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16. Abstract

This research project evaluates numerous transportation issues and develops findings and/or recommendations based on results. This project has been structured to address some of the emerging, critical, and unique considerations related to transportation.

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TxDOT ADMINISTRATION RESEARCH: TASKS COMPLETED FY 2011

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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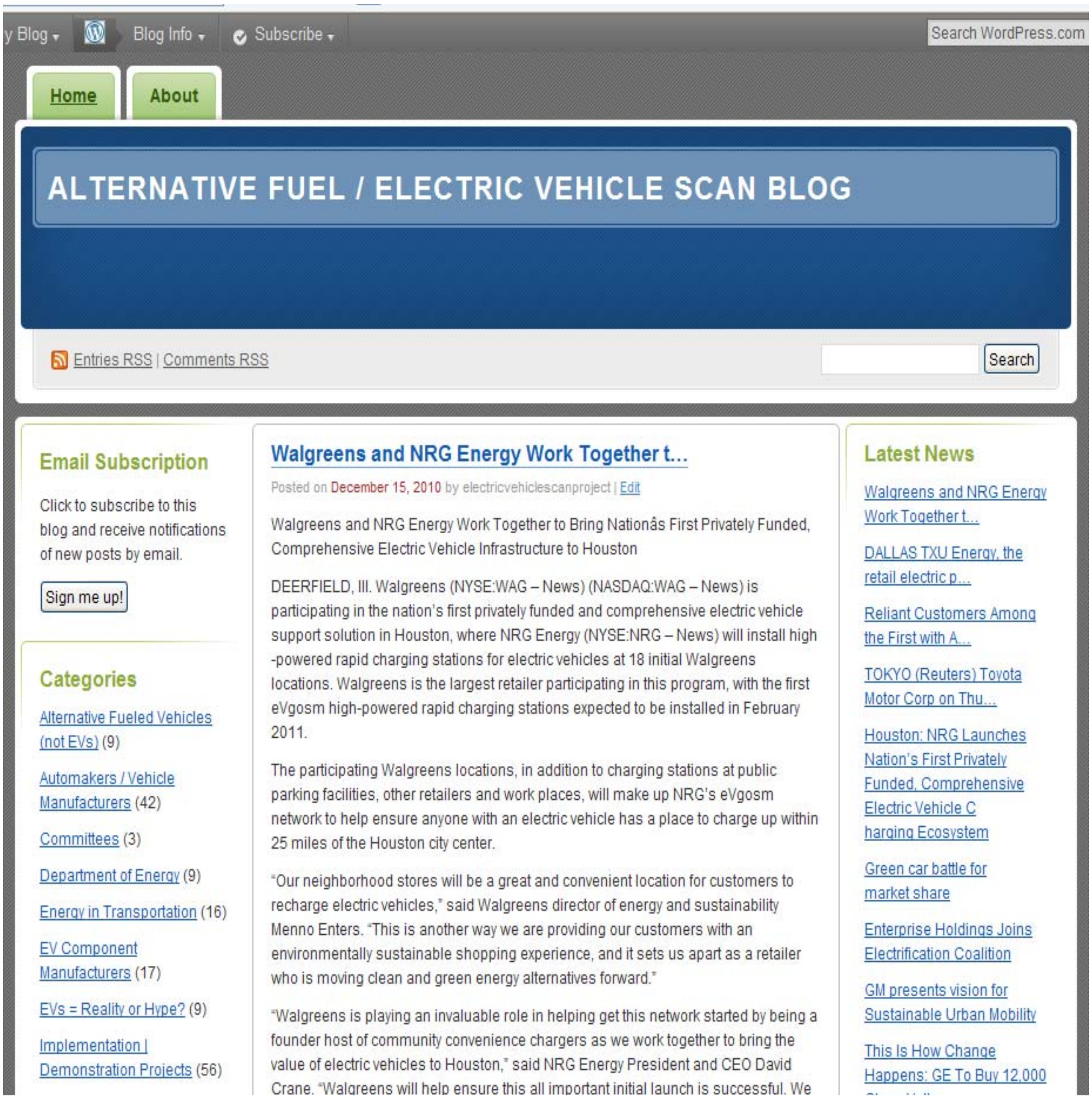
OVERVIEW

The Texas Department of Transportation (TxDOT) requested a literature review of the current market climate for alternative-fuel vehicles, in particular electric vehicles (EVs). The primary purpose of that review was to report on current and potential future trends that could represent opportunities or challenges to TxDOT. This review was based on information available in the public domain. However, there are reports available that one can purchase for a significant cost. The Texas Transportation Institute (TTI) has now scanned over 17,000 relevant articles. Researchers selected 430 of the most significant articles and posted them to the Alternative Fuel/Electric Vehicle Scan Blog established for this project—located at http://electricvehiclescanproject.wordpress.com/about/ and shown in Figure 1. Instructions on how to post to the blog are found in Appendix A. During this scan, TTI also gathered peer state incentives offered to alternative fuel vehicles. This listing can be found in Appendix B. TTI also reviewed more than 75 websites and compiled a list of websites that provided the most useful and timely information. A list of these resources can be found in Appendix C.

This briefing summarizes findings of information available in the public domain. The report will outline, in brief, the evolving market of electric vehicles as well as provide an overview of current implementation projects and peer-state incentives for electric vehicles.



Source: http://electricvehiclescanproject.wordpress.com/about/

Figure 1. Alternative Fuel/Electric Vehicle Scan Blog Screen Capture.

ELECTRIC VEHICLE PROJECTS, NATIONAL OVERVIEW

Major corporations and individual investors seek to be at the forefront of what they see as the next major global and environmental investment—electric and alternative-fuel vehicles. Corporations such as Intel, GM, Ford, Microsoft, UPS, Nissan, and FedEx—to name a few—are leading the charge of President Obama's electric vehicle provisions in the federal fuel economy and emissions rules announced on April 1, 2010. The fuel economy rules, which set the U.S. auto industry standard at 35.5 miles per gallon (mpg) average by 2016, sent many automakers and industry leaders back to their plants to put their electric vehicle projects on the fast track (http://www.epa.gov/oms/climate/regulations.htm). Automakers are investing in necessary facilities, and many plan to have at least one all-electric model on the road by 2011. Ford and Nissan are leading the way with models currently in production.

In the United States, new electric vehicle and technology projects seem to emerge daily. On August 5, 2010, President Barack Obama announced $2.4 billion in grants awarded to 48 projects across the country under the American Recovery and Reinvestment Act. The projects awarded were selected through a competitive process under the U.S. Department of Energy. Expectations are that these key projects will accelerate the development of U.S. manufacturing capacity for batteries and electric drive components as well as the deployment of electric drive vehicles.

Go to: http://bit.ly/aJcyeK for all the information related to these awards, including projects and locations.

Funding/Support

- Over 75 research and/or implementation projects across the U.S. since August 2009.
- The EV Project started in October 2009 with a $99.5 million grant awarded by the U.S. Department of Energy. An additional $15 million was added in June 2010.
- $2.4 billion in grants, primarily funded by the U.S. Department of Energy. This is new funding, separate from The EV Project.
- The Electric Vehicle Initiative (EVI) is a worldwide effort to implement electric vehicles. Countries actively participating: China, France, Germany, Japan, South Africa, Spain, Sweden, and the United States.
- China announced investing 100 billion yuan ($14.7 billion U.S.) over the next 10 years (2011–2020) with an annual production goal of 500,000 alternative fuel vehicles (AFV) starting in 2011
- Great Britain, although not a member of the EVI, is implementing infrastructure as well.

Projections

- Sales of hybrid and electric vehicles could top 3 million nationwide by 2015.[1]
- 20 million electric vehicles estimated worldwide by 2020. International Energy Administration (Appendix D).
- Ford Motor Company to introduce five new electric vehicle models by 2013. Ford anticipates electric-hybrid vehicles (EHV), plug-in electric vehicles (PHEV) and battery-electric vehicles (BEV) will represent 2–5 percent of its global fleet by 2015, rising to 10–25 percent by 2020.[2]

Demonstration/Implementation Projects

- The U.S. Department of Energy announced on August 5, 2009, that the largest deployment plan in the world of EVs and EV infrastructure would be awarded to the Electric Transportation Engineering Corporation (eTec), a subsidiary of ECOtality, Inc. The $99.8 million grant, awarded on October 1, 2009, officially marked the launch of The EV Project (http://theevproject.com).The EV Project will facilitate the installation of over 15,000 charging stations in five states and 16 cities including four cities in Texas – Austin, Dallas, Fort Worth, and Houston.
- Charging stations are being installed, currently in small numbers, in parking garages and businesses for employees to use. It is anticipated quick-charge stations (80% capacity charge of an EV in 20–30 minutes) will be installed in convenient locations where people are stopping over for an hour such as a Starbucks, grocery stores, and malls. The downtown Austin Whole Foods Market has an EV charging station, one of the first installed in Texas. Half Price Books installed two EV charging stations in 2010 at their 5803 E. Northwest Highway location.

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[1] Dibenedetto. B. "J.D. Power: Hybrid and EV Cars will be 3.5% of Sales by 2015." *TriplePundit People Planet Profit*. TriplePundit.com, 21/06/2010. Web. <http://www.triplepundit.com/2010/06/j-d-power-hybrid-and-ev-cars-will-be-3-5-of-sales-by-2015/>.

[2] "Ford Motor Company." *Ford's Electrification Strategy*. Ford Motor Company, 21/06/2010.Web. <http://media.ford.com/mini_sites/10031/Electrification/>.

Commercial

- FedEx's current fleet.
  - 300 electric hybrids.
  - 1,800+ worldwide.
- UPS.
  - Fleet of 250 electric hybrid delivery trucks.
  - 25 are located in Stafford, Texas.
- AT&T.
  - Invests $565 million for 15,000 alternative fuel vehicles in 10 years.

Consumer Use of Commercial Services

- Taxis.
  - Taxis across the nation are converting to hybrid vehicles.
- Rental Car Companies.
  - Enterprise.
    - Largest hybrid fleet.
    - Available in cities across the U.S. including Austin, Dallas, and Houston.
    - Rolling out 500 EVs in select markets.

Government

- Federal Government.
  - United States Postal Service.
    - Awarded $2 billion to convert 20,000 vehicles to electric over three years, by 2013.
- Municipalities, state agencies, and universities across the nation are designating minimum percents in their fleet purchases and identifying vehicles for conversion to LNG, CNG, or other alternative fuels as applicable.

THE ELECTRIC VEHICLE MARKET

The initial analysis shows a wide range of possibilities for the future. Projections of EV market penetration are available from a variety of sources such as U.S. Department of Energy, J.D. Power, Hong Kong Shanghai Banking Corporation (HSBC), and the automotive industry to name a few – but these sources rarely agree. Estimates of the number of EVs in Texas by 2020, for example, appear to range from several hundred to almost 3.5 million. The level of uncertainty surrounding the EV market can be at least partially attributable to two factors: vehicle cost and supporting infrastructure.

While a number of EVs are currently on the domestic automotive market, as a vehicle class they are not expected to constitute a significant presence on U.S. roadways until models from major automotive makers become available for purchase in 2011. Expectations for large-scale adoption by the driving public are very low in the near term, but in the long term, they could be widely adopted, posing significant challenges for funding roadway upkeep and expansion. Many models, such as pure plug-in electric vehicles, will not pay any fuel taxes, while those that utilize an internal combustion element in conjunction with their electric motors (such as HEVs and PHEVs) will probably pay very little in fuel taxes relative to traditional-fuel vehicles. Therefore, the rate at which the general public adopts these vehicles could significantly impact transportation funding sources. These funding sources, and specifically fuel taxes, are already facing long-term shortfalls, due in part to the ever-increasing fuel efficiency of the domestic passenger vehicle fleet. Researchers conducted a survey of automotive market literature and various data sources in order to identify potential trends for long-term market penetration for EVs.

Acronyms

EV—electric vehicle, a vehicle lacking an internal combustion engine that instead utilizes an electric-based propulsion system. *Example: Nissan Leaf.*

FCEV—fuel-cell electric vehicle, a vehicle with electric motors powered by energy from a fuel cell rather than a battery pack.

HEV—hybrid electric vehicle, a vehicle that utilizes both an internal combustion engine and electric-based propulsion. *Example: Toyota Prius*.

