 2010, 7). The post-assessment of Kyushu Shinkansen by the Japan Railway Construction, Transport, and Technology Agency confirms the increase in the number of passengers with the commencement of the new Shinkansen route, thus reducing the burden on air and ground transportation.

Congestion studies in the United States

In 2009, the Texas Transportation Institute conducted a study similar evaluating urban mobility. The study found that traffic congestion and lost productivity, along with related effects, diminish quality-of-life in and around the mega-regions of the United States. The Texas Transportation Institute estimated the cost of congestion in 2007 alone at $87.2 billion, and 2.8 billion gallons of gasoline were wasted in America's 439 urban areas (Texas Transportation Institute 2009, 1). The estimated costs of congestion indicated continued growth of these mega-regions will place more stress on local transportation systems. In these areas, the average annual delay per traveler is over 34 hours, which equates to about three days per year lost due to congestion (Texas Transportation Institute 2009, 1). The report finds high-speed rail could be particularly beneficial in relieving the economic and social costs caused by congestion in mega-region areas.

A recent analysis by the United States Conference of Mayors showed the introduction of high-speed rail services could have substantial impact on how many people make intercity trips. The report examined four potential high-speed rail hubs (Los Angeles, Albany, Orlando, and Chicago) and found that high-speed rail could potentially reduce automobile trips in these cities by 27 percent on average, and eliminate the need for 100,000 annual short haul flights (United States Conference of Mayors 2010, 26). A report by CALPIRG Education fund authors (Tony Dutzik and Erin Steva 2010, 1), investigates the benefits of high-speed rail around the world, and found high-speed rail a suitable replacement for short-haul air travel congestion, and a replacement for commuter automobile travel. In California, the report concluded that high-speed rail would ease future congestion on the roadways caused by population increases, and could reduce the need for expensive highway and airport expansions. High-speed rail service has virtually eliminated short-haul air service in several European corridors, such as Paris and Lyon, France; and Cologne and Frankfurt, Germany. The number of air passengers between London and Paris has reduced by half since high-speed rail service was initiated between the two cities through the Channel Tunnel. The recent launch of high-speed rail service between Madrid and Barcelona, Spain, has cut air travel by one third on what was once one of the world's busiest passenger air routes. High-speed rail service between Madrid and Seville has reduced the share of travel by car between the two cities from 60 percent to 34 percent (CALPIRG 2010, 1). Even in the northeastern United States where Amtrak Acela Express service is low by international standards, rail service accounts for 62 percent of the air/rail market on trips between New York and Washington D.C., and 47 percent of the air/rail market on trips between Boston and New York. Oliver Hauck, the president of the mobility division of Siemens industry, Inc., finds high-speed rail could take as many as 28 million car trips off the road yearly in the United States, reducing inner-city car travel by more than 27 percent. This reduction in highway congestion could free up existing highway lanes resulting in a lower annual number of accidents and automobile deaths.

The most congested car dependent cities receive the greatest benefit from high-speed rail operation, by reducing the number of intercity car trips and getting commuters within and from work without congestion that causes economic and social hardships. According to the 2010 study conducted by the United States Conference of Mayors, congestion rates can be reduced at the following rates in the following major cities due to the availability of high-speed rail, (in Los Angeles- reduced as much as 37 percent, in Chicago- reduced as much as 33 percent, in Orlando- reduced as much as 18 percent, and in Albany- reduced as much as 22 percent) (United States Conference of Mayors 2010, 26). As Benjamin Franklin said, ―time is money." Workers stuck in traffic are less productive, and delayed goods are less valuable to customers when delayed. Even if commuters are sacrificing only leisure time, delays still have social and economic consequences. For example, research shows that children's' school performance is heavily dependent on parental involvement, in schooling - which could be hindered if the parent is commuting on a congested freeway (Romero 2008, 9). In addition, wear and tear on vehicle parts (e.g., on brakes in stop and go traffic), plus fuel consumed while idling, are additional economic costs associated with traffic congestion (Romero 2008, 9). With the introduction of high-speed rail the amount the government spends annually on highway and public transit systems will decline in relation to fewer vehicles on the roads.

High- speed rail- influence on climate change and oil scarcity

The challenges confronting climate change and potential oil scarcity are increasingly becoming major policy issues. To reduce transport emissions and oil dependency, a wide array of system changes must be applied together, including more fuel-efficient vehicles, less carbon intensive fuels, urban planning that supports cycling and public transportation, and improved attractiveness of transport modes with a low climate impact. A key to reducing annual greenhouse gas emission levels occurs with carbon pricing. Carbon pricing is the generic term for placing a price on carbon through subsidies, a carbon tax, or an emissions trading (cap-and-trade) system. Assigning an approximate cost to damage done by greenhouse gas emissions using carbon pricing may incentivize a reduction of carbon emissions and the discovery or implementation of low-emission technologies, such as high-speed rail.

Oil powers 95 percent of America's cars, trucks, ships, planes, and railcars (Langer 2005, 3). The United States is the largest oil consumer and importer in the world, and relies on imports for more than half of its oil consumption (as shown in Appendix B). The environmental impact of petroleum powered vehicles is a rising concern; nevertheless, most Americans cannot afford automobiles that use an alternative energy source due to the cost. Today, an American driving thirty two miles a day, to and from work, will spend almost $1000 a year on gasoline (Langer 2005, 3). The recovery act seeks to directly tackle such issues with a multi-pronged approach investing in technologies that will make alternatively powered vehicles cheaper, technologies that will make an alternative energy vehicle structurally feasible, and a high-speed rail network that will reduce travel time and congestion (United States Department of Transportation 2009, 8).

High-speed rail- environmentally friendly transit

European countries are making the best of the available renewable energy technologies available to power high-speed rail networks. In Sweden, the country's high-speed trains are powered entirely with renewable energy, cutting emissions of global warming pollutants by 99 percent (CALPIRG 2010, 2). France, a model of non-oil transportation, constructed electrified railroad lines. The TGV high-speed passenger rail technology used in France is powered by nuclear generated electricity, lowering annual greenhouse gas emissions. High-speed rail networks would be constructed using Transit Orientated Development, and busy bus routes not diverted to high-speed rail would be converted to electric trolley buses. Cycling would also be encouraged (Drake, Bassi, Tennyson, Herren 2009, 5). In Europe, high-speed rail is electric and the only motorized mode of transport capable of shifting from fossil fuels to renewable energy without separate investment in the propulsion units. Europe could move to renewable electricity without changing anything else. At the present, renewable energy only accounts for 14 percent of the European Union's electricity production, but the European commission seeks to raise this to

20 percent by 2020 (Community of European Railway and Infrastructure Companies and International Union of railway 2008, 12).

Alberto Alvarez (2010) analyzes the differences between high-speed rail technologies, energy consumption and greenhouse gas emissions. The comparison includes an empirical verification of the differences between high-speed and conventional rail systems and an analysis based on theoretical models. Alvarez shows, on average, high-speed railway systems usually consume 29 percent less energy than conventional railway systems. With a comparison of the levels of energy consumption and emissions of high-speed passenger trains with those of all other modes of transportation with which it competes, the net effects on emissions of high-speed train service on any corridor can be analyzed. Alvarez compares the Spanish highway rail system Alta Velocidad Espanola (AVE) with the conventional rail system in place in Spain. His results conclude that although there is a difference in the energy consumption rates of the Spanish high speed rail system AVE, and that of conventional rail system, the cost is offset by, the diversion of passengers from air and automobile travel, which ultimately yields significant reductions in energy consumption and emissions. Japan’s Shinkansen uses one quarter the energy of air travel or 1/6 the energy of automobile travel per passenger. The energy efficiency of Shinkansen high-speed rail technology continues to improve over time, and today’s trains use nearly a third less energy, while traveling significantly faster, than the trains introduced in the mid-60s (CALPIRG 2010, 2). On Europe’s high-speed lines, a typical Monday morning business trip from London to Paris via high-speed rail uses approximately a third as much energy as a car or plane trip per passenger.

Diesel powered trains appear to be the technology of choice for most of the high-speed corridors, but these trains generate particulate matter and nitrogen oxides, which can aggravate, and possibly cause, health problems such as asthma. With the world's oil resources gradually being depleted and climate change developing into an environmental threats to human kind, transportation authorities are seeking alternatives to existing forms of energy used for transportation. Less energy consuming and more environmentally-friendly green mobilization alternatives can replace the now heavily gasoline dependent vehicles used for land and air transportation. Many countries are turning to high-speed rail systems as a solution to the decreasing of global oil resources and the development of climate change (Kao, Lai, Shih 2010, 18).

High-speed rail- safe, reliable, and accessible source of transportation

Another benefit of high-speed rail to the United States is a safe, reliable, and accessible transportation service. With respect to safety, any comparison of accident statistics for the different transport modes immediately confirms that high-speed rail is, along with air transport, the safest mode in terms of passenger fatalities per billion passenger-kilometers (Campos 2009, 25). There has never been a fatal accident on Japan's Shinkansen high-speed rail or France's TGV railways, despite those systems carrying millions of passengers over the course of several decades. As the United States population increases, more and more people will need safe and reliable transportation.

High-speed rail safety

While air travel in America is relatively safe, except for rare disasters, car travel is a major killer in United States. In 2008, more than 3,400 people died on California's highways, an improvement over previous years, but still shockingly high (California Office of Traffic Safety, 2010, 20). Appendix C shows the data recorded on traffic fatalities and traffic fatality rates per

100 million miles traveled in the United States from 1990 to 2009. The Federal Railroad administration is also dedicated to improving railroad safety by developing and enforcing safety regulations, along with research and development of railroad safety technologies. The Federal Railroad administration states that high-speed rail options in the United States will actually establish sustained safety records, better than the existing modes of transportation, as shown by zero fatalities in European and Asian nations using high-speed rail (United States Department of Transportation and Federal Railroad Administration 2010, 24). Both the United States Department of Transportation and Federal Railroad Administration agree that introducing high-speed rail into the nation's overburdened transportation system will ultimately reduce property damage, as well as human and monetary terms costs (United States Department of Transportation and Federal Railroad Administration 1997, 6-11).

James Glave and Rachel Swaby (2010, 11-3) insist that human error is less a possibility with high-speed rail, because modern bullet trains are equipped with regenerative brakes, power wheels sets, centralized control systems, and other safety features. Operators rely on a system known as automatic train control, in which traffic and speed information is monitored centrally and displayed on the screen in the driver's cab. Sensors can be placed along the route to monitor for high winds, mudslides, flooding, earthquakes, or misaligned tracks and can trigger alarms or stop the train immediately.

High-speed rail reliability

Another safety feature of high-speed rail is that high-speed trains do not have locomotives, but have powered axles paired into wheel sets called bogies. Rather than placing all the drive wheels at the front, these state-of-the-art systems have bogies up and down the length of the train. This design reduces axle load, maintenance costs, and the risk of a catastrophic "accordion" effect in the event of an accident. In human error scenarios, what happens if a train operator passes out at 150 mph? Nothing, thanks to a time-tested safety device: a dead man's switch. On some lines, drivers must press a button with their foot every 30 seconds. Should they neglect this duty, an audible alarm sounds, and if ignored, the train will initiate an emergency stop. With these safety features onboard high-speed rail trains, the likelihood of an accident is decreased.

Delays plague many forms of transportation, such as cars and planes, in a variety of ways. Air travel at major airports such as San Francisco and Los Angeles are prone to delays. Freeway congestion can force drivers to either allocate extra time to trips or risk changing schedules. High-speed rail provides a reliable mode to reach destinations in other cities on time without delay (CALPIRG 2010, 20).

High-speed rail accessibility

The high-speed train network has improved different regions throughout Europe. High-speed rail stations are located on interconnected railways making regions more accessible, bringing regions closer to each other for travel. This interconnected European network of high speed-railways has restructured entire communities by promoting regional development and encouraging interaction between regions (Gutierrez, Gonzalez, and Gomez 1996, 227). Accessibility is a major factor for a commuter choosing a mode of transportation. The most important and challenging elements in the design of a new high-speed rail network are the number and locations of stations. Each additional station increases the service accessibility crucial for travelers in choosing a mode of transportation (Givoni 2010, 5).

Lone Star Rail in central Texas

The proposed Lone Star Rail would service those who travel from the City of Georgetown (located north of Austin) to San Antonio, and the municipalities in between. Rail operations manager Joe Black says the rail could prove beneficial to students and to those who travel between the congested cities by providing an economic alternative to commuting by car or bus to class and to work. ―It connects just about every major school in the Austin-San Antonio region, like the Texas State campus in Round Rock," Black said. ―Both students and professors will have a better way to go back and forth. With gas prices creeping up, there comes a point where you just have to decide." Dana Stanesic, interdisciplinary studies junior, recently transferred to Texas State and lives in north Austin. She said she has not relocated to San Marcos because she will continue her studies at the Round Rock campus next year. ―I ride the bus to school, but it's half an hour drive from my house to the bus stop," Stanesic said. ―I try not to complain, but commuting is about four hours of my day wasted and sometimes I even get car sick. It would be awesome to have a direct route and not deal with those problems." The Lone Star rail would provide passengers an alternative mode of transportation equipped with free wireless internet, which Black says could benefit students by increasing study time (Bliss 2011, 1-2). Reduced travel time means efficiency.