ICE—internal combustion engine, an engine utilizing the combustion of fuels to perform work. *Example: most vehicles currently on the roadway.*

PHEV—plug-in electric hybrid vehicle, a hybrid vehicle that can be charged through an external electrical connection such as an electric wall socket. *Example: Chevrolet Volt.*

U.S. DEPARTMENT OF ENERGY MARKET PROJECTIONS

The Department of Energy (DOE) and the Energy Information Administration compile vehicle records as they pertain to energy consumption. As such, these entities are currently monitoring (and in some cases facilitating through research programs) the development of EVs. As part of the DOE's 2011 Energy Outlook Report, projections of EV purchases were developed. While these projections were not specific to Texas, Texas is included in the West South Central Region (WSCR) along with the states of Louisiana, Arkansas, and Oklahoma.

For the WSCR, DOE projects that electric vehicle sales in 2011 will be about 1,250 and about 2,590 in 2012 (Figure 2). Average yearly growth rate in EVs is expected to be 12.2 percent from 2012 through 2035. By 2035, the DOE predicts that annual EV sales will top 13,800 in the WSCR.

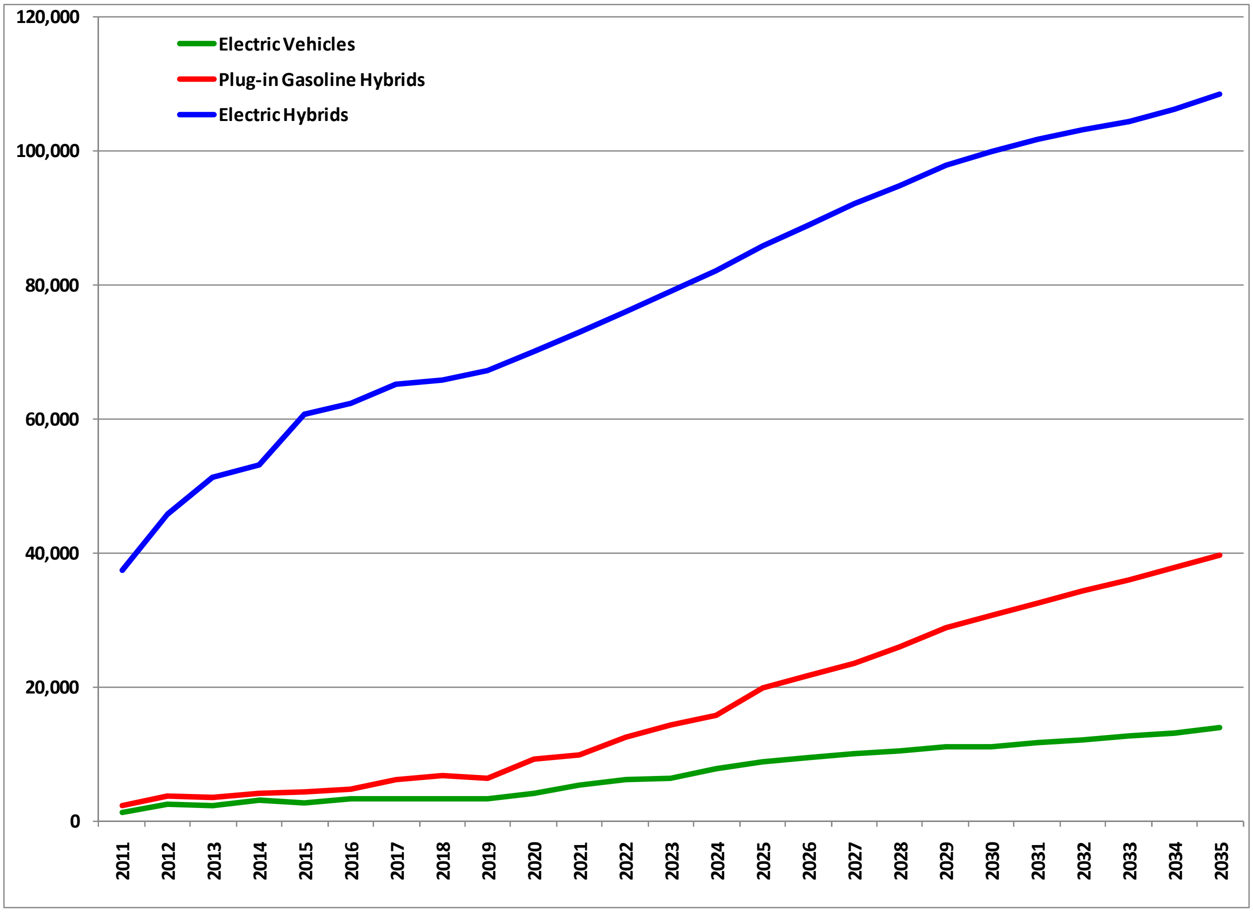

Figure 2. Annual Hybrid, Electric Vehicle, and Hybrid-Electric Vehicle Sales (2011–2035).
Source: United States Department of Energy, Energy Information Administration, "2011 Energy Outlook"

While the EV market is projected to continue growing through 2035, as Figure 3 shows, traditional petroleum–based automotive technologies will continue to dominate the roadway, but that share will decline. In 2010, traditional petroleum-based vehicles accounted for about 86 percent of new auto sales in the WSCR, and by 2035 they will account for 73 percent. Ethanol and flex fuel-based vehicles will constitute the most popular alternative fuel technologies, accounting for just under 20 percent of regional sales by 2035. Hybrids will account about 7 percent of regional auto sales while EVs will account for less than 1 percent.

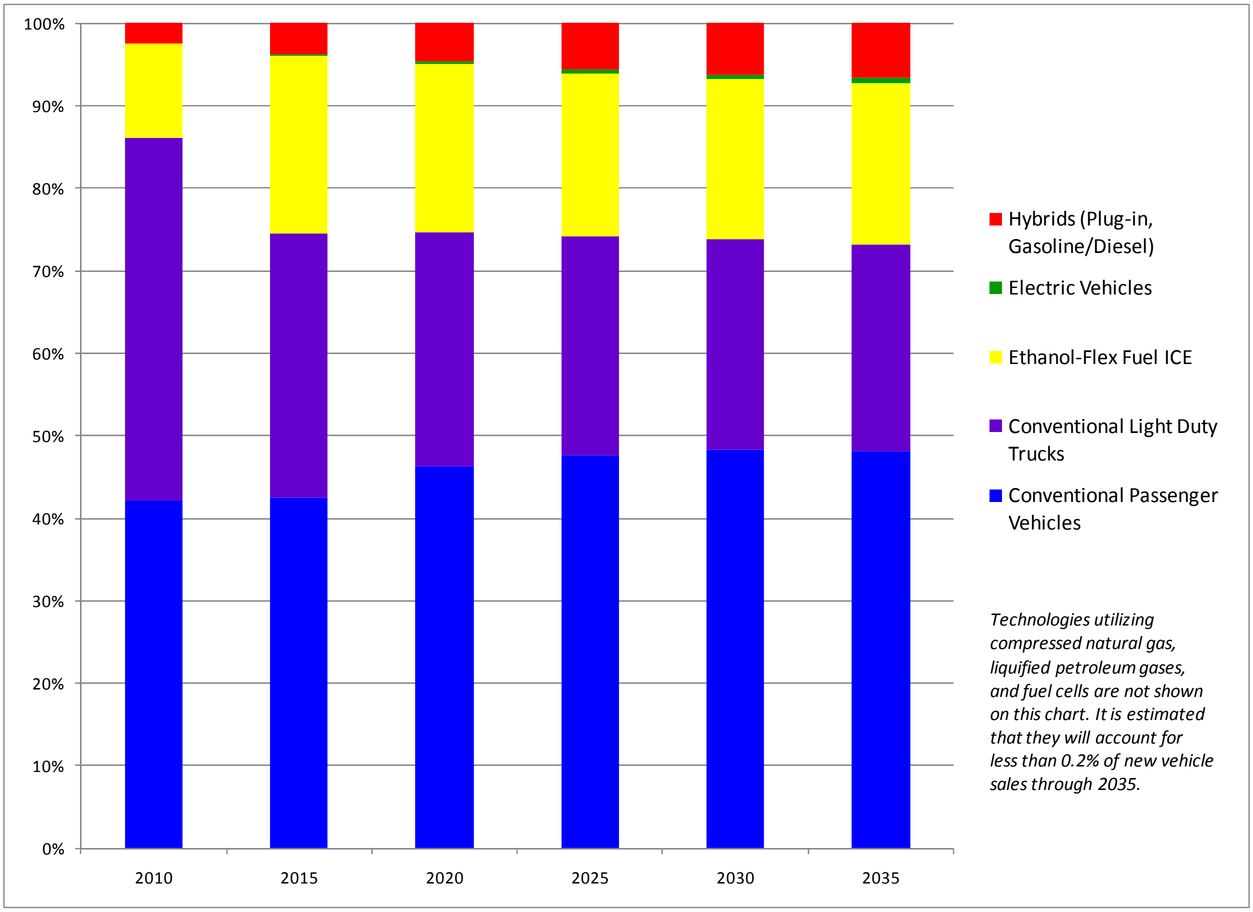

Figure 3. Composition of Annual New Vehicle Sales by Vehicle Technology.
Source: United States Department of Energy, Energy Information Administration, "2011 Energy Outlook"

COST OF ELECTRIC VEHICLES

The average purchase price of a reliable compact car, estimated by MotorTrend, ranges between $10,000 and $15,000. The expected purchase price (not including incentives) of alternative-fuel vehicles—$41,000 for the Chevrolet Volt (PHEV) and $33,000 for the Nissan Leaf (EV)—suggests that they are less likely to be utilized by a broad swath of the motoring public and will likely be only higher income individuals. This, according to Deloitte Consulting, small number of potential consumers will not be enough to spur mass adoption. While the federal government is offering a $7,500 tax credit for the purchase of an EV—about $2,000 of which can be applied to the purchase and installation of home charging stations—how long these incentives will be offered is unknown. To view the full report prepared by Deloitte Consulting regarding EV adoption, refer to Appendix E.

A significant portion of the estimated cost of a new EV is related to the battery. In some cases it can account for up to two-thirds of the overall purchase price. In an attempt to spur the domestic battery manufacturing industry, the Obama Administration has offered about $24 billion in various incentives for the EV industry. Also, $2.4 billion in American Recovery and Reconstruction Act (ARRA) money is available for EV component makers. The U.S. DOE is loaning significant funds to Nissan, Ford, GM, Tesla, and Fisker. These funds are being made available because the administration believes that by increasing production of these vehicles' most expensive components, namely the battery, that price will eventually drop due to economies of scale as mass production increases. The Obama Administration expects that battery costs alone will drop by 70 percent in the coming years as noted in Appendix F. Boston Consulting Group predicts a 60 to 65 percent drop in battery costs by 2020.[3] However, some analysts, such as those at Roland Berger Strategy Consultants, are predicting a possible "battery bubble" within five years because production of these components will outpace demand.[4] If such a bubble was to develop, many of the companies currently working to develop EV battery technology might not survive.

INFRASTRUCTURE

A big issue that will affect the purchase of EVs domestically is the presence of infrastructure for the support of these vehicles. Drivers of gasoline vehicles generally do not have to worry about the availability of gas stations should their fuel run low on a particular trip. However, EVs do not currently have the extensive support structure that has evolved for traditional-fuel vehicles. To what extent drivers will purchase these vehicles without available infrastructure is unknown.

"Range anxiety" refers to a general concern expressed by potential users of EVs regarding their ability to keep their vehicle charged on any given trip. Some consumer behavior experts have speculated that range anxiety will result in the appeal of EVs being mostly limited to urban drivers or will result in EVs serving as a secondary or tertiary vehicle for households using traditional-fuel vehicles.

Several fueling and/or charging options could potentially address range anxiety. EVs are generally envisioned as being charged in the home at night when demands on electricity grids, and hence electricity prices, are lower. Charging stations for home use are expected to run about

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[3] Lane, C.. "Rich man's ride; Electric cars likely to remain green status symbols, affordable only by households making $200,000 a year." *National Post*, August 14, 2010.
[4] Roland Berger Consultants (presentation dated February 2010). "Powertrain 2020: Li-Ion batteries—The next bubble ahead?"