Japanese Shinkansen high-speed rail

The Japanese high-speed rail technology Shinkansen reduced the travel time between Hakata and Kagoshima by approximately ninety minutes. Compared with the travel time by air over the same route, the travel time of the Shinkansen is ten minutes shorter. The travel time between the Kumamoto and Kagoshima corridor by rail was shortened by more than half, from two hours and twenty three minutes before Shinkansen, to fifty eight minutes after Shinkansen (Tanaka and Monji 2010, 7).

High-speed rail can expand the distances that people can travel, provide businesses with access to more workers with specialized skills, and allow workers to access a greater number of employers. These expanded markets offer important new opportunities, especially in an era of flexible work schedules where daily commutes are not required. In Los Angeles, officials anticipate high-speed rail to increase such communities from outlying areas such as Palmdale and business trips from the central valley and San Diego. In Orlando, high-speed rail could enable commuting from the Lakeland area and day trips from Tampa. In Chicago, high-speed rail could allow commuting from the Milwaukee area and day trips from cities such as Madison. In Albany, New York, faster trains could allow for commuting or business daytrips to New York City (The United States Conference of Mayors 2009, 6-7).

High-speed rail promotes economic development

High-speed rail, according to supporters, promotes economic development, as well as beneficial changes in land use and employment. In the short term, planning, design, and building high-speed rail creates jobs. A high-speed rail network will spur economic development and the creation of long-term jobs, particularly around high-speed rail stations. For example, the California High-Speed Rail Authority declares that its proposal for a high-speed rail connecting northern and southern Californian cities will create 160,000 short-term construction related jobs, and 450,000 long-term jobs in the proximity of high-speed rail stations (Peterman, Frittelli, Mallet 2009, 17). On the question of whether high-speed rail can provide economic benefits for the national economy as a whole by increasing depth of labor markets and improving business travel, President Barack Obama states the recovery and reinvestment plan and the funds allocated for the construction of a national high-speed rail network will save and create 150,000 jobs in the United States. (Office of the Press Secretary 2009,1). By making investments across the country, President Obama plans to lay a new foundation for our economic competitiveness and contribute to urban and rural growth. Jobs created cannot be outsourced, and demand for technology gives a new generation of innovators and entrepreneurs the opportunity to step up and lead the way in the 21st century.

High-speed rail connectivity overcomes traditional isolation from national and international transportation networks, significantly improving the connectivity between different regions throughout a nation. While inter-metropolitan air transport has only a minor impact on improving intermediate cities transport accessibility, high speed rail significantly improves the interconnectivity between cities and metropolises by considerably reducing time distances (Urena, Menerault, Garmendia 2009, 269). Daily expenditures from business tourists can be up to four times more than leisure travelers' expenditures. Business tourism is therefore a key strategy for cities and large urban areas. The high-speed rail that brings Lyon, France closer to the French capital has led to double of this kind of tourism. In addition, the high-speed rail contributed to putting the city of Lyon on the tourist map and increased tourist awareness of the city. As a result, urban tourism in Lyon recorded strong growth (Mason and Petiot 2009, 614). An analysis of the effects of the Mediterranean high-speed rail between Paris and Marseille implemented in 2001 on tourism shows a significant increase in the number of tourists. For example, the southern region has benefited from an increase in short stay travel (extended weekend getaways), and from an increase in travel from specific markets (e.g., young adults, seniors, upper social professional categories, and international travelers) (Masson and Petiot 2009, 614).

Japan's increase in gross domestic product

Japan's economy has also been affected by the construction of the Kyushu Shinkansen, with streamlined business activities. Reductions in business trip expenses, expansion of business opportunities, and ease of holding meetings and business negotiations are all benefits provided by high-speed rail. The economic ripple effect is shown in the post-assessment of the Kyushu Shinkansen. The results show high-speed rail providing an annual increase in the gross domestic product in 2008 (the fifth year of operation) of approximately ¥25 billion ($263 million). In 2013, the 10th year of operation, the gross domestic product will be approximately ¥29 billion ($305 million) (Tanaka and Monji 2010, 4-5).

By maximizing the high-speed rail corridors and station centers with new revitalized economic and community development, affected areas will reap full benefits economically, environmentally, and in energy conservation (United States Department of Transportation and Federal Railroad Administration 2010, 13). A study of the Frankfurt-Cologne high-speed rail line in Germany estimated that areas surrounding the two towns housing new high-speed rail stations experienced a 2.7 percent increase in overall economic activity compared with the rest of the region (CALPIRG 2010, 2). Several cities have used high-speed rail as the catalyst for ambitious urban redevelopment efforts. The city of Lille, France, used a rail station as the core of a multi-use development that now provides 6,000 jobs. The new international high-speed rail terminal at London's St. Pancras station is the centerpiece of a major redevelopment project that will add 1,800 residential units, as well as hotels, offices, and cultural venues in the heart of London. A

British study projects that the construction of the nation's first high-speed rail line will lead to more than $26 billion in net economic benefits over the next sixty years (CALPIRG 2010, 3).

The proposed national high-speed rail network has the potential to generate many benefits by interconnecting regions throughout the United States. These potential benefits mean new relationships between cities, new opportunities for economic investment, sustainable land use patterns, and meeting demand in the northeast corridor. High-speed rail, will affect the economic geography across the regions encompassed, creating significant economic development opportunities for all types of cities. Jobs, wages, business sales, and value added will significantly increase with the introduction of high-speed rail services. For larger cities, high-speed rail service will improve access to labor markets and consolidate business, financial, and cultural/tourism services. For midsized and smaller cities, high-speed rail service will expand access to specialized regional talent and help leverage local investments for accessing larger markets (The United States Conference of Mayors 2009, 7). The following section reviews the CO_2 emission data provided by the Center for Clean Air Policy and Center for Neighborhood Technology on the five high-speed rail technologies designated for operation in the Texas T-Bone corridor.

Designated high-speed rail technologies

This section reviews the CO_2 emission data provided by the Center for Clean Air Policy and Center for Neighborhood Technology on the five high-speed rail technologies (Shinkansen, TGV, ICE, IC-3, MagLev) to determine in the results chapter the best technology to have in operation within the Georgetown-San Antonio corridor.

Shinkansen

The first high speed rail technology looked at in the research comes from overseas in its origin, the country of Japan. Shinkansen literally means new trunk line, referring to the tracks, but the name is widely used inside and outside Japan to refer to the trains as well as the system as a whole. The Tōkaidō Shinkansen is the world's busiest high-speed rail line. Carrying 151 million passengers a year (March 2008), it has transported more passengers (over 4 billion, network over 6 billion) than any other high speed line in the world (Smith 2003, 222). Between Tokyo and Osaka, the two large metropolises in Japan, up to thirteen trains per hour with sixteen cars each (1,323 seats capacity) run in each direction with a minimum headway of three minutes between trains (Smith 2003, 222). Though largely a long-distance transport system, the Shinkansen also serves commuters who travel to work in metropolitan areas from outlying cities. The Center for Clean Air Policy and Center for Neighborhood Technology forecast that Shinkansen will emit 0.22 lbs CO_2 per passenger mile (as shown in Table 2.1)

Table 2.1: Shinkansen CO_2 emission data

Shinkansen Emissions Factor	
349	Kilojoules passenger km
349000	Joules per passenger km
3600000	Joules per kWh
0.097	kWh per passenger km
1.61	Km per mile
0.156	kWh per passenger mile
1.40	Lbs CO_2 per kWh
0.22	Lbs CO_2 passenger mile

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

TGV

The idea of the TGV was first proposed in the 1960s, after Japan had begun construction of the Shinkansen (also known as the bullet train) in 1959. At the time the French government favored new technologies, exploring the production of hovercraft and the Aérotrain air-cushion vehicle. Simultaneously, the French government began researching high speed trains that would operate on conventional track. In 1976 the government agreed to fund the first line. By the mid-1990s the trains were so popular that the French Transportation President Louis Gallois declared TGV "The train that saved French railways." The Center for Clean Air Policy and Center for Neighborhood Technology forecast that TGV will emit 0.15 lbs CO_2 per passenger mile (shown in Table 2.2).

Table 2.2: TGV CO_2 emission data

TGV Atlantique Emissions Factor	
22	kWh per train km
485	seats per vehicle
0.045	kWh per seat km
1.40	lbs CO_2 per kWh
0.06	lbs CO_2 per seat kilometer
0.10	lbs CO_2 per seat mile
0.7	passengers per seat
0.15	lbs CO_2 per passenger mile

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

ICE

The ICE originated as a concept for new land-based high-speed public transportation for Germany, competing with the Transrapid monorail system. The ICE succeeded in being adopted nationwide in Germany. It is argued that the ICE prospered in part because of its ability to run on conventional tracks (albeit not at full speeds - on tracks near stations they are known to be passed by commuter trains, especially by S-Bahn trains) (Peter 2006, 20). The shared use of old tracks also means that conventional trains often have to wait for late ICEs to pass, leading to further delays. ICE established the world speed record for conventional trains on 1 May 1988 although it has since been surpassed by French TGV (Peter 2006 20). The Center for Clean Air Policy and Center for Neighborhood Technology forecast that ICE will emit 0.11 lbs CO_2 per passenger mile (shown in Table 2.3).

Table 2.3: ICE CO_2 emission data

ICE line 6 Emissions Factor	
24.09	kWh/train km
689	seats per train
0.035	kWh per seat km
0.056	kWh per seat mile
1.40	lbs CO_2 per kWh[36]
0.079	lbs CO_2 per seat mile
0.7	passengers per seat
0.11	lbs CO_2 per pass mile

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

IC-3

The IC-3 is a Danish-built high-comfort medium/long distance diesel multiple-unit train. The sets were built by the Danish company ABB Scandia (later purchased by Adtranz, which itself was subsequently acquired by Bombardier Transportation). This train model has been operating in Denmark and Sweden since 1989. The name indicates simply that it is a three-carriage InterCity trainset (Bombardier INC, 2001). The short distances between stations on inter-city routes in Denmark makes acceleration more important than high top speed, and so the

IC-3 units are geared for a top service speed of only 180 km/h (112 mph) (Bombardier INC, 2001). The most significant feature of the IC-3 is the front- and cab-design. When viewed from the outside, the viewer will notice the large rubber diaphragm surrounding a flat cab. When two or more units are coupled together in a single train, the entire front door folds away to give a wide passage, and the rubber diaphragms at the ends form a flush aerodynamic seal. The IC3 can also couple and run in tandem with the electrical version, the IR4 (Bombardier INC, 2001). The Center for Clean Air Policy and Center for Neighborhood Technology forecast that IC-3 will emit 0.26 lbs CO_2 per passenger mile (shown in Table 2.4).

Table 2.4: IC-3 CO_2 emission data

Danish IC-3 Emissions Factor	
436.5	kg diesel per train per trip
197	km per trip
2.22	kg diesel per train km
138	seats per train
0.84	grams per ml diesel
0.000264172	gallon per ml
3.18	kg per gallon diesel
0.696	gallon diesel per km
1.609344	km per mile
1.12	gallon diesel per train mile
0.008	gallon diesel per seat mile
22.384	lbs CO_2 per gallon diesel
0.18	lbs CO_2 per seat mile
0.26	lbs CO_2 per pass mile

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

MagLev

Maglev (derived from magnetic levitation), is a system of transportation that uses magnetic levitation to suspend, guide and propel vehicles from magnets rather than using mechanical methods, such as friction-reliant wheels, axles and bearings. Maglev transport is a means of flying a vehicle or object along a guideway by using magnets to create both lift and thrust, only a few inches above the guideway surface (Yan 1999, 1-12). High-speed Maglev vehicles are lifted off their guideway and thus move more smoothly, quietly and require less maintenance than wheeled mass transit systems – regardless of speed. This non-reliance on friction also means that acceleration and deceleration can far surpass that of existing forms of transport. The power needed for levitation is not a particularly large percentage of the overall energy consumption; most of the power used is needed to overcome air resistance (drag), as with any other high-speed form of transport (Yan 1999, 1-12). The highest recorded speed of a Maglev train is 581 km/h (361 mph), achieved in Japan by the CJR's MLX01 superconducting Maglev in 2003, 6 km/h (3.7 mph) faster than the conventional TGV wheel-rail speed record (Yan 1999, 1-12). The Center for Clean Air Policy and Center for Neighborhood Technology forecast that MagLev will emit 0.49 lbs CO_2 per passenger mile (shown in Table 2.5).

Table 2.5: MagLev CO_2 emission data

MagLev TR07 Emissions Factor	
23.75	kWh per train km
1.609344	km per mile
38.22	kWh per train mile
1.40	pounds CO_2 per kWh
53.50	pounds CO_2 per train mile
156	seats per train
0.34	lbs CO_2 per seat mile
0.49	lbs CO_2 per passenger mile

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Summary

In summary, to reap the economic and transportation benefits known to other nations with high-speed rail networks, the United States must follow through on its decision to invest in high-speed rail and maximize the benefits that accompany the investment. The United States should follow through on its commitment to build a high-speed rail network, thus creating thousands of jobs and positions to counter economic hardship and relieve congested air and highway transportation networks. Diverting travelers onto high-speed rail will help preserve non-renewable energy resources and produce lower annual emissions. The United States' investment in high-speed rail will revive interstate highways, waterways, and aviation facilities (United States Department of Transportation and Federal Railroad Administration 2010, 26). The United States Government will need to make sure the benefits received will outweigh the costs associated with the integration of a national high-speed rail network. This research conducts a cost-benefit analysis following the conceptual framework below to determine the benefit in the amount of annual carbon dioxide (CO_2) savings in the Georgetown to San Antonio corridor should a high-speed rail network be in operation.

Conceptual Framework

The conceptual framework for this applied research project identifies the costs and benefits that have an effect on the results this research. This cost benefit analysis determines the net annual automobile emission savings of carbon dioxide (CO_2) the Georgetown-San Antonio corridor acquires as diverted commuters now travel by high-speed rail. This research then analyzes each of the five high-speed rail technologies determining the best option for the Georgetown-San Antonio corridor in having the lowest annual emission of CO_2.

Table 2.6: Conceptual framework of scholarly research

Conceptual Framework	
Research Purpose: to perform a cost-benefit analysis of the net annual carbon dioxide emissions savings within the Georgetown–San Antonio Interstate 35 corridor with the introduction of high-speed rail as a mode of transportation.	
Benefits:	Scholarly support:
- Annual vehicle trip cancellation for the Georgetown to San Antonio Corridor. - Annual commuter saves in automobile carbon dioxide emissions - Net Annual Automobile Carbon Dioxide Emissions Saved in the Corridor.	Alvarez (2010), Austin- San Antonio Inter-municipal Commuter Rail District (2005), Center for Clean Air Policy and Center for Neighborhood Technology (2006), Chen and Zhang (2010), Givoni, Capon, Haikalis, Simpson, and King (2010), Glaser (2009), Gutierrez, Gonzalez and Gomez (1996), Kao, Lai, Shih (2010), Levinson, Gillen, Kanafani, Mathieu (1996), Levinson, Mathieu, Gillen, and Kanafani (1997), Pazour, Meller, and Pohl (2010), Vukan and Casello (2002), Worsnop (1993), United States Department of Transportation (1997), United States Department of Transportation (2010), University of Pennsylvania (2010), U.S. PIRG Education Fund (2010).
Costs:	Scholarly support:
- What the individual commuter costs in annual CO_2 emission by using high-speed rail. -Projected high-speed rail annual emissions depending on high-speed rail technology selected (TGV, MagLev, ICE, IC-3, Shinkansen)	Center for Clean Air Policy and Center for Neighborhood Technology (2006), Austin – San Antonio Intermunicipal Commuter Rail District (2003) Annual Report.
Time Horizon	1 year analysis

CHAPTER 3: METHODOLOGY

Statement of research purpose:

The purpose of this paper is twofold. First, the research will provide introductory material on cost benefit analysis and its role in the decision-making process. Second, the study will apply the technique of cost benefit analysis to determine if a high-speed rail system between Georgetown and San Antonio will reduce the overall carbon dioxide level.

High-speed rail is often cited as a solution to many transportation problems: it reduces congestion on roads and at airports, it is cost effective and convenient, it improves mobility, and it benefits the environment. Greenhouse gas emissions are reduced as travelers switch to high-speed rail from other modes of travel, little modeling of this impact has been done to estimate the potential benefit that high-speed rail will have on greenhouse gas emissions in the United States. Traffic congestion between Georgetown and San Antonio has never been worse. The increase in population between the two cities has created bottleneck congestion on Interstate 35. The resulting congestion negatively impacts the environment within the corridor due to the continuously increasing amounts of carbon dioxide annually emitted into the atmosphere.

The purpose of this paper is to conduct a cost-benefit analysis on a high-speed rail system between Georgetown and San Antonio, to determine if this mode of transportation is a viable investment by reducing the overall carbon dioxide emissions. Benefits received by the corridor are the result of the cancelling out an annual of automobile trips, and annual mileage not driven due to diverting automobile passengers opting to use high-speed rail (forecasted by the Austin–San Antonio Intermunicipal Commuter Rail District 2003 Report). Due to the number of automobile trips canceled out and the annual mileage not driven by automobiles in the corridor, a resulting overall savings is acquired in the amount of automobile CO_2 emissions saved annually by the Georgetown-San Antonio corridor. This research analyzes the five high-speed rail technologies shown in the literature review to determine which of the five technologies has the lowest annual CO_2 emission during operation in the corridor. Emission rates per passenger mile for each of the five high-speed rail technologies have been provided by the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report. These centers have investigated high-speed rail networks throughout the United States and the high-speed rail technologies designated to be used on the nation's tracks. This research in following the same model used by the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report, determines the high-speed rail technology having the lowest annual emission of CO_2. The next section examines the associated costs and benefits of this analysis and shows how each are measured in the operationalization table.

Costs

The costs measured in the analysis include; what the individual commuter costs in annual CO_2 emission by using each of the five high-speed rail technologies. Another associated cost is the annual emission of CO_2 by each of the five high-speed rail technologies operating in the corridor. Emission data on the five high-speed rail technologies is provided by the Center for Clean Air Policy and Center for Neighborhood Technology. The forecasted annual ridership for the Georgetown-San Antonio corridor is provided by the Austin–San Antonio Intermunicipal Commuter Rail District 2003 Annual Report. The analysis will look at the five high-speed rail technologies listed in the literature and then determine which technology offers the best benefit for the Georgetown- San Antonio corridor.

Benefits

One expected benefit from introducing high-speed rail includes the following: the annual vehicle trip cancellations for the Georgetown-San Antonio corridor. Another benefit of high-speed rail derives from the amount each commuter saves in automobile carbon dioxide annually by switching to high-speed rail. By convincing more people to switch to high-speed rail as their primary source of travel, a commuter will save the corridor in the amount of carbon dioxide (CO_2) emitted. The final benefit of high-speed rail is the net annual automobile carbon dioxide emissions saved in the corridor, as the diverting of commuters from automobile travel to high-speed rail will result in lower net annual automobile emissions for the entire Georgetown-San Antonio corridor.

Timeframe

The time period for the analysis is the year 2020. A number of high-speed rail studies around the country are focusing target dates of operation around this time. Of course the actual target year remains in question due to the uncertainty of funding and construction schedules.

Operationalization

The methodology for this research is a cost-benefit analysis. Cost-benefit analysis is a practical way of assessing the desirability of a project. When it is important to take a long view and a wide view of a project, a long view evaluates project repercussions in the future, and a wide view evaluates stakeholder side effects (Prest and Turvey 1965, 683). A project or program is evaluated by comparing costs and benefits in order to generate meaningful results to support appropriate decision. The research demonstrates whether the benefits of a constructed high-speed rail corridor between Georgetown and San Antonio outweigh the costs resulting from the rail network's operation. Travel between Georgetown and San Antonio is evaluated based on the five high-speed rail technologies (MagLev, German ICE, Shankansen, TGV, Danish IC-3) designated for use in the United States, and to determine which has the least CO_2 emission.

The results of the cost-benefit analysis determine the amount of benefits received by the Georgetown-San Antonio corridor. The benefit of a lower annual level of carbon dioxide (CO_2) in the corridor will result from vehicle cancellation trips due to commuters switching to high-speed rail. The total number of diverted annual passengers can be calculated to determine the total annual amount of automobile emissions not emitted into the corridor due to commuters switching transportation mode and to high-speed rail. The cost in this analysis is the annual amount of carbon dioxide that a high-speed rail produces. Annual emission due to high-rail operation is subtracted from the annual automobile savings (Net annual automobile emissions saved), resulting in a net annual CO_2 savings for the corridor. This research analyzes each of the five high-speed rail technologies to determine which rail technology has the lowest annual emissions of CO_2 during operation.

Table 3.1: Operationalization of the Conceptual Framework Table

Calculation of acquired costs and benefits			
Benefits	**Components**	**Definition of components**	**Measurement**
Annual weekday vehicle trip cancellation for the Georgetown to San Antonio Corridor.	• Daily ridership forecast for Georgetown-San Antonio Corridor (provided by the Austin – San Antonio Intermunicipal Commuter Rail District (2003) Annual Report) • Average automobile occupancy (EPA) • Weekday daily vehicle trip cancellations (estimated by researcher) • Annual vehicle trip cancellations (estimated by researcher)	• Daily ridership forecast for Georgetown-San Antonio Corridor= 10,990 • Average automobile occupancy= 1.63 • Weekday daily vehicle trip cancellations= 6,742 • Annual vehicle trip cancellations= 1,752,920	1) Weekday daily vehicle trips canceled = 10,990/1.63= 6,742 2) Annual weekday vehicle trips canceled = (6,742 daily vehicle trips canceled * 5 weekdays * 52 weeks per year) 3) **1,752,920 annual weekday vehicle trips canceled**
Annual commuter saves in automobile carbon dioxide emissions.	• Automobile's emission of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 weekdays • 52 weeks a year	• Average automobile's emission of CO_2 per passenger mile= 0.53 • Average distance between rail stations= 46.10 miles • 5 weekdays • 52 weeks a year	1) Automobile's emission of CO_2 per passenger mile= (0.53 lbs CO_2 per passenger mile) * 46.10 miles (average distance between rail stations)* 5 days per week * 52 weeks per year = **10,188.1 lbs CO_2** **Average commuter saves in automobile carbon dioxide per year**
Net Annual Automobile Carbon Dioxide Emissions Saved in the Corridor.	• Average daily miles by riders in corridor (estimated by researcher) • Average occupancy of an automobile (EPA) • Automobile emission rate of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Daily savings of automobile emissions in corridor (estimated by researcher) • Net annual savings of automobile emissions in corridor (estimated by researcher)	• Average daily miles by riders in corridor= 492,546.68 • Average occupancy of an automobile= 1.63 • Automobile emission rate of CO_2 per passenger mile= 0.53. • Daily savings of automobile emissions in corridor= 160,153.22 lbs of CO_2 • Net annual savings of automobile emissions in corridor= 41,639,836.93 lbs of CO_2	1) **Daily savings of automobile emissions in corridor=** (Average daily miles by riders in corridor/ Average occupancy of an automobile)*Automobile emission rate of CO_2 per passenger mile 2) **Daily savings of automobile emissions in corridor=** (492,546.68/1.63)*0.53 = 160,153.22 lbs of CO_2 3) **Net annual savings of automobile emissions in corridor= 160,153.22 * 5 * 52= 41,639,836.93 lbs of CO_2**

Costs	Components	Definition of components	Measurement
What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected. (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 week days • 52 weeks per year	• Certain high-speed rail technology's CO_2 emissions per passenger mile. (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49) • Average distance between rail stations= 46.10 miles • 5 week days • 52 weeks per year	1) CO_2 per passenger mile (based on high-speed rail technology) * 46.10 miles (average commute between rail stations) * 5 days per week * 52 weeks per year = **What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected**
Projected high-speed rail annual emissions depending on high-speed rail technology selected. (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (provided by the Center for Clean Air Policy) • Daily miles by riders predicted for the Georgetown-San Antonio corridor (estimated by researcher) • Annual miles by riders predicted for the Georgetown-San Antonio corridor (estimated by researcher)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49) • Daily miles by riders predicted for the Georgetown-San Antonio corridor= 492,546.68 • Annual miles by riders predicted for the Georgetown-San Antonio corridor= 128,062,136.8	1) Certain high-speed rail technology's CO_2 emissions per passenger mile * Annual miles by riders predicted for the Georgetown-San Antonio corridor (128,062,136.8)= **Projected high-speed rail annual emissions**
Source of Data:			• Austin – San Antonio Intermunicipal Commuter Rail District (2003) Annual Report, 1- Appendix C-7-9. • Center for Clean Air Policy. (2006). High speed Rail and greenhouse gas emissions in the U.S. 21(7): 1-15

Strengths and weaknesses of a cost benefit analysis

The cost benefit analysis determines whether a high-speed rail network will be beneficial to the Georgetown-San Antonio corridor or not. One weakness of cost benefit analysis in this study is that the study does not take into account other greenhouse gases emitted into the air by high-speed rail and automobile operation. Another weakness is that the calculations in this analysis are educated guesses in terms of their results, based on the ridership numbers provided by the Austin- San Antonio Inter-municipal Commuter Rail District 2003 report and the formulas to calculate each expected benefit and cost by The Center for Neighborhood Technology (CNT), the Center for Clear Air Policy (CCAP). The results are not 100% accurate, meaning that this analysis should be used strictly to model as similar study after, and not cited as exact results. This study was conducted strictly on the possibility of high-speed being in operation within the Georgetown-San Antonio area.

Data Collection

The data for this analysis comes from various sources; however, most comes from The Center for Neighborhood Technology (CNT), the Center for Clear Air Policy (CCAP), Environmental Protection Agency (EPA), and the Austin- San Antonio Inter-municipal Commuter Rail District. The study determines the amount of net annual carbon dioxide (CO_2) emissions saved by the automobile passenger miles that do not occur in the Georgetown-San Antonio corridor due to commuters switching preferred mode of commute to high-speed rail from automobile. To calculate the net annual automobile emissions savings for the Georgetown-San Antonio corridor, the model and formulas used in the Center for Neighborhood Technology (CNT), the Center for Clear Air Policy (CCAP) 2006 study are replicated in this study. The analysis subtracts the estimated annual automobile emissions savings of CO_2 from the annual emission of CO_2 generated by each of the five high-speed rail technologies to determine which of the five options is most beneficial to corridor. The analysis considers data predicted for the year 2020 as the target date of construction. The results of this study as said before are not 100% accurate, meaning that this analysis should be used strictly to model as similar study after, and not cited by in having exact results.