$2,500, which includes installation costs. In terms of charging cost, the electricity required to fully charge a Nissan Leaf overnight is estimated at about $3.00, which compares to a mid-range ICE vehicle costing $5–6 per day in fuel.[5] Another battery option to addressing range anxiety might be to develop "battery swap" stations, where vehicles can have their depleted batteries swapped for freshly charged batteries. This approach has the advantage of being much faster than a typical vehicle charging that might occur at the home. However, EV batteries are not currently standardized. Better Place, a California-based firm, is currently testing battery-swapping stations in Japan and is planning tests in Israel.[6]

Numerous entities, both public and private, are working to develop stations that would allow vehicles to be charged outside the home. In Texas, TXU Energy will install at least a dozen EV charging stations on city property within Fort Worth and Dallas to encourage EV purchase. For the first year, TXU will pay for all of the electricity for these stations and will allow free charging of city employee vehicles in the second and third years.[7] Half Price Books installed North Texas' first EV charging station at their location on the Northwest Highway. This station will allow drivers to charge their vehicles for free until September 2011 and features two charging spots. Coulomb Technologies, Inc., developed the station at a cost of $10,000.[8] The California-based firm operates a system that directs drivers to the nearest available charging station. The company is part of ChargePoint America, a $37 million program funded with $15 million in ARRA grants from the DOE, which plans to install 4,600 to 5,000 of these devices in nine American cities. ChargePoint Amercia is currently donating charging stations to businesses in an attempt to establish the market for early adopters of EVs. Washington State is using $1.5 million in federal money to set in motion a program called the Green Highway Partnership (http://www.greenhighwayspartnership.org/index.php) that will turn the section of I-5 from Canada to Oregon into an "electric highway." The total estimated cost of the project is $250 million, and it will install charging stations capable of filling a lithium-ion battery to within 80 percent of capacity within 30 minutes.[9] The penetration of fuel-cell technologies will be similarly limited by the availability of hydrogen refueling stations. A fuel cell vehicle or FC vehicle (FCV) is a type of hydrogen vehicle, which uses a fuel cell to produce its on-board

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[5] Kissack, A. "In search of charging stations for electric cars." National Public Radio, October 12, 2010.
[6] Reed, J. "Electric cars are all the rage in Israel." *Financial Times*, September 17, 2010.
[7] Souder, E. "TXU offers free juice to spark electric-car use." *Dallas Morning News,* September 24, 2010.
[8] Souder, E. "Drop by, plug in, chill out." *Dallas Morning News*, September 21, 2010.
[9] Gorrie, P. "No reason to blow cash on recharging network." *The Toronto Star,* August 7, 2010.

motive power, similarly to a gasoline-electric hybrid. However, fuel cell vehicles will probably require substantially less time to refuel than EVs since refueling an FCV is similar to refueling an LNG or CNG fuel type vehicle.

OTHER ISSUES

Not all major vehicle manufacturers are jumping into the EV market. Mazda, for example, is choosing to improve existing technology for enhanced fuel efficiency before pursuing EV development.[10] With recent developments, such as the SKY-G and SKY-D gasoline and diesel (respectively) engines that can be combined with a new automatic transmission system, Mazda expects to provide subcompact vehicle fuel economy to compact and midsized vehicles. These technologies are predicted to be available to consumers in 2011.

Another unknown to contend with is the potential market for gas-to-electric conversions. For example, researchers at Keio University—based in Tokyo, Japan—recently converted a Suzuki Swift to run on lithium-ion rechargeable batteries, and some experts estimate that the future cost of similar conversions might run only a few thousand dollars.[11]

ELECTRIC VEHICLES IN TEXAS

Electric vehicles do not run on fossil fuels and will not pay fuel taxes, one of the two major funding sources for building and maintaining the state's roadways. Knowing how many of these types of vehicles are currently on the road and how many are expected in the future is of considerable importance to long-term funding and development of the state's infrastructure. The number of EVs currently registered in Texas is difficult to determine, as are estimates of future growth. Currently, the state lacks the necessary vehicle classifications and record-keeping procedures to determine the current number of registered EVs. Furthermore, various market factors inhibit the ability to project EV market penetration at the state level with any confidence: a lack of supporting infrastructure for the charging of these vehicles and their high cost compared to traditional gasoline- and diesel-based vehicles. Until EVs from major automobile manufacturers, such as the Nissan Leaf, are actually available for consumer purchase, projections of EV market penetration in Texas will not be reliable. A survey of available data sources related

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[10] Romano, D. "Mazda chooses to optimize existing technologies." *National Post*, September 27, 2010.
[11] Hata, Y. "SIM-Drive's Fukutake: E-car's future doesn't turn on batteries." *Electronic Engineering Times,* September 13, 2010.

state and national vehicle fleets has revealed a number of possible reasons for the lack of reliable data:

- The uncertainty surrounding the EV industry, in terms of when certain models will be available for purchase, has made long-term projections difficult.
- State vehicle registration entities do not currently categorize EVs as a separate vehicle class, so the number of EVs cannot be determined from vehicle registration records.
- EVs are not taxed at the state or federal level, something that would allow for analysis of current revenues or projection of future revenues from these vehicles.

Lack of Vehicle Class Data for EVs

Vehicle class is a two-digit number utilized by the Texas Department of Motor Vehicles and the counties responsible for administering vehicle registrations to classify various types of vehicles. Most vehicles registered for personal use in Texas fall under one of four vehicle classes:

- Class 25: passenger vehicle less than or equivalent to 6,000 lb.
- Class 26: passenger vehicle greater than 6,000 lb.
- Class 35: truck less than or equivalent to 1 ton.
- Class 36: truck greater than 1 ton.

EVs are likely to be classified as Class 25 vehicles, and no other categories differentiate engine type or fuel consumed. Thus, an analysis of EV use in Texas cannot occur based on vehicle classification.

Limitations of Vehicle Identification Number for EVs

Vehicle identification numbers (VINs) are typically 17 digits and contain a great deal of data pertaining to the specific vehicle. This information includes:

- Make, model, and year.
- Location of manufacture.
- Special vehicle features.
- Order of manufacture relative to other models from the same plant.

The "special features" series of digits in the VIN carry the most hope for identifying EVs. However, this series of numbers varies in terms of the information contained depending on the initial three digits (make, model, and location of manufacturer). For example, the information contained in the special features identifiers is different for vehicles manufactured in Japan, the United States, and Europe. Consequently, the special features identifiers are not uniform across all vehicle makes and models. Thus, identifying EVs from VINs recorded in vehicle registrations will be problematic, given that:

- A complete catalogue of all special feature identifiers for all makes and models would need to be compiled.
- All statewide vehicle registrations would need to be run through an algorithm capable of reading these numbers and identifying the vehicle as being electric.

> ***Why Is This Important to Texas?***
>
> Electric vehicles do not run on fossil fuels and will not pay fuel taxes, one of the two major funding sources for building and maintaining the state's roadways. Knowing how many of these types of vehicles are currently on the road and how many are expected in the future is of critical importance to long-term funding and development of the state's infrastructure.

ISSUES OF RELEVANCE TO TXDOT

As stated previously, a limited number of EVs are currently on the road. However, a growing number of alternative-fuel vehicles—passenger and commercial—are expected to impact fuel tax revenue. Departments of transportation across the nation are examining the impact of more fuel-efficient vehicles and vehicles that do not operate from fossil fuels at all and thus pay no taxes through traditional taxing.

The following issues are worth further examination to understand their impact on Texas' transportation revenue:

1) Impact electric vehicles will have on fuel consumption, user patterns, and loss of fuel tax revenue.
   a) Related market characteristics, market penetration, and future predictions.
   b) User pay/user fee options.
2) Impact of reduced vehicle emissions on the state's air quality.
   a) Implications for conformity, State Implementation Plan (SIP) for air quality, credits, etc.

3) Vehicle performance and safety.
    a) Design of roadway safety devices, etc. to accommodate different vehicle types.
    b) Vehicular safety due to batteries, collision with other vehicles, etc.
    c) First responder training and safety.
4) Battery performance issues.
    a) Weather and hazardous conditions.
    b) Traffic conditions.
5) Land use patterns—effect on the transportation system and use of hybrid/EV/alternative vehicles.
6) Other infrastructure to accommodate vehicles.
    a) Vehicle charging stations.
    b) Impact of EV charging on state's electricity grid.
    c) Review peer state investment in infrastructure.
7) Review of relevant legislation.
    a) Tax breaks, registration fees of electric and alternative fuel vehicles in peer states.
    b) Electric company incentives, disincentives for at-home charging stations.
8) Identification of best practices (through national/international literature scans).

APPENDIX A. ALTERNATIVE FUEL SCAN BLOG POSTING INSTRUCTIONS

The alternative fuel vehicle subject area, especially as it relates to electric vehicles, points to a rapidly increasing industry positioned for implementation in a variety of markets, including light vehicles, light and medium-duty trucks, and buses.

In order to share the information about this subject in a timely manner, a blog was created to serve as a repository for news and updates.

The Alternative Fuel/Electric Vehicle Scan Project blog provides articles and links to information related to research, policy, testing, and pilot projects. The clearinghouse-type project currently houses around 400 articles.

The Alternative Fuel/Electric Vehicle Scan Blog at: http://electricvehiclescanproject.wordpress.com.

Posting to the Alternative Fuel/Electric Vehicle Scan Blog

We encourage activity from sources within TTI and TxDOT. Please send your post to the Alternative Fuel/Electric Vehicle Scan blog.

To do so, simply send an email to: *didu354yuri@post.wordpress.com*.

APPENDIX B. TEXAS INCENTIVES

Source: alternative fuels and advanced vehicles data center

Neighborhood Electric Vehicle (NEV) Access to Roadways

NEVs are defined as vehicles that can attain a maximum speed of 35 miles per hour (mph) and must comply with the safety standards in Title 49 of the Code of Federal Regulations, section 571.500. NEVs may only be used on roads that have a posted speed limit of 45 mph or less but may cross a road or street at an intersection where the road or street has a posted speed limit of more than 45 mph. A county, municipality, or the Texas Department of Transportation may prohibit the operation of a NEV on a street or highway if the governing body determines that the prohibition is necessary in the interest of safety. (Reference Senate Bill 129, 2009, and Texas Statutes, Transportation Code 551.301-551.303)

Source: hybridcars.com

- The City of Austin's "Drive Clean--Park Free" program gives city-registered owners of hybrid vehicles that receive an EPA air pollution score of 8 or better a $100 pre-paid parking cards to park in any of the city's 3,700 parking meters. Owners must submit an application to the city and receive a bumper sticker showing their participation in the program. Eligible vehicles must be purchased at certified dealerships within the Austin City Limits.
- The City of San Antonio allows owners of hybrid vehicles to park for free at street parking meters. A City ordinance, which took effect immediately after City Council approval on May 4, 2006, requires all owners wishing to take advantage of the one-year pilot program to register their hybrid vehicles with the City's Parking Division located at 243 N. Center Street. Registered hybrid vehicle owners can park at any of the City's 2,010 street parking meters without charge, including the pilot Pay & Display locations. All drivers must follow street parking meter rules such as parking for only the time allotted at the respective meter. For more information, call (210) 207-8266.

CALIFORNIA INCENTIVES

Source: alternative fuels and advanced vehicles data center

Hybrid Electric Vehicle Purchase Vouchers

Through the Hybrid Truck and Bus Voucher Incentive Project (HVIP), the California Air Resources Board provides vouchers to eligible fleets in order to reduce the incremental cost of qualified medium- and heavy-duty hybrid electric vehicles at the time of purchase. Vouchers are available on a first-come, first-served basis and range from $10,000 to $45,000. Only fleets that operate vehicles in California are eligible. Refer to the HVIP website for a list of qualified vehicles and other requirements.

Plug-In Hybrid and Zero Emission Light-Duty Vehicle Rebates

Rebates are available through the Clean Vehicle Rebate Project (CVRP) for the purchase or lease of qualified clean vehicles. The rebates offer up to $5,000 for light-duty zero emission and plug-in hybrid vehicles and up to $20,000 for zero emission commercial vehicles that are approved or certified by the California Air Resources Board (ARB) on a first-come, first-served basis. The rebates are available on a first-come, first-served basis to individuals, business owners, and government entities in California that purchase or lease new eligible vehicles on or after March 15, 2010. Eligible vehicles are electric drive cars, trucks, commercial medium- and heavy-duty vehicles, motorcycles, or neighborhood electric vehicles. Manufacturers of zero emission vehicles must apply to ARB to have their vehicles included in CVRP. Refer to the CVRP website for a list of eligible vehicles and other requirements.