Calculating the cost benefit analysis

A cost benefit analysis indicates whether the predicted benefit of having a lower annual automobile CO_2 emission results from the introduction of high-speed rail in the Georgetown-San Antonio corridor. The following section describes how the benefits and costs are calculated. The formulas used to determine the costs and benefits of this study are modeled after the same formulas used in the Center for Clear Air Policy & Center for Neighborhood Technology 2006 report. Data concerning ridership and vehicle cancellation numbers for the Georgetown-San Antonio corridor has been forecasted by the 2003 Austin-San Antonio Intermunicipal Commuter Rail District study.

Benefits

Annual weekday vehicle trip cancellation for the Georgetown to San Antonio corridor

Vehicle trip cancellation is a benefit arising from the introduction of high-speed rail, because emissions savings occur ―when critical masses of passengers switch modes of transportation causing a vehicle trips to be cancelled" (Center for Clean Air Policy and Center for Neighborhood Technology 2005, 7). As people leave vehicles at home or at train stations, the vehicle cancellation effect causes lower annual amounts of carbon dioxide to be emitted into the air due to automobile trips not happening. High-speed rail leads to the canceling of a number of automobile trips and replaces each individual's emission output with a combined single source of emission that all the riders on the high-speed rail train share. This research uses forecasted ridership data acquired from the 2003 Austin-San Antonio Intermunicipal Commuter Rail

District study for the thirteen stops on the proposed Georgetown-San Antonio line to predict the vehicle trip cancellation effect on annual automobile emissions for the corridor in the year 2020. To calculate the number of daily vehicle trip cancellations, the research takes the number of daily diverted passengers 10,990 (as shown as predicted by Austin-San Antonio Intermunicipal Commuter Rail District study below in Table 3.2), and divides it by the average automobile occupancy shown in Table 3.3 by The 2001 National Household Travel Survey (1.63), resulting in the daily number of automobile trips cancelled in the corridor (Weekday vehicle trips canceled = 10,990/1.63= 6,742). In calculating the number of annual automobile trips cancelled by high-speed rail in the corridor, the research takes the daily automobile trips cancelled (6,742) and multiplies by five (weekdays), then multiplies the product by fifty two (weeks in a year). The resulting 1,752,920 amount is the number of automobile trips cancelled annually (Table 3.4).

Table 3.2: Year 2020 average weekday ridership estimate for Georgetown-San Antonio corridor

FINAL FORECASTS [1]

Commuter Rail Station Boarding Summary
YEAR 2020 AVERAGE WEEKDAY PERSON TRIPS

Station	Time Period		Total
	Peak	*Off-Peak*	
Georgetown	470	270	740
Round Rock	710	400	1,110
McNeil Jct.	170	40	210
Research	250	70	320
US 183	470	110	580
Austin CBD	1,520	290	1,810
Ben White	790	190	980
San Marcos	1,470	330	1,800
New Braunfels	400	90	490
Selma	210	130	340
San Antonio Airport	570	60	630
San Antonio CBD	1,150	350	1,500
Kelly	380	100	480
Total	*8,560*	*2,430*	*10,990*

18-Jan-99

Source: http://asarail.org/ASA_Annual_Report.pdf

Table 3.3: Average automobile occupancy

	Mean	Standard Error
All personal vehicle trips	**1.63**	0.012
Work	1.14	0.007
Work-related	1.22	0.020
Family/personal	1.81	0.016
Church/school	1.76	0.084
Social/recreational	2.05	0.028
Other	2.02	0.130
SOURCE: The 2001 National Household Travel Survey, daily trip file, U.S. Department of Transportation.		

Table 3.4: Annual weekday vehicle trip cancellation for the Georgetown to San Antonio corridor

Annual weekday vehicle trip cancellation for the Georgetown to San Antonio Corridor.	• Daily ridership forecast for Georgetown-San Antonio Corridor (provided by the Austin – San Antonio Intermunicipal Commuter Rail District (2003) Annual Report) • Average automobile occupancy (EPA) • Weekday daily vehicle trip cancellations (estimated by researcher) • Annual vehicle trip cancellations (estimated by researcher)	• Daily ridership forecast for Georgetown-San Antonio Corridor= 10,990 • Average automobile occupancy= 1.63 • Weekday daily vehicle trip cancellations= 6,742 • Annual vehicle trip cancellations= 1,752,920	1) Weekday daily vehicle trips canceled = 10,990/1.63= 6,742 2) Annual weekday vehicle trips canceled = (6,742 daily vehicle trips canceled * 5 weekdays * 52 weeks per year) 3) **1,752,920 annual weekday vehicle trips canceled**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf & Source: http://asarail.org/ASA_Annual_Report.pdf.

Annual commuter saves in automobile carbon dioxide emissions

By switching to high-speed rail from automobiles as a main source of travel, it is estimated that the average commuter will save the corridor in the amount of carbon dioxide (CO_2) emitted by automobile annually. In order to calculate the amount of carbon dioxide an average commuter saves by switching from automobile to high-speed rail travel, a few factors need to be calculated. The factors needed to complete the calculation are:

- The average automobile's emission of CO_2 per passenger mile (0.53 pound) (Table 3.5).

Table 3.5: Average automobile's emission of CO_2 per passenger mile

Mode	Emissions Per Passenger Mile (lbs CO_2)[22]	Emissions Per Vehicle Mile (lbs CO_2)	Passengers per Vehicle
Bus	0.14	4.87	35
Conventional Rail	0.21	66.96	322
High Speed Rail (IC-3)	0.26	25.10	97
Automobile	0.53	0.85	1.6
Airplane	0.62	48.04	77

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- Also needed, is the average distance between the thirteen train stations located within the corridor (46.10 miles).
  - (In Appendix D, the average distance between thirteen rail stations within the corridor is calculated by charting out the estimated distances from each train station to the other twelve connecting train stations. Then next step is to calculate the average distance of a train station from its connecting twelve stations. Once

the average distance for every train station has been charted, the researcher then calculates the overall average distance of the thirteen train stations from one another (46.10 miles. The distances computed are not exact and are disputable).

- And lastly needed are the number of days commuted per week (five weekdays), and the number of weeks per year the commuter makes the trip (fifty two weeks in a year) are needed as well.
- The formula used to calculate an individual's annual automobile emission is modeled after the same formula used in the Center for Clean Air Policy and Center for Neighborhood Technology study (shown in Table 3.6).
- The formula is: automobile CO_2 emission per passenger mile in 2020 (0.53) times average estimated distance between train stations (46.10) times five days per week times fifty two weeks per year.

Table 3.6: Annual commuter saves in automobile carbon dioxide emissions

Annual commuter saves in automobile carbon dioxide emissions.	• Automobile's emission of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 weekdays • 52 weeks a year	• Average automobile's emission of CO_2 per passenger mile= 0.53 • Average distance between rail stations= 46.10 miles • 5 weekdays • 52 weeks a year	1) Automobile's emission of CO_2 per passenger mile= (0.53 lbs CO_2 per passenger mile) * 46.10 miles (average distance between rail stations)* 5 days per week * 52 weeks per year = **10,188.1 lbs CO_2** **Average commuter saves in automobile carbon dioxide per year**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Net annual automobile carbon dioxide emissions saved in the corridor

In this section, a calculation modeled after the same formula used by the Center for Clean Air Policy and Center for Neighborhood Technology study determines the net automobile emissions savings within the corridor as a whole. The diverting of individuals from automobile travel to high-speed rail results in annual automobile emissions saved by the entire Georgetown-San Antonio corridor. The formula shown below in Table 3.7 determines the amount of automobile emissions saved annually in the Georgetown-San Antonio corridor.

- Needed is the average daily miles for riders in the entire corridor, the average daily miles is computed by multiplying the average distance between rail stations estimated by the researcher (46.10 miles) by the number of forecasted daily riders as predicted by the Austin-San Antonio Intermunicipal Commuter Rail District study (10,990). The result is the predicted daily miles by riders (492,546.69).
- Also needed is the average occupancy of an automobile estimated by the EPA (as shown above in table 3.2 being 1.63), and the automobile emission rate of CO_2 per passenger mile (shown in Table 3.5) (0.53 lbs CO_2 per passenger mile).
- The next step divides the corridor's daily miles by riders (492,546.68) by the average occupancy of an automobile (1.63). That result is then multiplied by the automobile emissions per passenger mile (0.53). The resulting amount is the daily savings of automobile emissions for the corridor (160,153.22 lbs of CO_2, as shown in Table 3.7).

To determine the annual amount of savings to the corridor one must simply multiply the daily amount of CO_2 savings for the corridor 160,153.22 by five days a week times fifty two weeks a year. The 41,639,836.93 lbs CO_2 resulting amount is the predicted annual automobile emissions savings for the Georgetown-San Antonio corridor.

Table 3.7: Net Annual Automobile Carbon Dioxide Emissions Saved in the Corridor

Net Annual Automobile Carbon Dioxide Emissions Saved in the Corridor.	• Average daily miles by riders in corridor (estimated by researcher) • Average occupancy of an automobile (EPA) • Automobile emission rate of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Daily savings of automobile emissions in corridor (estimated by researcher) • Net annual savings of automobile emissions in corridor (estimated by researcher)	• Average daily miles by riders in corridor= 492,546.68 • Average occupancy of an automobile= 1.63 • Automobile emission rate of CO_2 per passenger mile= 0.53. • Daily savings of automobile emissions in corridor= 160,153.22 lbs of CO_2 • Net annual savings of automobile emissions in corridor= 41,639,836.93 lbs of CO_2	1) **Daily savings of automobile emissions in corridor=** (Average daily miles by riders in corridor/ Average occupancy of an automobile)*Automobile emission rate of CO_2 per passenger mile 2) **Daily savings of automobile emissions in corridor=** (492,546.68/1.63)*0.53 = 160,153.22 lbs of CO_2 3) **Net annual savings of automobile emissions in corridor= 160,153.22 * 5 * 52= 41,639,836.93 lbs of CO_2**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Costs

What the individual commuter costs in annual CO_2 emission by using high-speed rail

The following calculation (Table 3.8) is replicated by the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 study. The formula determines the carbon dioxide emission annually by individual commuters by using one of the five high-speed rail technologies (TGV, ICE, IC-3, Shinkansen, MagLev). Each high-speed rail technology's emission rate per passenger mile determines how much an individual commuter is contributing in annual CO_2 emissions by using a selected high-speed rail technology.

- To calculate what the individual commuter emits annually by using a high-speed rail technology a few factors are needed. First is listing the lbs of CO_2 per passenger mile of the five high-speed technologies (Table 3.8).

Table 3.8: CO_2 emission rate per passenger mile based on five high-speed rail options

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile
Shinkansen	0.22
TGV	0.15
ICE	0.11
Danish IC-3	0.26
MagLev	0.49

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- The second step takes each of the high-speed rail technologies' pounds of CO_2 per passenger mile and multiplies each by the average distance between the thirteen rail stations that was estimated by the researcher at 46.10 miles (Appendix D).
- That amount is then multiplied by five days a week and fifty two weeks a year. The resulting emission produced is the amount of CO_2 an individual commuting on one of the five high-speed rail technologies produces annually (Table 3.9).
- The formula used in this calculation is modeled after the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report, which is shown on the next page in Table 3.9.

Table 3.9: What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected

What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 week days 52 weeks per year	• Certain high-speed rail technology's CO_2 emission per passenger mile (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49) • Average distance between rail stations= 46.10 miles • 5 week days • 52 weeks per year	1) CO_2 per passenger mile (based on high-speed rail technology) TIMES 46.10 miles (average commute between rail stations) TIMES 5 days per week TIMES 52 weeks per year = **What the individual commuter produces in annual CO_2 emission depending on high-speed rail technology selected** **TGV= 1,797.9 lbs CO_2 annually** **Shinkansen= 2,636.92 lbs CO_2 annually** **ICE= 1,318.46 lbs CO_2 annually** **IC-3=3,116. 36 lbs CO_2 annually** **MagLev= 5,873.14 lbs CO_2 annually**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Predicted annual emission of carbon dioxide for each of the five high-speed rail technologies operating in the Georgetown-San Antonio corridor

The resulting annual cost in high-speed rail operation and emission of CO_2 must be considered when choosing the most efficient technology for operation. By using emission data on the five high-speed rail technologies provided by the Center for Clean Air Policy and Center for Neighborhood Technology, the high-speed rail technology option with the lowest annual carbon dioxide production deems the appropriate choice of high-speed rail technology selected.

- Needed to determine the high-speed rail technology with the lowest annual emission of CO_2 are the following factors:
- The first factor needed, is the CO_2 emission per passenger mile for each of the five high-speed rail technologies (Table 3.10).

Table 3.10: CO_2 emission rate per passenger mile based on five high-speed rail options

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile
Shinkansen	0.22
TGV	0.15
ICE	0.11
Danish IC-3	0.26
MagLev	0.49

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- The second factor needed is the annual miles by riders predicted for the Georgetown-San Antonio corridor.
- Annual miles by riders are determined by first calculating the daily miles by riders. Daily miles by riders is calculated by taking the 46.10 miles (average distance between rail stations within the corridor) and multiplying by the daily predicted ridership of the corridor (10,990) as predicted by the Austin-San Antonio Intermunicipal Commuter Rail District study.
- The result is 492,546.69 daily miles by riders within the corridor (Table 3.11).