Alternative Fuel and Vehicle Research and Development Incentives

The Alternative and Renewable Fuel and Vehicle Technology Program, established by Assembly Bill 118 and administered by the California Energy Commission, aims to increase the use of alternative and renewable fuels and innovative technologies. Grants and loans are available for projects that:

- Develop and improve alternative and renewable low carbon fuels.
- Optimize alternative and renewable fuels for existing and developing engine technologies.
- Produce alternative and renewable low carbon fuels in California.
- Decrease the overall impact of an alternative and renewable fuel's lifecycle carbon footprint and increase sustainability.
- Expand fuel infrastructure, fueling stations, and equipment.
- Improve light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and non-road vehicle fleets.
- Expand infrastructure connected with existing fleets, public transit, and transportation corridors.
- Establish workforce training programs, conduct public education and promotion, and create technology centers.

High Occupancy Vehicle (HOV) Lane Exemption

Qualified compressed natural gas, hydrogen, electric, and hybrid electric vehicles (HEV) meeting specified California and federal emissions standards may use HOV lanes regardless of the number of occupants in the vehicle. Vehicles must be affixed with a Clean Air Vehicle sticker issued by the California Department of Motor Vehicles, which expire January 1, 2011. A limited number of Clean Air Vehicle stickers are available. Drivers of qualified HEVs registered to an address in the nine-county San Francisco Bay region must also obtain a Bay Area FasTrak account before using HOV lanes. For more information about qualified vehicles, see the

California Air Resources Board Carpool Lane Use Stickers website. (Reference California Vehicle Code 5205.5 and 21655.9)

Alternative Fuel Vehicle (AFV) and Fueling Infrastructure Grants

The Assembly Bill (AB) 2766 Motor Vehicle Registration Fee Program provides funding for projects that reduce air pollution from on- and off-road vehicles. Eligible projects include purchasing AFVs and developing alternative fueling infrastructure. Contact local air districts for more information about available grant funding and distribution from the AB 2766 Motor Vehicle Registration Fee Program. (Reference Health and Safety Code 44220 (b))

Electric Vehicle (EV) Parking Incentive – Sacramento

Sacramento offers free parking to individuals or small businesses certified by the city's Office of Small Business Development that own or lease EVs with an EV parking pass in designated downtown parking garages and surface lots. Free EV charging is also provided in several parking garages.

Alternative Fuel Vehicle (AFV) and Hybrid Electric Vehicle (HEV) Parking Incentive – Santa Monica

The City of Santa Monica offers free meter parking for dedicated electric vehicles displaying the Zero Emission Vehicle decal, and compressed natural gas and HEVs displaying properly affixed California Clean Air Vehicle Decals. Vehicles may park free for the maximum time limit posted on the meter per trip.

Electric Vehicle (EV) Parking Incentive – Los Angeles Airport

The Los Angeles Airport (LAX) offers free parking and charging for EVs in the lower/arrivals level of Parking Structures 1 and 6.

Alternative Fuel Vehicle (AFV) and Hybrid Electric Vehicle (AFV) Insurance Discount

Farmers Insurance provides a discount of up to 10 percent on all major insurance coverage for HEV and AFV owners. To qualify, the automobile must be: 1) designed to use a dedicated alternative fuel as defined in the Energy Policy Act of 1992; or 2) an HEV. A complete Vehicle Identification Number is required to validate vehicle eligibility.

Electric Vehicle (EV) Charging Rate Reduction – SMUD

The Sacramento Municipal Utility District (SMUD) offers a discounted rate of approximately 50 percent as compared to the regular residential rate for electricity used by residential customers to charge EVs. EV drivers must sign up for the appropriate residential time-of-use rate. SMUD also offers lower off-peak time-of-use rates for EV charging by commercial customers.

Electric Vehicle (EV) Charging Rate Reduction – LADWP

The Los Angeles Department of Water and Power (LADWP) offers a discounted rate of $0.025/kWh for electricity used to charge EVs during off-peak times. LADWP also provides guidance on EV infrastructure to help customers determine applications for EVs in their fleet operations, EV maintenance services, and training.

Electric Vehicle (EV) Charging Rate Reduction – SCE

Southern California Edison (SCE) offers a discounted rate to customers for electricity used to charge EVs. Two rate schedules are available for EV charging during on- and off-peak hours.

Clean Vehicle Electricity Rate Reduction – PG&E

Pacific Gas & Electric (PG&E) offers a discounted rate for electricity used to charge battery electric vehicles, plug-in hybrid electric vehicles, and natural gas vehicle home fueling appliances.

Electric Vehicle (EV) and Natural Gas Infrastructure Charging Rate Reduction – SDG&E

San Diego Gas & Electric (SDG&E) offers discounted rates to customers for electricity used to charge EVs or qualified compressed natural gas fueling facilities. SDG&E's EV Time of Use (TOU) rate is available in three variations, all of which charge customers based on the time of day the energy is consumed. These TOU rates are non-tiered, and all SDG&E rates have four main components, notably the Residential Rate Tariff and the Electric Energy Commodity Rates. For more information about the rates and their components, see the SDG&E Electric Tariff website.

Low Emission Taxi Incentives – San Francisco

The San Francisco Taxicab Commission has committed to reduce greenhouse gas emissions from the San Francisco taxi fleet by 20 percent by 2012, as compared to 1990 emissions levels. Under the Clean Taxi Program, companies may apply for a surcharge of up to $7.50 on any gate fee charged for the use of certain low emission vehicles. Additionally, grants of up to $2,000 per vehicle may be available from the San Francisco County Transportation Authority toward the purchase of light-duty hybrid electric and compressed natural gas taxis.

Employee Vehicle Purchase Incentives – Riverside

City of Riverside employees are eligible to receive a rebate toward the purchase of qualified natural gas or hybrid electric Advanced Technology Partial Zero Emission Vehicles that are purchased from a City of Riverside automobile dealership. The rebate for a new qualified vehicle is worth up to $2,000, or $1,000 for a qualified used vehicle.

Source: hybridcars.com

- The Department of Motor Vehicles is no longer accepting applications from drivers who own a Toyota Prius, Honda Civic, or older Honda Insight hybrids for carpool stickers. State law allowed the DMV to issue 85,000 stickers to certain hybrid drivers on a first-come, first-served basis. Spokesman Steve Haskins said that his agency had 700 applications over that level and no longer wanted motorists to send in an application. “We have no more stickers available to issue and any applications sent to DMV will likely not be successfully processed,”Haskins said. “Any unprocessed applications and checks will be returned as soon as the last of the stickers are mailed to customers.”
- California Gov. Arnold Schwarzenegger signed Assembly Bill 1500 on July 7, 2010, providing a perk that allows drivers of pure electric vehicles and cars running on compressed natural gas to drive solo in California carpool lanes until January 1, 2015. But the privilege was not extended to conventional hybrids. There is still a chance that SB 535 could pass, pushing the deadline for hybrids to July 1, 2011. Source: hybridcars.com
- Rebates of up to $5,000 per light-duty vehicle will be available for individuals and business owners who purchase or lease new eligible zero-emission or plug-in vehicles until the funding runs out. Plug-in hybrids qualify for rebates up to $3,000, and electric motorcycles and neighborhood electric vehicles up to $1,500. Certain zero-emission commercial vehicles are eligible for rebates up to $20,000. Vehicles must be purchased or leased after official launch of the program on March 15, 2010.
- Sacramento offers free parking to individuals or small businesses certified by the city’s Office of Small Business Development that own or lease EVs with an EV parking pass in designated downtown parking garages and surface lots. Free EV charging is also provided in several parking garages.
- Many utilities offer discounted rates for residential vehicle charging during off-peak hours.
- Hybrid Car owners who have purchased their hybrids from **San Jose** dealers are exempt from local parking fees.
- On February 10, 2009, the **Los Angeles** City Council voted to end the free metered parking program for alternative fuel vehicles begun in 2002. The City of Los Angeles Department of Transportation (LADOT) will begin citing alternative fuel vehicles parked at expired parking meters starting March 1, 2009.
- If your vehicle has the decal affixed to your alternative fuel, hybrid, or electric vehicle, the **Santa Monica** Municipal Code (3.16.120) allows you to park in any metered parking space in the city without charge for the maximum amount of time allowed by that meter. In other words, if you’re at a 2-hour meter, you can park there free for 2 hours—but beyond that, you’re subject to ticketing for overstaying your welcome. Clean Air Vehicle decals are issued by the state.

NEW YORK INCENTIVES

Source: hybridcars.com

- New York's Alternative Fuel (Clean Fuel) Vehicle Tax Incentive Program, which offered tax credits and a tax exemption for purchasing new hybrid electric vehicles (HEVs), have expired. In January 2006, Governor Pataki proposed new incentives. For more information, please contact the New York State Energy Research & Development Authority (NYSERDA) at 866- NYSERDA, via email at info@nyserda.org, or visit the website at www.nyserda.org.
- Clean Pass is a program allowing eligible low-emission, energy-efficient vehicles to use the 40-mile Long Island Expressway High Occupancy Vehicle (LIE/HOV). Clean Pass is a multi-agency pilot program partnering three New York State agencies, the State Department of Transportation (NYSDOT), the State Department of Motor Vehicles (DMV), and State Department of Environmental Conservation (DEC). The number to inquire about a Clean Pass sticker is (518) 486-9786, Option 7.
- Hybrid owners in Westchester County are allowed to park for free at two county-owned commuter lots. The cost of a monthly permit is usually $75.00. For more information, contact County Legislator Martin Rogowski at mlr1@westchestergov.com.

ILLINOIS INCENTIVES

Source: alternative fuels and advanced vehicles data center

High Occupancy Toll Lane Access

Phase Two of the Illinois Tollway Congestion-Relief Program (PDF 840 KB) includes a Dedicated Green Lanes Plan that will provide access to qualified hybrid electric vehicles at premium prices. The conversion is scheduled to begin in 2010.

Neighborhood Electric Vehicle (NEV) Access to Roadways

Neighborhood vehicles may only be operated on streets if authorized by the local government and posted speed limits are 35 miles per hour (mph) or less. Neighborhood vehicles are allowed to cross a road or street at an intersection where the road or street has a posted speed limit greater than 35 mph. Neighborhood vehicles are defined as self-propelled, electronically powered, four-wheeled motor vehicles (or a self-propelled, gasoline-powered four-wheeled motor vehicle with an engine displacement under 1,200 cubic centimeters) which are capable of attaining in one mile a speed of more than 20 mph, but not more than 25 mph, and which conform to federal regulations under Title 49 of the Code of Federal Regulations, Part 571.500. (Reference 625 Illinois Compiled Statutes 5/11-1426.1)

Source: hybridcars.com

- Under its Green Rewards program, the Treasurer's Office has committed $2 million in rebates to make high-mileage hybrid vehicles, which run on gasoline and electricity,

more affordable. Illinois drivers are eligible for a $1,000 rebate with the purchase of a new hybrid or other fuel-efficient vehicle. Participating banks and credit unions agree to accept a discounted deposit rate from the state for one year in exchange for providing the $1,000 rebates to Illinois residents. For more information:
http://www.treasurer.il.gov/cultivateillinois/greenrewards.aspx

- The Illinois Alternate Fuels Rebate Program (Rebate Program) provides rebates for 80 percent of the incremental cost of purchasing an AFV or converting a vehicle to operate on an alternative fuel. The maximum amount of each rebate is $4,000. Eligible vehicles include natural gas, propane, and electric. Gasoline-electric hybrid vehicles are **not** eligible.