Table 3.11: Average daily miles by riders in the Georgetown-San Antonio corridor

Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	**46.10**
Number of daily riders	740	1,110	210	320	580	1,810	980	1,800	490	340	630	1,500	480	**10,990**
Avg. daily miles driven by riders from each station (Average Distance * Riders)	38,258.00	49,164.46	9,112.38	13,725.54	21,937.38	66,078.92	35,679.54	68,676.92	20,821.23	16,063.69	34,553.08	87,057.69	31,417.85	**492,546.69**

- Annual miles by riders is then calculated by simply multiplying the 492,546.69 daily miles, by five week days, and fifty two weeks a year, resulting in 128,062,136.8 annual miles by riders.

Now it is possible to predict the annual emission of CO_2 for each of the five high-speed rail technologies operating in the Georgetown-San Antonio corridor, due to now having the CO_2 emission rate per passenger mile based on five high-speed rail options, along with the 128,062,136.8 annual miles by riders.

- To calculate the annual emission of CO_2 for each of the five high-speed rail technologies operating within the corridor, the formula used is shown in Table 3.12.
- The calculation is completed by multiplying the emissions per passenger mile for the each high-speed rail technology by the annual miles by riders predicted for the Georgetown-San Antonio corridor (128,062,136.8).

Table 3.12: Projected high-speed rail annual emissions depending on high-speed rail technology selected

Projected high-speed rail annual emissions depending on high-speed rail technology selected. (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 week days • 52 weeks per year	• Certain high-speed rail technology's CO_2 emission per passenger mile. (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49). • Daily miles by riders predicted for the Georgetown-San Antonio corridor= 492,546.68. • Annual miles by riders predicted for the Georgetown-San Antonio corridor= 128,062,136.8	1) Certain high-speed rail technology's CO_2 emission per passenger mile TIMES 2) Annual miles by riders (128,062,136.8) = **Projected high-speed rail annual emissions**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Human subjects protection

This research poses no risk to human subjects and has been approved by the Institutional Review Board. The reviewers have determined that your IRB Application Number 2011I7755 is exempt from IRB review. The project is approved.

Chapter 4: RESULTS

Introduction

This chapter presents the findings of the cost benefit analysis conducted based on the benefit received when commuters switch preferred mode of travel from automobile to high-speed rail technology on the Interstate 35 corridor. The results of this analysis determine whether travel by high-speed rail is environmentally beneficial in the reduction of carbon dioxide levels emitted by automobile travel on interstate 35. This analysis considers the emission data presently available on high-speed rail technologies along with data on automobile emissions due to a realistic possibility exists that construction of a high-speed rail system could occur.

United States' predicted benefits with high-speed rail operation

Current projections supplied by the Center of Clean Air Policy and Center for Neighborhood Technology show that passengers would take 112 million trips on high-speed rail in the U.S. in 2025, traveling more than 25 billion passenger miles. These trips would result in 29 million fewer automobile trips and nearly 500,000 fewer flights. The Center of Clean Air Policy and Center for Neighborhood Technology calculated, as a result of the canceled automobile trips and flights, a total emission savings of six billion pounds of CO_2 per year (2.7 $MMTCO_2$, Million Metric Tons) should all proposed high speed rail systems considered in the United States be built. These organizations predict the savings from the canceled automobile and airplane trips to be the primary sources of the emissions savings; together these two modes make up 80 percent of the estimated emissions savings among all modes of transportation.

Cost benefit analysis

The results of the cost benefit analysis determine the amount of benefits received by the Georgetown-San Antonio corridor. As commuters decide not to use their automobile to make their daily commute they produce savings in the reduced annual amount of automobile CO_2 emitted into the air. The total number of diverted annual passengers can be calculated to determine the total annual amount of automobile emissions were not emitted into the corridor due to commuters switching mode of transportation to high-speed rail. The cost represented in this analysis is the annual amount of carbon dioxide a high-speed rail produces annually, (Projected high-speed rail annual emissions). The annual emission from high-rail operation is then subtracted from the annual automobile savings, resulting in a net annual automobile savings for the corridor. The study then analyses each of the five high-speed rail technologies to determine the rail technology with the lowest annual contribution of emissions. The next section discusses the benefits received when commuters switch preferred mode of transportation from automobile to high-speed rail.

Benefits

Direct Benefits

One benefit that would be a direct result of the proposed high-speed rail system is the annual number of vehicle trip cancellations in the Georgetown-San Antonio corridor. A second benefit produced by commuters using high-speed rail is the savings to individual commuter's annual amount of automobile emissions due to a change in primary mode of transportation. Lastly, after calculating the total number of individual trips annually diverted in the Georgetown-San Antonio corridor, the resulting benefit is the total amount of automobile CO_2 emissions savings annually in the corridor; because the total number of automobile trips canceled in the corridor produce lower annual CO_2 emission levels.

Annual Weekday Vehicle Trip Cancellation for the Georgetown to San Antonio Corridor

Vehicle trip cancellation is a benefit of the introduction of high-speed rail, because emissions savings occur ―when critical masses of passengers switch modes of transportation causing vehicle trips to be canceled" (Center for Clean Air Policy and Center for Neighborhood Technology 2006, 7). As people leave their vehicles at home or at train stations, vehicle trip cancellation causes lower annual amounts of carbon dioxide to be emitted into the air. High-speed rail leads to the canceling of automobile trips and replaces each individual's emission output with a combined single source of emission that all the riders on the high-speed rail train share. Table 4.1 provided by the Austin-San Antonio Intermunicipal Commuter Rail District study forecasts the predicted weekday ridership for the planned train stations along the Georgetown-San Antonio corridor.

Table 4.1: Average weekday commuter trips diverted in favor of rail for the year (2020)

FINAL FORECASTS [1]

Commuter Rail Station Boarding Summary

YEAR 2020 AVERAGE WEEKDAY PERSON TRIPS

Station	Time Period		Total
	Peak	Off-Peak	
Georgetown	470	270	740
Round Rock	710	400	1,110
McNeil Jct.	170	40	210
Research	250	70	320
US 183	470	110	580
Austin CBD	1,520	290	1,810
Ben White	790	190	980
San Marcos	1,470	330	1,800
New Braunfels	400	90	490
Selma	210	130	340
San Antonio Airport	570	60	630
San Antonio CBD	1,150	350	1,500
Kelly	380	100	480
Total	*8,560*	*2,430*	*10,990*

18-Jan-99

This research uses forecasted ridership data by the Austin-San Antonio Intermunicipal Commuter Rail District study for the thirteen stops on the Georgetown-San Antonio line. The formula used by the Center of Clean Air Policy and Center for Neighborhood Technology is modeled after in this study to predict the vehicle trip cancellation for the corridor in the year 2020. Table 4.1, predicts 10,990 passengers is the daily ridership prediction in the Georgetown-San Antonio corridor.

Table 4.2: Average automobile occupancy by daily trip purpose

	Mean	Standard Error
All personal vehicle trips	1.63	0.012
Work	1.14	0.007
Work-related	1.22	0.020
Family/personal	1.81	0.016
Church/school	1.76	0.084
Social/recreational	2.05	0.028
Other	2.02	0.130
SOURCE: The 2001 National Household Travel Survey, daily trip file, U.S. Department of Transportation.		

- To calculate the number of daily vehicle trip cancellations, the research takes the 10,990 daily diverted passengers and divides by the average automobile occupancy 1.63 (Table 4.2). The resulting daily number of automobile trips cancelled in the corridor equals 6,742.

- Calculating the number of annual automobile trips cancelled by high-speed rail in the corridor is calculated by following the formula in Table 4.3.
- The first step is taking the 6,742 daily automobile trips cancelled and multiplying by 5 (weekdays), then multiplying by fifty two (weeks in a year).
- The resulting number of automobile trips cancelled annually by high-speed rail is 1,752,920.

Table 4.3: Annual weekday vehicle trip cancellation for the Georgetown to San Antonio corridor

Benefits:	Name of Components	Definition of components	Measurement:
Annual weekday vehicle trip cancellation for the Georgetown to San Antonio corridor	• Daily ridership forecast for Georgetown-San Antonio Corridor (provided by the Austin – San Antonio Intermunicipal Commuter Rail District (2003) Annual Report) • Average automobile occupancy (EPA) • Weekday daily vehicle trip cancellations (estimated by researcher) • Annual vehicle trip cancellations (estimated by researcher)	• Daily ridership forecast for Georgetown-San Antonio Corridor= 10,990 • Average automobile occupancy= 1.63 • A weekday daily vehicle trip cancellations= 6,742 • Annual vehicle trip cancellations= 1,752,920	1) Weekday vehicle trips canceled = 10,990/1.63= 6,742 2) Annual weekday vehicle trips canceled = (6,742 daily vehicle trips canceled * 5 weekdays * 52 weeks per year) 3) **1,752,920 annual weekday vehicle trips canceled**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

How much the commuter saves in annual automobile carbon dioxide emissions

By convincing more people to switch to high-speed rail from automobile travel, the average commuter will save the corridor in the amount of carbon dioxide (CO_2) not emitted annually. Planning and constructing environmentally friendly adjacent housing and development areas in high-speed rail districts, daily commuters will find high-speed rail a beneficial mode of transportation. The corridor will benefit by the amount of carbon dioxide an average commuter saves annually by switching from automobile to high-speed rail. In order to calculate the amount of carbon dioxide an average commuter saves in annual automobile CO_2 emissions, a few factors are needed:

- The 0.53 pounds of CO_2 per passenger mile an automobile emits (Table 4.4).

Table 4.4: Summary CO_2 Emissions Factors by Mode

Mode	Emissions Per Passenger Mile (lbs CO_2)[22]	Emissions Per Vehicle Mile (lbs CO_2)	Passengers per Vehicle
Bus	0.14	4.87	35
Conventional Rail	0.21	66.96	322
High Speed Rail (IC-3)	0.26	25.10	97
Automobile	0.53	0.85	1.6
Airplane	0.62	48.04	77

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- The average distance between the thirteen train stations that was computed by the researcher at 46.10 miles (Table 4.5, exact distance is disputable),

Table 4.5: Average daily miles by riders in the Georgetown-San Antonio corridor

Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	**46.10**
Number of daily riders	740	1,110	210	320	580	1,810	980	1,800	490	340	630	1,500	480	**10,990**
Avg. daily miles driven by riders from each station (Average Distance * Riders)	38,258.00	49,164.46	9,112.38	13,725.54	21,937.38	66,078.92	35,679.54	68,676.92	20,821.23	16,063.69	34,553.08	87,057.69	31,417.85	**492,546.69**

- The five days commute per week, and the fifty two weeks per year the commuter makes the trip.

The formula used to calculate an individual's annual automobile emission has been replicated in Table 4.6 from the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report.

- The first step in calculating the annual commuter' savings of automobile carbon dioxide savings, is taking the 0.53 pounds of CO_2 per passenger mile emitted from automobiles, and multiplying by the average distance between train stations along the corridor (46.10 miles),
- The result is then multiplied by five (5 weekdays) and lastly multiplied by fifty two (52 weeks in a year).
- As the result, the annual commuter within the corridor will be saving 10,188.1 lbs of automobile CO_2 by opting not to use their automobile to travel by.

Table 4.6: Formula to calculate the annual commuter's savings of automobile carbon dioxide savings

Annual commuter saves in automobile carbon dioxide emissions.	• Automobile's emission of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Average distance between rail stations (estimated by researcher) • 5 weekdays • 52 weeks a year	• Average automobile's emission of CO_2 per passenger mile= 0.53 • Average distance between rail stations= 46.10 miles • 5 weekdays • 52 weeks a year	1) Average automobile's emission of CO_2 per passenger mile (0.53 lbs CO_2 per passenger mile) TIMES 46.10 miles (average distance between rail stations) TIMES 5 days per week TIMES 52 weeks per year = **10,188.1 lbs CO_2 Average commuter saves in automobile carbon dioxide per year**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Net annual automobile carbon dioxide emissions saved in the corridor

In this section a calculation determines the net automobile emissions savings within the corridor as a whole due to annual automobile trip cancellations. As a result, diverting individuals from automobile travel to high-speed rail results in net annual automobile emissions savings for the Georgetown-San Antonio corridor, as shown in Table 4.10.To determine the net annual automobile emissions savings for the Georgetown-San Antonio corridor, the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report will be replicated to do so.

To determine the amount of automobile emissions saved annually for the Georgetown-San Antonio corridor, a few factors are required including the following:

- The total daily miles by riders for the corridor (Table 4.7). Total daily miles by riders is calculated by multiplying the average distance between rail stations (46.10 miles) times the number of daily riders (10,990).

- Resulting in 492,546.69 total daily miles by riders (Table 4.7).

Table 4.7: Average daily miles by riders in the Georgetown-San Antonio corridor

Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	**46.10**
Number of daily riders	740	1,110	210	320	580	1,810	980	1,800	490	340	630	1,500	480	**10,990**
Daily miles driven by riders from each station (Average Distance * Riders)	38,258.00	49,164.46	9,112.38	13,725.54	21,937.38	66,078.92	35,679.54	68,676.92	20,821.23	16,063.69	34,553.08	87,057.69	31,417.85	**492,546.69**

- Also needed is the 1.63 average occupancy of an automobile (shown in Table 4.8).