PENNSYLVANIA INCENTIVES

Source: alternative fuels and advanced vehicles data center

Alternative Fuel Vehicle (AFV), Hybrid Electric Vehicle (HEV), and Fueling Infrastructure Funding

The Alternative Fuels Incentive Grant (AFIG) Program is administered by the Pennsylvania Department of Environmental Protection and provides financial assistance and information on alternative fuels, AFVs, HEVs, plug-in hybrid electric vehicles, anti-idling technologies that use alternatives to diesel fuel for heavy-duty trucks, and advanced vehicle technology research, development, and demonstration. Projects that result in product commercialization and the expansion of Pennsylvania companies will be favored in the selection process. (Reference Title 73 Pennsylvania Statutes 1647.3)

Plug-In Hybrid Electric Vehicle (PHEV) Promotion

The Commonwealth of Pennsylvania urges auto manufacturers to develop and produce PHEVs for consumer use. (Reference House Resolution 106, 2007)

Alternative Fuels Tax

A tax is imposed on alternative fuels used to propel vehicles of any kind on public highways. The rate of tax is determined on a gasoline gallon equivalent basis. The tax rates are posted in the Pennsylvania Bulletin. (Reference Title 75 Pennsylvania Statutes, Section 9004)

Source: hybridcars.com

- Pennsylvania's Department of Environmental Protection will offer an opportunity to Commonwealth residents to apply for a rebate to assist with the incremental cost for the purchase of a new hybrid, bi-fuel, dual-fuel, or dedicated alternative fuel vehicle. The rebate amount is $500. The rebate will be offered as long as funds are available. Rebates will be offered on a first-come, first-served basis. Rebate applications shall be submitted no later than six months after the purchase.

- A press release issued by the Commonwealth of Pennsylvania on March 9, 2006: The program has been so successful that the state is expected to run out of rebate money sometime in April. DEP Secretary Kathleen A. McGinty said the commonwealth already has awarded more than $1.3 million in rebates from the $1.5 million allotted for the program for the 2005-06 fiscal year. Another $1 million will become available for the fiscal year beginning July 1. Because buyers have six months from the time of the purchase to apply for the rebates, people buying hybrid electric and alternative fuel vehicles after the current funding runs out still will be able to apply for rebates when the programs reopens.

OHIO INCENTIVES

Source: alternative fuels and advanced vehicles data center

- No incentives listed regarding electric vehicles or electric plug-in hybrid vehicles.

MICHIGAN INCENTIVES

Source: alternative fuels and advanced vehicles data center

Advanced Vehicle Battery Manufacturer Tax Credits

Manufacturers of traction battery packs for use in vehicles may be eligible for a tax credit from the Michigan Economic Growth Authority for tax years beginning on or after January 1, 2010, and ending before January 1, 2015. The amount of the credit is based on kilowatt hours of battery capacity. Qualified batteries must have a traction battery capacity of at least four kilowatt hours, be equipped with an electrical plug for charging purposes, and be installed in a new, qualified plug-in electric drive motor vehicle that qualifies for the federal tax credit specified in 26 U.S. Code 30D.

Beginning on or after January 1, 2012, a manufacturer may claim a tax credit of up to 75 percent of the qualified expenses for vehicle engineering to support battery integration, prototyping, and launching, so long as the expenses are incurred between January 1, 2009, and January 1, 2014. The same credit is available to a manufacturer that increases its engineering activities for advanced automotive battery technologies.

Taxpayers may also claim a tax credit equal to 50 percent of the capital investment expenses for the construction of an integrative cell manufacturing facility that includes anode and cathode manufacturing and cell assembly, if the project creates at least 300 new jobs in the state. Taxpayers that have received federal loan guarantees may claim a credit equal to 25 percent of the capital investment expenses for the construction of a facility that will produce large scale batteries and manufacture integrated power management, smart control, and storage systems, if the project creates at least 500 new jobs in the state.

Hybrid Electric Vehicle Research and Development Tax Credit

A taxpayer engaged in research and development of a qualified hybrid system that has the primary purpose of propelling a motor vehicle may claim a tax credit under the Michigan Business Tax through December 31, 2015. This tax credit is equal to 3.9 percent of all wages, salaries, fees, bonuses, commissions, or other payments made in the taxable year on behalf of or for the benefit of employees for services performed in a qualified facility. The maximum amount of credit allowed for any one taxpayer is $2 million per tax year.

Hybrid Transit Vehicle Promotion

In an effort to promote best practices for public transportation services in Michigan, the Michigan Department of Transportation is directed to coordinate with the Michigan Economic Development Corporation to promote the transition of transit bus fleets to hybrid vehicles with improved fuel economy.

Source: hybridcars.com

- The City of Ferndale allows free parking at city meters for drivers of hybrids and other vehicles that average 30 miles per gallon or more in city driving. Owners of eligible automobiles must register and pay an annual fee in order to get a permit for the exemption. To find out if your car qualifies, call the City Assessor at (248) 546-2372.

GEORGIA INCENTIVES

Source: alternative fuels and advanced vehicles data center

Zero Emission Vehicle (ZEV) Tax Credit

An income tax credit is available for 20percent of the cost to purchase or lease a new ZEV, or $5,000, whichever is less. For the purpose of this credit, a ZEV is defined as a motor vehicle that has zero tailpipe and evaporative emissions, including a pure electric vehicle. Low-speed vehicles do not qualify for this credit. Any portion of the credit not used in the year the ZEV is purchased or leased may be carried over for up to five years. (Reference Georgia Code 48-7-40.16)

Electric Vehicle Supply Equipment (EVSE) Tax Credit

An eligible business enterprise may claim an income tax credit for the purchase or lease of qualified EVSE, provided the EVSE is located in the state. The amount of the credit is 10 percent of the cost of the EVSE or $2,500, whichever is less.

Source: hybridcars.com

- Income tax credits for up to 20 percent of the cost of an electric car—maximum of $5,000—or 10 percent (with a max of $2,500) for a car conversion to use an “alternative fuel” including electricity.

- An income tax credit is available to any eligible business enterprise for the purchase or lease of each EV charger that is located in the state. The amount of the credit is 10 percent of the cost of the charger or $2,500, whichever is less. (Reference Georgia Code 48-7-40.16)
- Contact: James Udi, Environmental Specialist, Georgia Environmental Protection Division, james_udi@dnr.state.ga.us.
- Hybrid electric vehicles (HEVs) shall be authorized to use high occupancy vehicle lanes, regardless of the number of passengers if the U.S. Congress or U.S. Department of Transportation approves such authorization through legislative or regulatory action. (Reference Georgia Code Section 32-9-4) The term 'alternative fuel vehicle' is expanded to include HEVs. An HEV is defined as a motor vehicle, which draws propulsion energy from onboard sources of stored energy, which include an internal combustion or heat engine using combustible fuel and a rechargeable energy storage system. HEVs must also meet Federal Clean Air Act and California emissions standards and must have a fuel economy that is 1.5 times the Model Year 2002 EPA composite class average for the same vehicle class.

NORTH CAROLINA INCENTIVES

Source: alternative fuels and advanced vehicles data center

Alternative Fuel Vehicle (AFV) and Hybrid Electric Vehicle (HEV) Grants

The Clean Fuel Advanced Technology (CFAT) project focuses on reducing transportation related emissions in North Carolina's non-attainment and maintenance counties for National Ambient Air Quality Standards. Projects that are adjacent to areas may also be eligible if emissions will be reduced in the eligible counties. The project is funded by the North Carolina Department of Transportation, State Energy Office, and the Division of Air Quality, and covers three broad areas: education and outreach; project funding; and recognition of exemplary activities. Although funding is not currently available, future financial support may be available for AFVs, fueling infrastructure, idle reduction technologies, heavy-duty HEVs, heavy-duty buses, and diesel retrofits.

Alternative Fuel and Alternative Fuel Vehicle (AFV) Fund

The North Carolina State Energy Office administers an energy credit banking program, which enables the state to generate funds from the sale of Energy Policy Act of 1992 (EPAct) credits. The monies generated by the sale of EPAct credits are deposited into the Alternative Fuel Revolving Fund (Fund), which enables state agencies to offset the incremental costs of purchasing alternative fuel, developing fueling infrastructure, and purchasing AFVs. Funds are distributed to state departments, institutions, and agencies in proportion to the number of EPAct credits generated by each. For the purposes of this program, the definition of alternative fuel includes 100 percent biodiesel (B100), biodiesel blends of at least 20 percent (B20), ethanol/gasoline blends consisting of at least 85 percent ethanol (E85), compressed natural gas, propane, and electricity, and includes hybrid electric vehicles. The Fund also covers additional projects approved by the Energy Policy Council. (Reference Senate Bill 457, 2009, and North Carolina General Statutes 143-58.4, 143-58.5, 143-341(8)i, and 136-28.13)

Alternative Fuel Vehicle (AFV) and Hybrid Electric Vehicle (HEV) Loans

State and local government credit unions offer green vehicle loans to purchase new AFVs, HEVs, and qualified fuel-efficient vehicles. The loans are offered at a 1 percent interest rate discount as compared to traditional new vehicle loan rates.

APPENDIX C. ALTERNATIVE FUEL/ELECTRIC VEHICLE RESOURCES

Organization	Website	Description
ASME Electric Vehicles	http://www.asme.org/	ASME helps the global engineering community develop solutions to real-world challenges. Founded in 1880 as the American Society of Mechanical Engineers, ASME is a not-for-profit professional organization that enables collaboration, knowledge sharing, and skill development across all engineering disciplines, while promoting the vital role of the engineer in society. ASME codes and standards, publications, conferences, continuing education and professional development programs provide a foundation for advancing technical knowledge and a safer world.
Austin Area Electric Automobile Association	http://www.austinev.org/	About Austin EV: It is a group of people who gather to discuss electric vehicles, their construction, the technologies that make them work, and how we can further their continued re-introduction into central Texas. Several of us own EVs or have conversions in progress.
Autoblog	http://www.autoblog.com/	Autoblog obsessively covers the auto industry with news, reviews, podcasts, high-quality photography, and commentary about automobiles and the automotive industry.
Canada Takes Lead on Electric Vehicle Policy—Hybrid Cars	http://www.hybridcars.com/news/canada-leads-electric-vehicle-policy-25937.html	Canada shows a genuine determination on the part of a coalition of city planners, lawmakers, businesses, and green car activists to lead the world in electric vehicle adoption. So far, at least from a policy standpoint, they're getting results.
Climate Compass Blog of the Pew Center on Global Climate Change	http://www.pewclimate.org/blog/nigron/building-electric-vehicle-here-usa	In 2008, the transportation sector accounted for 28% of U.S. GHG emissions, according to the EIA. In achieving the goal of reducing emissions, transportation policy must reduce GHG emissions from travel without compromising the mobility of Americans. To that end, electric vehicles provide a much-needed alternative to gasoline and diesel powered cars. Carmakers are responding to this challenge by designing plug-in electric vehicles (PHEVs) and all electric vehicles (EVs).
CNET / Greentech News	http://news.cnet.com/greentech/?tag=bc	CBS Interactive is the premier online content network for information and entertainment. Our brands dive deep into the things people care most about across news, sports, entertainment, technology, and business. With hundreds of millions of unique visitors from around the world each month, CBS Interactive is a global top 10 web property and the largest premium content network online.

DOT Signals Major Shift on Public Transportation Policy Gas 2.0	http://gas2.org/2010/01/15/dot-signals-majorshift-on-public-transportation-policy/	More and more people are finding they need to use public transportation in the U.S. Of course, unless you live in a big city, chances are your public transportation options are limited…or pretty bad. If public transportation were better, more people would be apt to use it. The Obama Administration, through U.S. Transportation Secretary Ray LaHood, has proposed a major revision to the guidelines followed when considering public transportation projects. But this is ground that needs to be tread carefully, especially considering recent eminent domain rulings.
Electric Auto Association	http://www.eaaev.org/	The Electric Auto Association (EAA) was formed in 1967 by Walter Laski in San Jose, California. The EAA is a non-profit educational organization that promotes the advancement and widespread adoption of Electric Vehicles. The EAA's mission is to act as a public source of information about developments in electric vehicle technology, to encourage experimentation in the building of electric vehicles, and to organize public exhibits and events of electric vehicles to educate the public on the progress and benefits of electric vehicle technology.
Electric Drive Transportation Association	http://www.electricdrive.org/	Founded in 1989, EDTA is the preeminent industry association dedicated to advancing electric drive as a core technology on the road to sustainable mobility. As an advocate for the adoption of electric drive technologies, EDTA serves as the unified voice for the industry and is the primary source of information and education related to electric drive. Our membership includes a diverse representation of vehicle and equipment manufacturers, energy providers, component suppliers, and end users.
Electric Reliability Council of Texas (ERCOT)	http://www.ercot.com/news/press_releases/2010/nr-03-25-10b	All systems are "go" for the nodal day-ahead market trial scheduled to begin April 1, for operating day April 2, Electric Reliability Council of Texas (ERCOT) executives said at Tuesday's monthly board of directors meeting. ERCOT, grid operator and manager of the electric market for most of the state, was charged by the Public Utility Commission of Texas in 2003 to develop a nodal wholesale market design to improve market and operating efficiencies through more minutely detailed pricing and scheduling of energy services. The nodal market is scheduled to "go live" on Dec. 1.
Energy Boom	http://www.energyboom.com/transportation	Energy Boom is a global leader in news information about the renewable energy sector, offering expert analysis to keep you on the cutting edge of the renewable energy world. From public policy and financial analysis to company profiles to social commentary and the basics, EnergyBoom is your 360° view of the renewable energy world. Our contributors scour the globe daily for the latest news and information delivering insight and analysis, covering everything from new technologies to breaking news. Leading experts in policy, technology, and the financial markets provide editorial insights to equip viewers with the information necessary to keep up with the rapid pace of development in this exciting field. Investment professionals provide analysis to help guide viewers through the world of new energy investments, letting you know what's hot and why. Built with groundbreaking technology on a Web 2.0 platform, EnergyBoom is the first renewable energy website to incorporate user generated content, investor tips, editorials, and semantic web technology to serve as your one-stop home for the latest thinking on clean energy. EnergyBoom is the go-to site for everyone seeking the latest information on renewable energy – from politicos to financial analysts to thought leaders to the general public and individuals interested in investing in renewable technology companies for the first time.

Energy Efficiency News	http://www.energyefficiencynews.com/transport/i/2757/	Electric vehicle infrastructure providers are powering ahead with $350 million in equity financing for battery-swap company Better Place and the launch of ECOtality's electric vehicle charging software. Better Place has signed a new agreement with an HSBC-led investor consortium, which has valued the U.S. company at $1.25 billion. The company plans to use the funds for research and development, furthering its current projects in Israel and Denmark, and widening the scope of activities in the U.S., Australia, and Europe.
Energy Matters	http://www.thinkenergy.com/	Associations Directory | Energy Matters
Energy Matters, Associations Directory	http://www.thinkenergy.com/assn/index.html	Energy Matters was established as a world wide trading site for information on Energy, Fuels, and Power Generation.
Energy Task Force	http://en.wikipedia.org/wiki/Energy_Task_Force	The Energy Task Force, officially the National Energy Policy Development Group, was a task force created by then-president George W. Bush during his second week in office. Vice President Dick Cheney was named chairman. This group was intended to "develop a national energy policy designed to help the private sector, and, as necessary and appropriate, State and local governments, promote dependable, affordable, and environmentally sound production and distribution of energy for the future." The Bush Transition Energy Advisory Team shaped the administration's supply-side energy policy administration and was a precursor to the Energy Task Force.
Green Tech	http://news.cnet.com/greentech/?tag=bc	Rather than drill more holes to get natural gas, Luca Technologies wants to "grow" more gas in existing wells. The Golden, Colo.-based company has developed a process to generate and then extract more natural gas from depleted coalbed methane wells by injecting water, microbes, and nutrients into the coal seams. The company is now pursuing permitting in Wyoming's Powder River Basin to expand pilot testing of its technology, said CEO Robert Pfeiffer. He anticipates that Luca will obtain permits for larger-scale pilot projects of "restoring" existing wells in the next four to six months.
Hybrid Cars	http://www.hybridcars.com/hybrid-research	HybridCars.com is the Internet's premier website dedicated to hybrid gas-electric vehicles and the full range of consumer information and tools about cars, energy, and the environment. Car reviews, interactive tools, news, and user forums are designed to help car shoppers make informed purchase decisions. Content from HybridCars.com is syndicated to Yahoo!Autos, Reuters, BusinessWeek Online, and numerous newspaper, television, and radio station websites. HybridCars.com works closely with R. L. Polk to produce its Hybrid Market Dashboard, and with academic institutions and industry analysts to conduct research related to the emerging market for hybrid, alternative fuel, and electric cars. Journalists and students can reference content on this site by crediting (and, if possible, linking to) HybridCars.com. Unless otherwise noted, the author should be listed as Bradley Berman,

		Editor, HybridCars.com. We usually accept interview requests from the media; requests should be submitted via e-mail. We are not employees or agents of any car maker or car company. We maintain a strict policy of editorial independence. We welcome the possibility of site sponsorships, with the provision that sponsors will in no way influence the truthful and candid presentation of the facts about hybrid cars. While we believe strongly that hybrid cars are the way to go, we do not hesitate to present information that is critical of any particular product, service, or technology. Our goal is to combine solid research and factual information with some candid opinion — all free of marketing “hoo-ha” and presented in the cleanest, most accessible web format.
National Transportation Journal	http://transportation.nationaljournal.com/2010/06/what-should-transportation-dep.php?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+njgroup-transportation+%28Transportation+Experts--Q+with+Answer+Previews%29	Much of the policy debate over electric vehicles has focused on their impact on the environment and energy consumption. For instance, when the federal government gave out more than $2 billion in stimulus money for electric vehicle technology last year, it was the Energy Department that selected the 48 winning projects. But are we paying enough attention to issues that are normally in the Transportation Department's purview, like fuel efficiency and infrastructure needs?
NewRules Project	http://www.newrules.org/energy/publications/electric-vehicle-policy-midwest-scoping-document	According to the National Conference of State Legislatures (NCSL), 68 bills from 25 different states were introduced in 2009 that involved electric vehicles (about a dozen have been enacted). There have been limited efforts in the RE-AMP states (Illinois, Iowa, Michigan, Minnesota, North Dakota, Ohio, South Dakota, and Wisconsin) to push EV policies. The most aggressive efforts have been in the state of Michigan, which has what appears to be an effective strategy for attracting both EV and advanced battery research and manufacturing. The RE-AMP network's core goal is to enable dramatic reductions in GHG emissions.
Plug-in America	Plug-in America	
Plug-in America	http://www.pluginamerica.org/index.shtml	Mission: Plug In America drives change. We accelerate the shift to plug-in vehicles powered by clean, affordable, domestic electricity to reduce our nation's dependence on petroleum and improve the global environment.

Precourt Energy Efficiency Center	http://piee.stanford.edu/cgi-bin/htm/Transportation/transportation.php	Energy efficient automobiles depend on the right automotive systems, energy-efficient engines, and power trains, appropriate fuels, and policies that encourage energy efficiency. Public policy to promote diversity in transportation modes can also reduce fuel consumption.
SAE International, Guidelines for Electric Vehicle Safety	http://standards.sae.org/j2344_199806/	This SAE Information Report identifies and defines the preferred technical guidelines relating to safety for Electric Vehicles (EVs) during normal operation and charging. Guidelines in this document do not necessarily address maintenance, repair, or assembly safety issues. The purpose of this SAE Information Report is to provide introductory safety guidelines information that should be considered when designing electric vehicles for use on public roadways.
SmartPlanet	SmartPlanet	SmartPlanet.com is the premier destination for savvy advice, thought-provoking analysis, and expert discussion on the intersection of technology, business, and life. Covering decisions that reach from the boardroom to the living room, SmartPlanet.com is the place to go for innovative insight and ideas that impact the world around you.
Texas A&M Energy Engineering Institute	Texas A&M Energy Engineering Institute	
Texas, City of Austin	http://www.ci.austin.tx.us/cleancities/electricvehiclerebate.htm Stakeholders: http://www.ci.austin.tx.us/cleancities/stakeholderlist.htm	Central Texas Clean Cities
Texas, City of Houston	http://www.houstontx.gov/plugin/index.html	The City of Houston and Reliant Energy are working to ensure a better future for our city by exploring new technologies that will conserve energy and improve our environment. We're partnering to demonstrate the power of electric vehicles and to show how this environmentally friendly solution can work in our busy urban lifestyles. Reliant Energy has sponsored the conversion of 10 City of Houston cars to plug-in hybrid electric vehicles (PHEVs) that can deliver up to 100 mpg as well as lower emissions. It's a unique opportunity for all of us to learn more about how PHEV technology works for real people in real-world situations. We look forward to bringing you updates on this ambitious initiative as it progresses. In the meantime, keep an eye out for "Power of the Plug-In" vehicles in your neighborhood.

Texas, City of San Antonio	http://www.aacog.com/CleanCities/electricvehicles/electricvehicles.asp	
Texas, North Central Texas Council of Governments	http://nctcog.org/trans/air/programs/evnt/ Stakeholders: http://nctcog.org/trans/air/programs/evnt/EVNTStakeholderList.pdf	Electric Vehicles North Texas (EVNT) was developed to coordinate a partnership with utility companies, regional governments, school districts, transit authorities, and local businesses in an effort to develop a plan that prepares the region for the transition to plug-in electric vehicles. This plan will be used as a guide to progress and overcome initial barriers in order to implement necessary infrastructure and incentives to ensure vehicle support throughout the region.
The EV Project	http://www.theevproject.com/	ECOtality North America will deploy nearly 15,000 charging stations in 16 cities located in six states (Oregon, Washington, California, Arizona, Tennessee, and Texas) and the District of Columbia. Nissan North American and General Motors/Chevrolet are partners in The EV Project. Drivers of the Nissan LEAF zero-emissions electric car and the Chevrolet Volt plug-in hybrid with extended range, who qualify to participate in The EV Project, a residential charger will be provided free, and most if not all of the costs of installation will be paid for by The EV Project. The EV Project will collect and analyze data to characterize vehicle use in diverse topographic and climatic conditions, evaluate the effectiveness of charge infrastructure, and conduct trials of various revenue systems for commercial and public charge infrastructure. The ultimate goal of The EV Project is to take the lessons learned from the deployment of these first 8,300 EVs, and the charging infrastructure supporting them, to enable the streamlined deployment of the next 5,000,000 EVs. In 2010, charging infrastructure will be deployed in the following major population areas: Phoenix (AZ), Tucson (AZ), San Diego (CA), Los Angeles (CA), Portland (OR), Eugene (OR), Salem (OR), Corvallis (OR), Seattle (WA), Nashville (TN), Knoxville (TN), and Chattanooga (TN), Washington D.C., Dallas (TX), Fort Worth (TX), and Houston (TX).
The EV Project | Partners	http://www.theevproject.com/partners.php	ECOtality and ECOtality North America are working with strategic partners in every market where charging infrastructure and EVs are being deployed. Our partners are critical to ensuring project success and providing valuable information and a strategic roadmap that will aid the rest of the country in rolling out EVs.
The Institute for Energy Research	http://www.instituteforenergyresearch.org/ http://www.instituteforenergyresearch.org/states/	The Institute for Energy Research (IER) is a not-for-profit organization that conducts intensive research and analysis on the functions, operations, and government regulation of global energy markets. IER maintains that freely functioning energy markets provide the most efficient and effective solutions to today's global energy and environmental challenges and, as such, are critical to the well-being of individuals and society.

		Founded in 1989 from a predecessor organization, IER is a public foundation under Section 501(c)(3) of the Internal Revenue Code and is funded entirely by tax deductible contributions from individuals, foundations, and corporations. No financial support is sought for or accepted from government sources.
Treehugger.com | Cars & Transportation	Treehugger.com | Cars & Transportation	
U.S. Department of Energy	http://www.energy.gov/	**The Department of Energy's** overarching mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex. The Department's strategic goals to achieve the mission are designed to deliver results along five strategic themes: **Energy Security:** Promoting America's energy security through reliable, clean, and afforda **Nuclear Security:** Ensuring America's nuclear security **Scientific Discovery and Innovation:** Strengthening U.S. scientific discovery, economic c quality of life through innovations in science and technology **Environmental Responsibility:** Protecting the environment by providing a responsible res of nuclear weapons production **Management Excellence:** Enabling the mission through sound management Within these themes there are 16 strategic goals, which are designed to help DOE successfully achieve its mission and vision.
United States Department of Energy, Energy Information Administration, "*2011 Energy Outlook*"	http://www.eia.gov/forecasts/aeo/	This release is an abridged version of the *Annual Energy Outlook* that highlights changes in the AEO Reference case projections for key energy topics. The Early Release includes data tables for the Reference case only. The full AEO2011 will be released March 2011.