Table 4.8: Average automobile occupancy

	Mean	Standard Error
All personal vehicle trips	1.63	0.012
Work	1.14	0.007
Work-related	1.22	0.020
Family/personal	1.81	0.016
Church/school	1.76	0.084
Social/recreational	2.05	0.028
Other	2.02	0.130
SOURCE: The 2001 National Household Travel Survey, daily trip file, U.S. Department of Transportation.		

- And lastly needed is the automobile emissions rate per passenger mile (Table 4.9)

Table 4.9: Summary CO_2 Emissions Factors by Mode

Mode	Emissions Per Passenger Mile (lbs CO_2)[22]	Emissions Per Vehicle Mile (lbs CO_2)	Passengers per Vehicle
Bus	0.14	4.87	35
Conventional Rail	0.21	66.96	322
High Speed Rail (IC-3)	0.26	25.10	97
Automobile	0.53	0.85	1.6
Airplane	0.62	48.04	77

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Now the pieces have been found to determine the net annual emissions savings in the corridor (as shown in Table 4.10).

- The first step is taking the estimated 492,546.68 daily miles by riders (Table 4.7), and dividing by the average occupancy of an automobile (1.63).
- Then multiplying that result by the 0.53 lbs CO_2 automobile emissions per passenger mile.
- The resulting amount is the 160,153.22 lbs of CO_2 daily savings of automobile emissions by the corridor (as shown below in Table 4.10).
- To determine the annual amount of savings for the corridor, simply multiply the 160,153.22 daily savings of CO_2 by five (5 days a week) times fifty two (52 weeks a year).
- The resulting annual automobile emissions savings for the Georgetown-San Antonio corridor is 41,639,836.93 lbs of CO_2 (Table 4.10).

Table 4.10: Annual savings of automobile CO_2 emissions in corridor

Net Annual Automobile Carbon Dioxide Emissions Saved in the Corridor.	• Average daily miles by riders in corridor (estimated by researcher) • Average occupancy of an automobile (EPA) • Automobile emission rate of CO_2 per passenger mile (provided by the Center for Clean Air Policy) • Daily savings of automobile emissions in corridor (estimated by researcher) • Net annual savings of automobile emissions in corridor (estimated by researcher)	• Average daily miles by riders in corridor= 492,546.68 • Average occupancy of an automobile= 1.63 • Automobile emission rate of CO_2 per passenger mile= 0.53. • Daily savings of automobile emissions in corridor= 160,153.22 lbs of CO_2 • Net annual savings of automobile emissions in corridor= 41,639,836.93 lbs of CO_2	1) **Daily savings of automobile emissions in corridor**= (Average daily miles by riders in corridor/ Average occupancy of an automobile)*Automobile emission rate of CO_2 per passenger mile 2) **Daily savings of automobile emissions in corridor**= (492,546.68/1.63)*0.53 = 160,153.22 lbs of CO_2 3) **Net annual savings of automobile emissions in corridor= 160,153.22 * 5 * 52= 41,639,836.93 lbs of CO_2**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

Result

The total amount of automobile emissions saved in the Georgetown-San Antonio corridor due to the number of total miles of automobile trips canceled and number of diverted automobile passengers to high-speed rail has the predicted resulting effect of a net annual automobile savings of 41,639,836.93 lbs of CO_2 annually (Table 4.11).

Table 4.11: Annual automobile emissions saved by station and corridor

	Daily miles by riders from each city	Average Occupancy	Automobile emission per passenger mile (lbs of CO_2)	Automobile Emissions Saved Daily	Automobile Emissions Saved Annually
Georgetown	38,258.00	1.63	0.53	12,439.72	3,234,326.63
Round Rock	49,164.46	1.63	0.53	15,985.99	4,156,357.55
McNeil Jct.	9,112.38	1.63	0.53	2,962.92	770,359.88
Research	13,725.54	1.63	0.53	4,462.91	1,160,355.34
US 183	21,937.38	1.63	0.53	7,133.01	1,854,583.80
Austin CBD	66,078.92	1.63	0.53	21,485.78	5,586,304.05
Ben White	35,679.54	1.63	0.53	11,601.32	3,016,343.80
San Marcos	68,676.92	1.63	0.53	22,330.53	5,805,938.65
New Braunfels	20,821.23	1.63	0.53	6,770.09	1,760,224.29
Selma	16,063.69	1.63	0.53	5,223.16	1,358,022.58
SA Airport	34,553.08	1.63	0.53	11,235.05	2,921,112.88
San Antonio CBD	87,057.69	1.63	0.53	28,307.10	7,359,846.63
Kelly	31,417.85	1.63	0.53	10,215.62	2,656,060.86
Total	**492,546.69**	**1.63**	**0.53**	**160,153.22**	**41,639,836.93**

In the next section, this analysis determines annual costs associated with high-speed rail operation. The first cost identified is the annual amount of CO_2 the individual commuter using a high-speed rail technology emits into the corridor.

Costs

What the individual commuter costs in annual CO_2 emission by using high-speed rail

In Table 4.14, the following calculation determines what the individual commuter emits in carbon dioxide annually using each of the five high-speed rail technologies. The formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report will be replicated to determine what the individual commuter emits in annual CO_2 emissions by traveling by each of the high-speed rail technologies.

To determine what the individual will emit annually by high-speed rail, will depend on a few factors. The first being what high-speed rail technology is being used, and what the high-speed rail technology's emission rate per passenger mile is. As shown in Table 4.12 are the five high-speed rail technologies looked at in this study and their emission rates per passenger mile.

Table 4.12: CO_2 emission rate per passenger mile based on five high-speed rail options

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile
Shinkansen	0.22
TGV	0.15
ICE	0.11
Danish IC-3	0.26
MagLev	0.49

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- Also needed is the average distance between rail stations (46.10 miles) that was estimated by the researcher (distance is disputable, shown in Table 4.13).

Table 4.13: average distance between Georgetown-San Antonio corridor rail stations

	Georgetown	Round Rock	McNeil Jct.	Research	US 183	Austin CBD	Ben White	San Marcos	New Braunfels	Selma	San Antonio Airport	San Antonio CBD	Kelly	Total
Georgetown	0	9.7	17.6	20.3	22.7	27.7	32	57	74.9	88.1	101.1	106.1	114.9	672.1
Round Rock	9.7	0	9	9.8	14.1	19.2	23.5	48.4	66.3	79.5	92.5	97.5	106.3	575.8
McNeil Jct.	17.6	9	0	7.7	12.2	16.9	21.6	46.5	64.4	77.6	90.6	95.6	104.4	564.1
Research	20.3	9.8	7.7	0	11.1	15.8	20.4	45.4	63.3	76.5	89.5	94.5	103.3	557.6
US 183	22.7	14.1	12.2	11.1	0	6.5	10.8	35.7	53.6	66.8	79.8	84.8	93.6	491.7
Austin CBD	27.7	19.2	16.9	15.8	6.5	0	5.5	30.4	48.4	61.6	74.6	79.6	88.4	474.6
Ben White	32	23.5	21.6	20.4	10.8	5.5	0	26.5	44.5	57.6	70.7	75.7	84.5	473.3
San Marcos	57	48.4	46.5	45.4	35.7	30.4	26.5	0	19.1	32.3	45.3	50.3	59.1	496
New Braunfels	74.9	66.3	64.4	63.3	53.6	48.4	44.5	19.1	0	15	28	33.1	41.8	552.4
Selma	88.1	79.5	77.6	76.5	66.8	61.6	57.6	32.3	15	0	13.4	18.5	27.3	614.2
San Antonio Airport	101.1	92.5	90.6	89.5	79.8	74.6	70.7	45.3	28	13.4	0	9.5	18	713
San Antonio CBD	106.1	97.5	95.6	94.5	84.8	79.6	75.7	50.3	33.1	18.5	9.5	0	9.3	754.5
Kelly	114.9	106.3	104.4	103.3	93.6	88.4	84.5	59.1	41.8	27.3	18	9.3	0	850.9
Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	**46.10**

- To calculate what the individual commuter costs in annual CO_2 emissions by using the five high-speed rail technologies, the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology 2006 report (Table 4.14) is modeled after.
- The calculation is completed in taking each of the five high-speed rail technologies' emission of CO_2 per passenger mile, and multiplying each by the average distance between rail stations in the corridor (46.10 miles),

- The result from each of the five rail technologies is then multiply by five (5 days a week) and fifty two (52 weeks a year) that the commute is made.

Table 4.14: Commuter's annual emission footprint by using a high-speed rail technology

What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected. (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile • Average distance between rail stations • 5 week days • 52 weeks per year	• Certain high-speed rail technology's CO_2 emissions per passenger mile. (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49) • Average distance between rail stations= 46.10 miles • 5 week days • 52 weeks per year	1) CO_2 per passenger mile (based on high-speed rail technology) * 46.10 miles (average commute between rail stations) * 5 days per week * 52 weeks per year = **What the individual commuter costs in annual CO_2 emission depending on high-speed rail technology selected**

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- The resulting annual CO_2 emission for a commuter using each of the five high-speed technologies in the Georgetown-San Antonio corridor is shown below in Table 4.15.

Table 4.15: Annual emission for a commuter using each of the five high-speed rail technologies within the Georgetown-San Antonio corridor

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile	Average distance between rail stations (miles)	Five weekdays	Fifty two weeks a year	Annual CO_2 emission for an individual commuter using high-speed rail in the Georgetown-San Antonio Corridor (Lbs of CO_2)
Shinkansen	0.22 X	46.10 X	5 X	52	= 2,636.92
TGV	0.15 X	46.10 X	5 X	52	= 1,797.9
ICE	0.11 X	46.10 X	5 X	52	= 1,318.46
Danish IC-3	0.26 X	46.10 X	5 X	52	= 3,116.36
MagLev	0.49 X	46.10 X	5 X	52	= 5,873.14

The results show that the ICE high-speed rail technology produces the lowest annual amount of CO_2 emission per individual rider. In the next section the research will determine out of the five high-speed rail technologies designated for operation in the corridor, of which produces the lowest amount of annual CO_2 emissions due to each of the five technologies operation.

Predicted annual emission of carbon dioxide for each of the five high-speed rail technologies running in the Georgetown to San Antonio corridor

An annual savings of 41,639,836.93 lbs of automobile carbon dioxide (CO_2) emissions means the air quality and environment would benefit from a high-speed rail system. But, the resulting annual cost by high-speed rail operation and emission of CO_2 must be considered when choosing the most efficient technology for operation. Emission data on the five high-speed rail technologies provided by the Center for Clean Air Policy and Center for Neighborhood Technology, will determine the high-speed rail technology option with the lowest carbon dioxide production annually and the appropriate choice of high-speed rail technology to use in the Georgetown-San Antonio corridor.

- The formula used to determine each high-speed rail annual emissions appears in Table 4.18, as replicated by the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology report.
- Criteria needed for calculation include:
    - The emissions per passenger mile for the each high-speed rail technology (Table 4.16) ,

Table 4.16: Five high-speed rail technologies' CO_2 lbs per passenger mile

High Speed-Rail Technology	Lbs CO_2 Per Passenger Mile
Shinkansen	0.22
TGV	0.15
ICE	0.11
Danish IC-3	0.26
MagLev	0.49

Source: http://www.cnt.org/repository/HighSpeedRailEmissions.pdf

- And the annual miles by riders forecasted by the researcher for the Georgetown-San Antonio corridor :
    - (492,546.68 daily miles by riders (Table 4.17) predicted for the Georgetown-San Antonio corridor times
    - five days a week times
    - fifty two weeks a year= 128,062,136.8 annual miles by riders).

Table 4.17: Average daily miles by riders in the Georgetown-San Antonio corridor

Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	**46.10**
Number of daily riders	740	1,110	210	320	580	1,810	980	1,800	490	340	630	1,500	480	**10,990**
Daily miles driven by riders from each station (Average Distance * Riders)	38,258.00	49,164.46	9,112.38	13,725.54	21,937.38	66,078.92	35,679.54	68,676.92	20,821.23	16,063.69	34,553.08	87,057.69	31,417.85	**492,546.69**

Now having the parts needed to complete the formula replicated after the formula used in the Center for Clean Air Policy and Center for Neighborhood Technology report (Table 4.18).

Table 4.18: Formula to determine the projected high speed rail technology's annual emissions footprint

Projected high-speed rail annual emissions depending on high-speed rail technology selected. (TGV, Shinkansen, ICE, IC-3,MagLev)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (provided by the Center for Clean Air Policy) • Daily miles by riders predicted for the Georgetown-San Antonio corridor (estimated by researcher) • Annual miles by riders predicted for the Georgetown-San Antonio corridor (estimated by researcher)	• Certain high-speed rail technology's CO_2 emissions per passenger mile (TGV= 0.15, Shinkansen= 0.22, ICE= 0.11, IC-3= 0.26, MagLev= 0.49) • Daily miles by riders predicted for the Georgetown-San Antonio corridor= 492,546.68 • Annual miles by riders predicted for the Georgetown-San Antonio corridor= 128,062,136.8	1) Certain high-speed rail technology's CO_2 emissions per passenger mile TIMES 2) Annual miles by riders predicted for the Georgetown-San Antonio corridor (128,062,136.8) = **Projected high-speed rail annual emissions**

- To determine the annual emission of CO_2 for each of the five high-speed rail technologies operating in the Georgetown-San Antonio corridor, is simply done by taking each of the five high-speed rail technologies' lbs of CO_2 per passenger mile and multiply each by the (128,062,136.8) annual miles by riders estimated in the corridor.