U.S. Department of Energy, Advance Fuels and Advanced Vehicles Data Center	http://www.afdc.energy.gov/afdc/laws/ Alternative fueling station locations: http://www.afdc.energy.gov/afdc/locator/stations/	Formerly known as the Alternative Fuels Data Center, the Alternative Fuels and Advanced Vehicles Data Center (AFDC) is a comprehensive clearinghouse of data, publications, tools, and information related to advanced transportation technologies. Sponsored by the U.S. Department of Energy's Clean Cities initiative and technically administered by the National Renewable Energy Laboratory, the AFDC hosts more than 3,000 documents, interactive tools that help fleets and consumers make transportation decisions, and a wealth of information to educate the public on alternative fuels and advanced vehicles. The AFDC was originally developed in 1991 in response to the Alternative Motor Fuels Act of 1988 and the Clean Air Act Amendments of 1990. Since then, the AFDC has expanded its focus from alternative fuels to include all advanced transportation fuels, vehicles, and technologies. The educational tools and information featured in the AFDC are geared toward helping consumers and fleets reduce petroleum consumption. Clean Cities stakeholders and fleets covered under the Energy Policy Act of 1992 share this goal and regularly use the information offered in AFDC. You can access the complete collection of tools, database searches, calculators, and interactive maps available on the Alternative Fuels and Advanced Vehicles Data Center on the AFDC Tools page.
VOA News	http://www1.voanews.com/english/news/american-life/Electric-Vehicles-Charge-Ahead-in-US-87825607.html	What's billed as the biggest rollout of electric vehicle infrastructure in the world is about to begin in the United States. Urban planners are deciding where to locate more than 11,000 charging stations in 11 major cities. They want those stations up and running when the first mass-market electric cars from Nissan and General Motors go on sale at the end of this year.
Washington Department of Transportation, West Coast Green Highway	http://westcoastgreenhighway.com/electrichighways.htm	The West Coast Green Highway is an initiative to advance the adoption and use of electric and alternative-fuel vehicles along the I-5 corridor. The states of Washington, Oregon, California, and the province of British Columbia are working together to promote clean fuels to reduce our region’s greenhouse gas emissions and reliance on foreign oil.
Washington State Department of Transportation	http://wsdotfederalfunding.blogspot.com/2010/07/electric-vehicles-infrastructure-news.html	Washington State DOT blogspot following federal transportation issues, news, and policy discussion updates.

Wired.com	http://www.wired.com/autopia/tag/electric-vehicles/	News related to EV emerging technology, deployment and fleet development, government and corporate investment

APPENDIX D. TECHNOLOGY ROADMAP

Technology Roadmap

Electric and plug-in hybrid electric vehicles

International Energy Agency

DISCLAIMER

This report is the result of a collaborative effort between the International Energy Agency (IEA), its member countries, and various consultants and experts worldwide. Users of this report shall make their own independent business decisions at their own risk and, in particular, without undue reliance on this report. Nothing in this report shall constitute professional advice, and no representation or warranty, express or implied, is made in respect of the completeness or accuracy of the contents of this report. The IEA accepts no liability whatsoever for any direct or indirect damages resulting from any use of this report or its contents. A wide range of experts reviewed drafts. However, the views expressed do not necessarily represent the views or policy of the IEA or its individual member countries.

ABOUT THE IEA

The IEA is an autonomous body, which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

The IEA carries out a comprehensive programme of energy co-operation among 28 of the 30 OECD member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on international oil markets.
- To provide data on other aspects of international energy markets.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies, including those relating to climate change.

The OECD is a unique forum where the governments of 30 countries work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The OECD provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

Foreword

Current trends in energy supply and use are unsustainable – economically, environmentally and socially. Without decisive action, energy-related greenhouse gas (GHG) emissions will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies. We can and must change the path that we are now on; low-carbon energy technologies will play a crucial role in the energy revolution it will take to make this change happen. To effectively reduce GHG emissions, energy efficiency, many types of renewable energy, carbon capture and storage (CCS), nuclear power and new transport technologies will all require widespread deployment. Every major country and sector of the economy must be involved and action needs to be taken now, in order to ensure that today's investment decisions do not burden us with sub-optimal technologies in the long-term.

There is a growing awareness of the urgent need to turn political statements and analytical work into concrete action. To address these challenges, the International Energy Agency (IEA), at the request of the G8, is developing a series of roadmaps for some of the most important technologies needed for achieving a global energy-related CO_2 target in 2050 of 50% below current levels. Each roadmap develops a growth path for the covered technologies from today to 2050, and identifies technology, financing, policy and public engagement milestones that need to be achieved to realise the technology's full potential. These roadmaps also include special focus on technology development and diffusion to emerging economies, to help foster the international collaboration that is critical to achieving global GHG emissions reduction.

The *Electric and Plug-in Hybrid Vehicle (EV/PHEV) Roadmap* for the first time identifies a detailed scenario for the evolution of these types of vehicles and their market penetration, from annual production of a few thousand to over 100 million vehicles by 2050. It finds that the next decade is a key "make or break" period for EVs and PHEVs: governments, the automobile industry, electric utilities and other stakeholders must work together to roll out vehicles and infrastructure in a coordinated fashion, and ensure that the rapidly growing consumer market is ready to purchase them. The roadmap concludes with a set of near-term actions that stakeholders will need to take to achieve the roadmap's vision. It is the IEA's hope that this roadmap provides additional focus and urgency to the international discussions about the importance of electric-drive vehicles as a technology solution.

Nobuo Tanaka
Executive Director

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Key Findings

The mass deployment of electric and plug-in hybrid electric vehicles (EVs and PHEVs) that rely on low greenhouse gas (GHG) emission electricity generation has great potential to significantly reduce the consumption of petroleum and other high CO_2-emitting transportation fuels. The vision of the *Electric and Plug-in Hybrid (EV/PHEV) Vehicles Roadmap is* **to achieve by 2050 the widespread adoption and use of EVs and PHEVs, which together represent more than 50% of annual LDV (light duty vehicle) sales worldwide.** In addition to establishing a vision, this roadmap sets strategic goals to achieve it, and identifies the steps that need to be taken to accomplish these goals. This roadmap also outlines the roles and collaboration opportunities for different stakeholders and shows how government policy can support the overall achievement of the vision.

The strategic goals for attaining the widespread adoption and use of EVs and PHEVs worldwide by 2050 cover the development of the EV/PHEV market worldwide through 2030 and involve targets that align with global targets to stabilise GHG concentrations. These technology-specific goals include the following:

- **Set targets for electric-drive vehicle sales.** To achieve the roadmap's vision, industry and government must work together to attain a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050. By 2020, global sales should achieve at least 5 million EVs and PHEVs (combined) per year. Achieving these milestones will require that national governments lead strategic planning efforts by working with "early adopter" metropolitan areas, targeting fleet markets, and supporting education programmes and demonstration projects via government-industry partnerships. Additionally, EV/PHEV sales and the development of supporting infrastructure should first occur in selected urban areas of regions with available, low GHG emission electricity generation.
- **Develop coordinated strategies to support the market introduction of electric-drive vehicles.** Electric-drive vehicles are unlikely to succeed in the next five to ten years without strong policy support, especially in two areas: making vehicles cost competitive with today's internal combustion engine (ICE) vehicles, and ensuring adequate recharging infrastructure is in place. Governments need to coordinate the expansion of EV and PHEV sales, help provide recharging infrastructure, and, along with electric utilities, ensure adequate electricity supply.
- **Improve industry understanding of consumer needs and behaviours.** Wider use of EVs and PHEVs will require an improved understanding of consumer needs and desires, as well as consumer willingness to change vehicle purchase and travel behaviour. Currently, the profile of car buyers in most countries is not well known; the industry needs to gain a better understanding of "early adopters" and mainstream consumers in order to determine sales potential for vehicles with different characteristics (such as driving range) and at different price levels. This information will also inform the development of appropriate policies to overcome market barriers and increase the demand for electric-drive vehicles. Auto manufacturers regularly collect such information and a willingness to share this can assist policy makers.
- **Develop performance metrics for characterising vehicles.** Industry should develop consistent performance metrics to ensure that EVs and PHEVs are achieving their potential. These include metrics related to vehicle performance (e.g., driving range) and technical characteristics (e.g., battery requirements). EVs and PHEVs are different in important respects; thus, the set of performance metrics for each must be tailored to each technology separately. Additionally, governments should set appropriate metrics for energy use, emissions and safety standards, to address specific issues related to EVs, PHEVs and recharging infrastructure.
- **Foster energy storage RD&D initiatives to reduce costs and address resource-related issues.** Research, development and demonstration (RD&D) to reduce battery costs is critical for market entry and acceptance of EVs. In order to achieve a break-even cost with internal combustion engines (ICEs), battery costs must be reduced from the current estimated range of USD 500 to USD 800 per kilowatt-hour (kWh) of storage at high volume down to USD 300 to USD 400 per kWh by 2020, or sooner. RD&D to improve battery durability and life spans that approach vehicle life spans is also imperative. Over the medium-term, strong RD&D programmes for advanced energy storage concepts should continue, to help bring the next generation of energy storage to market, beyond today's various lithium-ion concepts. Additionally, industry needs to focus RD&D efforts on addressing resource requirement

issues and establishing secure supply chains. In particular, lithium and rare earth metals supply and cost are areas of concern that should be monitored over the near-to mid-term to ensure that supply bottlenecks are avoided. Governments should help offset initial costs for battery manufacturing plant start-up efforts to help establish and grow this important part of the supply chain.

- **Develop and implement recharging infrastructure.** Reliable electricity supply must be available for EV/PHEV recharging and recharging stations must be convenient to access. It is therefore critical to understand the likely impact of a given number of EVs and PHEVs on daily electricity demand, generation and capacity, and to provide a sufficient planning horizon for utilities. While it will be necessary to standardise the vehicle-to-grid interface, it is important to avoid over-regulating in order to allow for innovation. Policies should foster low-cost infrastructure to facilitate PHEV and EV introduction. Other valuable areas to explore include innovative electricity recharging systems (e.g., battery swapping centres), grid powering from batteries, smart metering, and implications for drivers and utilities. To make these efforts most effective, the role of utilities and governments (including policymaking and regulatory agencies) in developing the recharging infrastructure should be clearly established.

The roadmap outlines additional recommendations that must be considered in order to successfully meet the technology milestones and strategic goals. These recommendations include the following:

- **Use a comprehensive mix of policies that provide a clear framework and balance stakeholder interests.** Governments should establish a clear policy framework out to at least 2015 in order to give stakeholders a clear view. To the extent that it is possible, policies should not favour particular technologies, but rather promote good performance. Policy goals should be grounded in societal goals (e.g., energy security, low CO_2 emissions).

- **Engage in international collaboration efforts.** Industry and government can work together on an international level to help lower costs and accelerate EV/PHEV technology diffusion. Key areas for information sharing and collaboration include: research programs; codes and standards; vehicle testing facilities; setting of vehicle sales targets; alignment of infrastructure, charging and vehicle systems as appropriate; and policy development and experience in implementing different approaches. It will be important to track progress (e.g., regional EV/PHEV production, infrastructure investments, etc.) and keep all stakeholders in all regions up to date.

- **Address policy and industry needs at a national level.** Successful implementation of this roadmap requires that governments around the world enact the policies supportive of the necessary technology development and dissemination, possibly via the policy recommendations for governments put forth in this document. Like this roadmap, national roadmaps can be developed that set national targets and help stakeholders better set their own appropriate targets, guide market introduction, understand consumer behaviour, advance vehicle systems, develop energy, expand infrastructure, craft supportive policy and collaborate, where possible. By formulating common goals, targets and plans, countries and the global community can work toward an electric-drive transport future.

The IEA will work in an ongoing fashion with governments and stakeholder organisations to coordinate activities identified in this roadmap and monitor and report on progress toward identified goals and milestones.

Introduction

Roadmap scope

The *Electric and Plug-in Hybrid (EV/PHEV) Vehicles Roadmap* has been developed in collaboration with governments, industry and non-government organisations (NGOs). The approach began with a review and assessment of existing domestic and international collaboration efforts by member governments and industry groups on EV/PHEV technology and deployment. These efforts included all technical and policy-related activities associated with moving this technology from the laboratory to widespread commercial use.