Table 4.19: Five high-speed rail technologies' annual emission footprint for Georgetown-San Antonio Corridor

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile	Annual miles by riders for the Georgetown-San Antonio corridor	Annual Emission footprint for Georgetown-San Antonio Corridor (Lbs of CO_2 per year)
Shinkansen	0.22 X	128,062,136.8 =	28,173,670.10
TGV	0.15 X	128,062,136.8 =	19,209,320.52
ICE	**0.11 X**	**128,062,136.8 =**	**14,086,835.05**
Danish IC-3	0.26 X	128,062,136.8 =	33,296,155.57
MagLev	0.49 X	128,062,136.8 =	62,750,447.03

This analysis determines in Table 4.19 the high-speed rail technology to have the least effect on the net annual automobile emissions savings of CO_2 in the Georgetown-San Antonio corridor by producing the lowest amount of CO_2 annually. As shown above in Table 4.19, after calculating the five high-speed rail trains' projected high-speed rail annual emissions , this analysis indicates out of the five high-speed rail technologies, the German Intercity Express (ICE) train would provide the best benefit. The ICE high-speed rail technology has the lowest CO_2 emission per passenger mile during operation (0.11), as well as the smallest annual emission footprint (14,086,835.05 lbs of CO_2 per year). The next section determines the effect that each of the five high-speed rail technologies' annual emissions of CO_2 has on the net annual automobile emissions savings (41,639,836.93lbs of CO_2) projected for the Georgetown- San Antonio corridor.

Model Results

Resulting net annual emissions savings of CO_2 in Georgetown-San Antonio corridor due to a high-speed rail operation

To calculate the effect that each high-speed rail technology's annual emission of CO_2 would have on the saved net annual automobile emissions for the Georgetown- San Antonio corridor, the following equation (Table 4.20) applies.

Table 4.20: Net annual emissions savings for Georgetown-San Antonio corridor

Net annual emissions savings= • 41,639,836.93lbs of CO_2 automobile annual emissions savings (minus) • Projected high-speed rail technology annual emission.

To determine the best high-speed rail option to use in the Georgetown-San Antonio corridor is done by taking the 41,639,836.93lbs of CO_2 net annual automobile emissions savings in the corridor (shown on the next page in Table 4.21) ,

Table 4.21: Annual automobile emissions saved by station and corridor

	Daily miles by riders from each city	Average Occupancy	Automobile emission per passenger mile (lbs of CO_2)	Automobile Emissions Saved Daily	Automobile Emissions Saved Annually
Georgetown	38,258.00	1.63	0.53	12,439.72	3,234,326.63
Round Rock	49,164.46	1.63	0.53	15,985.99	4,156,357.55
McNeil Jct.	9,112.38	1.63	0.53	2,962.92	770,359.88
Research	13,725.54	1.63	0.53	4,462.91	1,160,355.34
US 183	21,937.38	1.63	0.53	7,133.01	1,854,583.80
Austin CBD	66,078.92	1.63	0.53	21,485.78	5,586,304.05
Ben White	35,679.54	1.63	0.53	11,601.32	3,016,343.80
San Marcos	68,676.92	1.63	0.53	22,330.53	5,805,938.65
New Braunfels	20,821.23	1.63	0.53	6,770.09	1,760,224.29
Selma	16,063.69	1.63	0.53	5,223.16	1,358,022.58
SA Airport	34,553.08	1.63	0.53	11,235.05	2,921,112.88
San Antonio CBD	87,057.69	1.63	0.53	28,307.10	7,359,846.63
Kelly	31,417.85	1.63	0.53	10,215.62	2,656,060.86
Total	**492,546.69**	**1.63**	**0.53**	**160,153.22**	**41,639,836.93**

and subtracting from the 41,639,836.93lbs CO_2 automobile emissions saved, each of the five high-speed rail technologies' annual emission produced (shown below in Table 4.22).

Table 4.22: Five high-speed rail technologies' annual emission footprint for Georgetown-San Antonio Corridor

High Speed Rail Technology	Lbs CO_2 Per Passenger Mile	Annual miles by riders for the Georgetown-San Antonio corridor	Annual Emission footprint for Georgetown-San Antonio Corridor (Lbs of CO_2 per year)
Shinkansen	0.22 X	128,062,136.8 =	28,173,670.10
TGV	0.15 X	128,062,136.8 =	19,209,320.52
ICE	**0.11 X**	**128,062,136.8 =**	**14,086,835.05**
Danish IC-3	0.26 X	128,062,136.8 =	33,296,155.57
MagLev	0.49 X	128,062,136.8 =	62,750,447.03

After completing the formula in Table 4.22 for each of the five high-speed rail technologies, the results are shown in Table 4.23 to determine which of the five high-speed rail technologies produces the greatest benefit by having the lowest cost in its own operation and annual emission.

Table 4.23: Total annual net emissions savings by high-speed rail technology

	Shinkansen	**TGV**	**ICE**	**Danish IC-3**	**MagLev**
Automobile emissions saved annually	41,639,836.93	41,639,836.93	41,639,836.93	41,639,836.93	41,639,836.93
Projected high-speed rail annual emission	28,173,670.10	19,209,320.52	14,086,835.05	33,296,155.57	62,750,447.03
Net annual emissions savings by rail technology	13,466,166.83	22,430,516.41	27,553,001.88	8,343,681.36	-21,110,610.10

This study predicts that an annual net automobile emissions savings of 27,553,001.88 lbs of carbon dioxide (CO_2) in the Georgetown-San Antonio corridor because German ICE high-speed rail technology produces the lowest projected annual emission cost of the five high-speed rail technologies (14,086,835.05 lbs of CO_2). Thus, the ICE high-speed rail technology would be the appropriate choice for the Georgetown-San Antonio corridor.

Conclusion

This chapter discusses the costs and benefits as a result of commuters switching from automobile technology to one the five high-speed rail technologies in the Georgetown-San Antonio corridor. Each high-speed rail technology was evaluated to determine which of the five high-speed rail technologies' annual net emission impacts would benefit the Georgetown- San Antonio corridor the greatest by diverting automobile commuters to the railway producing an annual carbon dioxide emission during operation not detrimental to the net automobile emissions saved. In estimating each of the five high-speed rail technologies' annual net emission impacts, the resulting carbon dioxide (CO_2) saved from automobile commuters switching to the ICE high-speed rail would result in an annual emissions savings of 27,553,001.88 lbs of carbon dioxide (CO_2). Though the German Intercity Express (ICE) high speed rail system produces the best results in terms of net emissions saved annually, planners should also take into consideration all costs and benefits of a high-speed rail systems' implementation and decide the capital project's viability accordingly. The following chapter discusses the conclusions of the analysis.

Chapter 5: CONCLUSION

Introduction

This chapter provides a summary of the cost-benefit analysis performed on a proposed high-speed rail transportation system in Central Texas. This chapter recommends the German Intercity Express (ICE) high-speed rail technology as the train system that will provide the largest benefit to the region while causing the smallest annual emission thereby minimally impacting the net annual automobile emissions savings in the corridor.

Summary

This research project began by discussing the ongoing problems caused by traffic congestion along the Interstate 35 corridor, and how the State of Texas has tried to remodel its roadways to ease the burden on its highway transportation system, with little effect. The vision of constructing a high-speed rail system that breezes through and connecting the state's major cities exhausted by overcrowding and traffic congestion has been a goal of the state's public administrators as well as anyone who has travelled down Interstate 35 at rush hour. All the benefits associated with high-speed rail systems in operation worldwide are possible in Texas, as well. Chapter two researched, reviewed, and examined the available literature on high-speed rail transportation systems around the world and the costs and benefits associated with their high-speed networks. The chapter also examines from the beginning, United States President Barack Obama's vision to incorporate a high-speed rail system into the nation's already overburdened transportation system. The literature review begins the cost-benefit analysis by identifying the environmental costs and benefits that would result in the operation of a high-speed network;

specifically, the effect of the greenhouse gas carbon dioxide (CO_2) and the gases' emission rates based on available high-speed rail technologies.

Chapter three, the Methodology chapter, reviews why a cost benefit analysis was an appropriate method to address the research question. The purpose of this paper is to conduct a cost-benefit analysis focusing on a high-speed rail system between Georgetown and San Antonio, and to determine if this mode of transportation is a viable investment in reducing the annual amount of automobile carbon dioxide emissions. The data used for this study derived from existing published studies utilizing modeling shows high-speed rail, if built as planned, will generate substantial environmental savings. Benefits occur when annual automobile trips are canceled and by annual mileage not driven in the corridor due to diverting automobile passengers onto the railway. The resulting annual savings occurs in the amount of automobile CO_2 not emitted into the air for that year. While there is a savings in the annual amount of automobile CO_2 not being emitted into the air, high-speed rail itself produces a cost in the annual amount of CO_2 it produces due to its operation. The research evaluates five high-speed rail technologies to determine which of the five is the least detrimental to the Georgetown-San Antonio corridor's annual amount of automobile savings, i.e., which is the best option by producing the lowest amount of annual emission of CO_2. The best option is the high-speed rail technology with the lowest annual emission of CO_2; that is the least detrimental to the net annual automobile emissions saved in the corridor. The data for the five high-speed rail technology emission rates, average automobile emission rate, and ridership and diversion rates, came from existing data published by The Center for Neighborhood Technology (CNT), the Center for Clear Air Policy (CCAP), Environmental Protection Agency (EPA), and the Austin- San Antonio Intermunicipal Commuter Rail District Study

Chapter four, the Results chapter, shows the direct benefits and costs associated with implementation of a high-speed rail network in the Georgetown-San Antonio corridor. The results show the direct benefits in the form of annual vehicle trip cancellations, how much the average commuter saves in carbon dioxide emissions by switching to high-speed rail, and net annual automobile emissions saved in the corridor. The only cost considered is the operation and annual running of the selected high-speed rail technology. The research analyzed each high-speed rail technology to determine which of the five high-speed rail technologies' net emission impacts would benefit the Georgetown- San Antonio corridor the greatest by diverting automobile commuters onto its rails and producing an annual carbon dioxide level not detrimental to the automobile emissions saved. This research concludes that the German Intercity Express (ICE) high-speed rail technology produces the best results (as shown in Table 4.23) in the lowest amount of emission per passenger mile (0.11 lbs of CO_2), the lowest cost in annual production of carbon dioxide (CO_2) due to its operation (14,086,835.05 lbs of CO_2), and most importantly, the highest amount of annual net emission savings totaled at 27,553,001.88 lbs of carbon dioxide (CO_2) annually. The results are based on current projections of available data at this time. If the project actually begins construction later than year 2020, a new forecast should be done taking in consideration changes in technology and data available.

Recommendations

The results of this cost-benefit analysis forecast the annual emissions savings produced by the five high-speed rail technologies for the year 2020. By following the methodology used in this research, the State of Texas, as well as other states and nations can model research in similar fashion to determine whether high-speed rail will benefit local annual carbon dioxide levels. This study along with the Center for Neighborhood Technology (CNT) and Center for Clean Air Policy (CCAP) recommends further research to better understand the potential impact of high speed rail's costs and benefits. In areas with cleaner than average electricity generation production derived from other natural resources, such as wind, solar, or hydroelectric generated electricity high-speed rail may be much more environmentally sound and the preferred choice. Improved and updated energy and emissions data on past and emerging high-speed rail technologies should constantly be reviewed to improve the understanding of the energy use and emissions impact of intercity travel by high-speed rail technologies. The most direct way to impact the emissions associated with high-speed rail is to improve the efficiency of the trains. As described in the literature review, more efficient diesel locomotive engines and other improvements, such as regenerative braking, are being developed to improve high-speed rail efficiency. Local, state, and federal government can use cost benefit analysis to determine whether a project benefits the public. The same can be said for the environment. Officials may also use cost benefit analysis to determine the best transportation options based on environmental impact.

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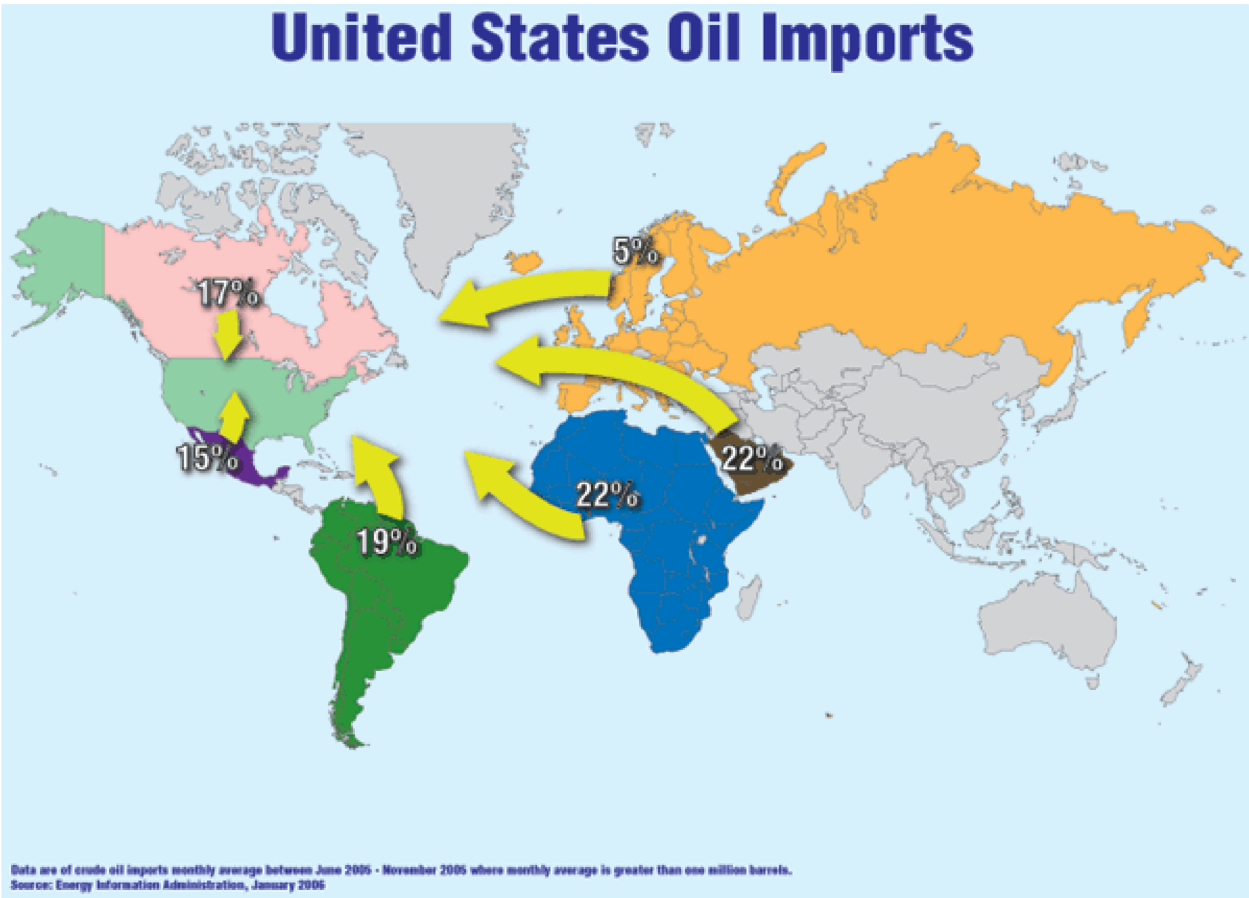
Appendix A

Map of Proposed Lone Star Commuter Rail

Appendix B

Map of United States' petroleum imports



Appendix C

United States Traffic fatalities rates from 1990-2009 per 100 million miles traveled

Alabama	1,121	996	1,154	1,148	1,207	1,110	969	848	2.6	1.8	2.0	1.9	2.0	1.8	1.6	1.5
Alaska	98	106	101	73	74	82	62	64	2.5	2.3	2.0	1.5	1.5	1.6	1.3	1.3
Arizona	869	1,036	1,151	1,179	1,293	1,071	938	807	2.5	2.1	2.0	2.0	2.1	1.7	1.5	1.3
Arkansas	604	652	703	654	665	649	600	585	2.9	2.2	2.2	2.1	2.0	2.0	1.8	1.8
California	5,192	3,753	4,120	4,333	4,240	3,995	3,434	3,081	2.0	1.2	1.3	1.3	1.3	1.2	1.1	1.0
Colorado	544	681	667	606	535	554	548	465	2.0	1.6	1.5	1.3	1.1	1.1	1.2	1.0
Connecticut	385	341	294	278	311	296	302	223	1.5	1.1	0.9	0.9	1.0	0.9	1.0	0.7
Delaware	138	123	134	133	148	117	121	116	2.1	1.5	1.4	1.4	1.6	1.2	1.4	1.3
District of Columbia	48	48	43	48	37	44	34	29	1.4	1.4	1.2	1.3	1.0	1.2	0.9	0.8
Florida	2,891	2,999	3,244	3,518	3,357	3,213	2,980	2,558	2.6	2.0	1.7	1.8	1.7	1.6	1.5	1.3
Georgia	1,562	1,541	1,634	1,729	1,693	1,641	1,495	1,284	2.2	1.5	1.4	1.5	1.5	1.5	1.4	1.2
Hawaii	177	132	142	140	161	138	107	109	2.2	1.5	1.5	1.4	1.6	1.3	1.0	1.1
Idaho	244	276	260	275	267	252	232	226	2.5	2.0	1.8	1.9	1.8	1.6	1.5	1.5
Illinois	1,589	1,418	1,355	1,363	1,254	1,248	1,043	911	1.9	1.4	1.2	1.3	1.2	1.2	1.0	0.9
Indiana	1,049	886	947	938	902	898	820	693	2.0	1.3	1.3	1.3	1.3	1.2	1.1	0.9
Iowa	465	445	388	450	439	446	412	372	2.0	1.5	1.2	1.5	1.4	1.4	1.3	1.2
Kansas	444	461	459	428	468	416	384	386	1.9	1.6	1.6	1.4	1.6	1.4	1.3	1.3
Kentucky	849	820	964	985	913	864	825	791	2.5	1.8	2.0	2.1	1.9	1.8	1.7	1.7
Louisiana	959	938	927	963	987	993	916	821	2.5	2.3	2.1	2.1	2.2	2.2	2.0	1.8
Maine	213	169	194	169	188	183	155	159	1.8	1.2	1.3	1.1	1.3	1.2	1.1	1.1
Maryland	707	588	643	614	652	614	591	547	1.7	1.2	1.2	1.1	1.2	1.1	1.1	1.0
Massachusetts	605	433	476	441	429	434	364	334	1.3	0.8	0.9	0.8	0.8	0.8	0.7	0.6
Michigan	1,571	1,382	1,159	1,129	1,086	1,087	980	871	1.9	1.4	1.1	1.1	1.0	1.0	1.0	0.9
Minnesota	566	625	567	559	494	510	455	421	1.5	1.2	1.0	1.0	0.9	0.9	0.8	0.7
Mississippi	750	949	900	931	911	884	783	700	3.1	2.7	2.3	2.3	2.2	2.0	1.8	1.7
Missouri	1,097	1,157	1,130	1,257	1,096	992	960	878	2.2	1.7	1.6	1.8	1.6	1.4	1.4	1.3
Montana	212	237	229	251	264	277	229	221	2.5	2.4	2.0	2.3	2.3	2.5	2.1	2.0
Nebraska	262	276	254	276	269	256	208	223	1.9	1.5	1.3	1.4	1.4	1.3	1.1	1.2
Nevada	343	323	395	427	431	373	324	243	3.4	1.8	2.0	2.1	2.0	1.7	1.6	1.2
New Hampshire	158	126	171	166	127	129	138	110	1.6	1.0	1.3	1.2	0.9	1.0	1.1	0.9
New Jersey	886	731	723	747	771	724	590	583	1.5	1.1	1.0	1.0	1.0	1.0	0.8	0.8
New Mexico	499	432	521	488	484	413	366	361	3.1	1.9	2.2	2.0	1.9	1.5	1.4	1.4
New York	2,217	1,460	1,495	1,434	1,454	1,332	1,238	1,156	2.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
North Carolina	1,385	1,557	1,573	1,547	1,554	1,676	1,428	1,314	2.2	1.7	1.6	1.5	1.5	1.6	1.4	1.3
North Dakota	112	86	100	123	111	111	104	140	1.9	1.2	1.3	1.6	1.4	1.4	1.3	1.7
Ohio	1,638	1,366	1,286	1,321	1,238	1,255	1,191	1,021	1.8	1.3	1.2	1.2	1.1	1.1	1.1	0.9
Oklahoma	641	650	774	803	765	766	750	738	1.9	1.5	1.7	1.7	1.6	1.6	1.6	1.6
Oregon	579	451	456	487	478	455	416	377	2.2	1.3	1.3	1.4	1.4	1.3	1.2	1.1
Pennsylvania	1,646	1,520	1,490	1,616	1,525	1,491	1,468	1,256	1.9	1.5	1.4	1.5	1.4	1.4	1.4	1.2
Rhode Island	84	80	83	87	81	69	65	83	1.1	1.0	1.0	1.1	1.0	0.8	0.8	1.0
South Carolina	979	1,065	1,046	1,094	1,045	1,077	921	894	2.8	2.3	2.1	2.2	2.1	2.1	1.9	1.8
South Dakota	153	173	197	186	191	146	121	131	2.2	2.1	2.2	2.2	2.1	1.6	1.4	1.4
Tennessee	1,177	1,307	1,339	1,270	1,284	1,211	1,043	989	2.5	2.0	1.9	1.8	1.8	1.7	1.5	1.4
Texas	3,250	3,779	3,699	3,536	3,531	3,466	3,476	3,071	2.1	1.7	1.6	1.5	1.5	1.4	1.5	1.3
Utah	272	373	296	282	287	299	276	244	1.9	1.7	1.2	1.1	1.1	1.1	1.1	0.9
Vermont	90	76	98	73	87	66	73	74	1.5	1.1	1.3	1.0	1.1	0.9	1.0	1.0
Virginia	1,079	929	922	947	962	1,027	825	757	1.8	1.2	1.2	1.2	1.2	1.3	1.0	0.9
Washington	825	631	567	649	633	571	521	492	1.8	1.2	1.0	1.2	1.1	1.0	0.9	0.9
West Virginia	481	411	410	374	410	432	378	356	3.1	2.1	2.0	1.8	2.0	2.1	1.8	1.8
Wisconsin	769	799	792	815	724	756	605	561	1.7	1.4	1.3	1.4	1.2	1.3	1.1	1.0
Wyoming	125	152	164	170	195	150	159	134	2.1	1.9	1.8	1.9	2.1	1.4	1.7	1.4

FOOTNOTES

\1 Deaths per 100 million vehicle miles traveled.

Source: U.S. National Highway Traffic Safety Administration, Traffic Safety Facts, annual.

For more information:
http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.a0bd5d5a23d09ec24ec86e10dba046a0/
http://www-nrd.nhtsa.dot.gov/CATS/index.aspx

Internet release date: 09/30/2011

Appendix D

Average distance traveled between destinations, Number of daily riders, Average daily miles driven by riders from each station, Daily number of car trip cancelled, Average auto occupancy

	Georgetown	Round Rock	McNeil Jct.	Research	US 183	Austin CBD	Ben White	San Marcos	New Braunfels	Selma	San Antonio Airport	San Antonio CBD	Kelly	Total
Georgetown	0	9.7	17.6	20.3	22.7	27.7	32	57	74.9	88.1	101.1	106.1	114.9	672.1
Round Rock	9.7	0	9	9.8	14.1	19.2	23.5	48.4	66.3	79.5	92.5	97.5	106.3	575.8
McNeil Jct.	17.6	9	0	7.7	12.2	16.9	21.6	46.5	64.4	77.6	90.6	95.6	104.4	564.1
Research	20.3	9.8	7.7	0	11.1	15.8	20.4	45.4	63.3	76.5	89.5	94.5	103.3	557.6
US 183	22.7	14.1	12.2	11.1	0	6.5	10.8	35.7	53.6	66.8	79.8	84.8	93.6	491.7
Austin CBD	27.7	19.2	16.9	15.8	6.5	0	5.5	30.4	48.4	61.6	74.6	79.6	88.4	474.6
Ben White	32	23.5	21.6	20.4	10.8	5.5	0	26.5	44.5	57.6	70.7	75.7	84.5	473.3
San Marcos	57	48.4	46.5	45.4	35.7	30.4	26.5	0	19.1	32.3	45.3	50.3	59.1	496
New Braunfels	74.9	66.3	64.4	63.3	53.6	48.4	44.5	19.1	0	15	28	33.1	41.8	552.4
Selma	88.1	79.5	77.6	76.5	66.8	61.6	57.6	32.3	15	0	13.4	18.5	27.3	614.2
San Antonio Airport	101.1	92.5	90.6	89.5	79.8	74.6	70.7	45.3	28	13.4	0	9.5	18	713
San Antonio CBD	106.1	97.5	95.6	94.5	84.8	79.6	75.7	50.3	33.1	18.5	9.5	0	9.3	754.5
Kelly	114.9	106.3	104.4	103.3	93.6	88.4	84.5	59.1	41.8	27.3	18	9.3	0	850.9
Average Distance	51.70	44.29	43.39	42.89	37.82	36.51	36.41	38.15	42.49	47.25	54.85	58.04	65.45	46.10
Number of daily riders	740	1,110	210	320	580	1,810	980	1,800	490	340	630	1,500	480	10,990
Avg. daily miles driven by riders from each station (Average Distance * Riders)	38,258.00	49,164.46	9,112.38	13,725.54	21,937.38	66,078.92	35,679.54	68,676.92	20,821.23	16,063.69	34,553.08	87,057.69	31,417.85	492,546.69
Daily number of car trip cancelled	454	681	129	196	356	1,110	601	1,104	301	209	387	920	294	6,742
Average auto occupancy	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63