This roadmap covers the two main types of electrification for light-duty vehicles: pure battery-electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). Non plug-in hybrids and other efficiency improvements in current ICE vehicles will be covered under a separate roadmap.

In the near term, electric-drive vehicles will most likely appear as personal vehicles—sedans, light trucks and electric scooters and bikes. Buses may also be relatively early adopters, especially in applications such as extended electric range hybrids and electric trolleys (i.e., trolleys that can leave the overhead line system and run autonomously on batteries for part of the route). However, for heavier vehicles such as long-haul trucks, planes and ships, for example, the energy density and range limitations of batteries are likely to prevent significant market penetration until additional advances are made in lightweight, energy-dense battery (or other energy storage) technology. As such, this roadmap focuses on passenger vehicles and what stakeholders can do to expedite their electrification.

Roadmap vision

The vision of this roadmap is to achieve the future outlined in the ETP BLUE Map scenario, whereby EVs and PHEVs contribute approximately a 30% reduction in light-duty vehicle CO_2 emissions by 2050 (see box below). More generally, the vision is to achieve the widespread adoption and use of EVs and PHEVs worldwide by 2050 and, if possible, well before, in order to provide significant reductions in GHG emissions and oil use. These reductions must be achieved in an economically sustainable manner, where EVs and PHEVs and their associated infrastructure achieve commercial success and meet the needs of consumers.

The EV/PHEV roadmap vision

To achieve the widespread adoption and use of EVs and PHEVs worldwide by 2050 and, if possible, well before, in order to provide significant reductions in GHG emissions and oil use.

Roadmap purpose and content

The penetration rate of pure battery EVs and PHEVs will be influenced by a range of factors: supplier technologies and vehicle offerings, vehicle characteristics, charging infrastructure, and, as a function of these, consumer demand. Government policies influence all of these factors. The primary role of this roadmap is to help establish a "big picture" vision for the EV/PHEV industry; set approximate, feasible goals and milestones; and identify the steps to achieve them. This roadmap also outlines the role for different stakeholders and describes how they can work together to reach common objectives.

Energy Technology Perspectives 2008 BLUE Map scenario

This roadmap outlines a set of quantitative measures and qualitative actions that define one global pathway for EV/PHEV deployment to 2050. This roadmap starts with the IEA *Energy Technology Perspectives* (ETP) BLUE Map scenario, which describes how energy technologies may be transformed by 2050 to achieve the global goal of reducing annual CO_2 emissions to half that of 2005 levels. The model is a bottom-up MARKAL model that uses cost optimisation to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. The ETP model is a global fifteen-region model that permits the analysis of fuel and technology choices throughout the energy system. The model's detailed representation of technology options includes about 1 000 individual technologies. The model has been developed over a number of years and has been used in many analyses of the global energy sector. In addition, the ETP model was supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors.

It is important to be clear that some of the rates of change (e.g., annual change in vehicle technology sales) in the BLUE Map scenario are unprecedented historically. To achieve such a scenario, strong policies will be needed from governments around the world. The scenario also assumes robust technological advances (e.g., battery cost reduction) that, if they do not occur, will make achieving the targets even more difficult. On the other hand, some unforeseen advances may assist in achieving the scenario or certain aspects of it.

EV/PHEV Status Today

Overview

Battery-powered EVs use an electric motor for propulsion with batteries for electricity storage. The energy in the batteries provides all motive and auxiliary power onboard the vehicle. Batteries are recharged from grid electricity and brake energy recuperation, and also potentially from non-grid sources, such as photovoltaic panels at recharging centres.

EVs offer the prospect of zero vehicle emissions of GHGs and air pollutants, as well as very low noise. An important advantage of EVs over conventional ICE vehicles is the very high efficiency and relatively low cost of the electric motor. The main drawback is their reliance on batteries that presently have very low energy and power densities compared to liquid fuels. Although there are very few electric automobiles for road use being produced today (probably only a few thousand units per year worldwide), many manufacturers have announced plans to begin serious production within the next two to three years.

Hybrid electric vehicles (HEVs) use both an engine and motor, with sufficient battery capacity (typically 1 kWh to 2 kWh) to both store electricity generated by the engine or by brake energy recuperation. The batteries power the motor when needed, to provide auxiliary motive power to the engine or even allow the engine to be turned off, such as at low speeds. Hybrid electric vehicles have been sold for the past decade, and their market penetration is approaching 3% in developed countries such as the United States. Over the past decade, over 1.5 million hybrid vehicles have been sold worldwide.

None of today's hybrid vehicles has sufficient energy storage to warrant recharging from grid electricity, nor does the powertrain architecture allow the vehicles to cover the full performance range by electric driving. However, a new generation of PHEVs is designed to do both, primarily through the addition of significantly more energy storage to the hybrid system. The new PHEVs combine the vehicle efficiency advantages of hybridisation with the opportunity to travel part-time on electricity provided by the grid, rather than just through the vehicle's internal recharging system.

PHEVs are a potentially important technology for reducing the fossil fuel consumption and CO_2 emissions from LDVs because they can run on electricity for a certain distance after each recharge, depending on their battery's energy storage capacity – expected to be typically between 20 km and 80 km. PHEV nomenclature typically reflects this; for example, a "PHEV20" can travel 20 km on electricity after completely recharging while a "PHEV80" can travel 80 km on electricity. PHEVs offer the opportunity to rely more on the electricity sector for energy while retaining the driving range of today's ICE vehicles. Worldwide, a significant share of daily driving probably can be satisfied by PHEVs' all-electric range. For example, in the United Kingdom, 97% of trips are estimated to be less than 80 km. In Europe, 50% of trips are less than 10 km and 80% of trips are less than 25 km. In the United States, about 60% of vehicles are driven less than 50 km daily, and about 85% are driven less than 100 km.[1]

Though a handful of PHEV demonstration projects have been initiated around the world, no manufacturer currently produces PHEVs on a commercial scale; thus, the current market penetration of PHEVs is near zero. But some manufacturers have announced plans to initiate PHEV production over the next few years, and a few models have already appeared as demonstration vehicles in very low-volume production.

1 Estimates taken from comments made at the IEA EV/PHEV Roadmap Workshop.

EV technology

Battery-powered EVs benefit from the removal of the entire ICE system, the drivetrain and fuel tank, giving savings of up to USD 4 000 per vehicle as compared to PHEVs;[2] however, EVs require much greater battery capacity than PHEVs in order to have a minimum acceptable driving range and peak power. EVs provide a substantial energy efficiency advantage, with up to three times the engine and drivetrain efficiency of conventional ICE vehicles and over twice that of HEVs (hybrid electric vehicles). At typical retail electricity prices, the fuel cost per kilometre for EVs can be far below that for ICE vehicles.

Battery cost

Energy storage requirements create major hurdles for the success of EVs. For example, if drivers demand 500 km of range (about the minimum for today's vehicles), even with very efficient vehicles and battery systems that are capable of repeated deep discharges, the battery capacity will need to be at least 75 kWh. At expected near-term, high-volume battery prices of approximately USD 500/kWh, the battery alone would cost USD 35 000 to USD 40 000 per vehicle. Thus, to make EVs affordable in the near-term, most recently announced models have shorter driving ranges (50 km to 200 km) that require significantly lower battery capacities.

This roadmap assumes that EVs have an average range of 150 km with 30 kWh of batteries, which reflects an average efficiency of 0.15 kWh/km to 0.2 kWh/km, with some additional reserve battery capacity. This translates to a battery cost for such a vehicle of USD 15 000, with USD 2 000 to USD 4 000 in fuel costs (depending on the engine size and the transmission type), which partially offsets the cost of the battery. However, if the battery needs to be replaced during the life of the vehicle, the lifetime battery costs will be significantly higher.

Recharging infrastructure

Many households around the world already have parking locations with access to electricity plugs. For many others, such access will require new investments and modifications of electrical systems. If charging components such as converters are located on board vehicles, many vehicles should be able to use standard outlets and home electrical systems, at least for slow recharging (such as overnight).

For daytime recharging, public recharging infrastructure (for example at office locations, shopping centres and street parking) will be needed. Currently, public recharging infrastructure for EVs is very limited or non-existent in most cities, though a few cities have already installed significant infrastructure as part of pilot projects and other programmes. To enable and encourage widespread consumer adoption and use of EVs, a system with enough public recharging locations to allow drivers to recharge on a regular basis during the day will be necessary. Such infrastructure will effectively increase the daily driving range of EVs (and PHEVs range on electricity).

Public charging infrastructure could include opportunities for rapid recharging, either via fast recharge systems (with compatible batteries) or via battery swapping stations that allow quick replacement of discharged battery packs with charged ones. While a battery swapping system would require a way to ensure full compatibility and similar performance between all batteries, it also has the potential to help decrease battery ownership costs for EV consumers via innovative business models where swapping charges cover both electricity and battery "capital" costs on an incremental basis. Even for home recharging-oriented systems, the cost of batteries could be bundled into the daily costs of recharging, allowing consumers to pay for batteries over time. Decoupling battery costs from vehicle purchase costs could enable EVs to be sold at more competitive prices – but doing so may be closely linked to the development of infrastructure and the associated business models adopted.[3]

2 Cost estimates for EVs, PHEVs, and batteries in this section are based on analysis presented in IEA (2009).

3 See Berkeley CET study by T. Becker (July 2009).

PHEV technology

PHEVs retain the entire ICE system, but add battery capacity to enable the extended operation of the electric motor, as compared to HEVs. PHEVs have an advantage of being less dependent on recharging infrastructure and possibly less expensive (depending on battery costs and range) than EVs, and therefore might be targeted for higher volumes in early years. While PHEVs need far less battery capacity than pure EVs, they will likely need at least five times the battery capacity of today's HEVs. PHEVs will also have to be capable of repeated deep discharges, unlike today's HEVs, which typically are operated in a near-constant "state-of-charge" mode and are prevented from experiencing deep discharge-recharge cycles. Further, since the battery capacity levels are still far below those of pure EVs, more power-oriented battery configurations are needed to deliver power at levels required for operating the vehicle when the engine is idle or during bursts of acceleration. Additionally, power-oriented batteries can be much more expensive per kWh capacity than energy-oriented batteries. The IEA publication *Transport, Energy and CO_2 Moving Toward Sustainability* (2009) estimates battery costs for PHEVs to be 1.3 to 1.5 times higher per kWh than for EVs, although total battery costs for PHEVs will likely be lower than for EVs because the total battery capacity for PHEVs is significantly lower.

Assuming near-term, mass production estimates for lithium-ion batteries close to USD 750/kWh of capacity, medium-range PHEVs (e.g., a driving range of 40 km with 8 kWh of energy storage capacity) would require roughly USD 6 000 to cover battery costs. PHEVs may also need a larger motor, adding to their cost. Without discounting, a vehicle driven 200 000 km over its lifetime might save USD 4 000 in fuel costs; this saving is not enough to offset such a high battery cost. However, if battery costs for PHEVs can be reduced to around USD 500/kWh in the future, the resulting battery cost per medium range vehicle (around USD 4 000 for an 8 kWh system) could be competitive. Cost competitiveness will also depend on future electricity and oil prices, and consumer willingness to pay more (or possibly less) overall for PHEVs than similar ICE vehicles.

Table 1: Key differences between PHEVs and EVs

PHEVs	EVs
Infrastructure: • Home recharging will be a prerequisite for most consumers; public recharge infrastructure may be relatively unimportant, at least to ensure adequate driving range, though some consumers may place a high value on daytime recharge opportunities.	Infrastructure: • Greater need for public infrastructure to increase daily driving range; quick recharge for longer trips and short stops; such infrastructure is likely to be sparse in early years and will need to be carefully coordinated.
Economies of scale: • Mass production levels needed to achieve economies of scale may be lower than those needed for EVs, for example if the same model is already mass-marketed as a non-PHEV hybrid; however, high-volume battery production (across models) will be needed.	Economies of scale • Mass production level of 50 000 to 100 000 vehicles per year, per model will be needed to achieve reasonable scale economies; possibly higher for batteries (though similar batteries will likely serve more than one model).
Vehicle range: • PHEV optimal battery capacity (and range on grid-derived electricity) may vary by market and consumer group. Willingness to pay for additional batteries (and additional range) will be a key determinant.	Vehicle range: • Minimum necessary range may vary by region – possibly significantly lower in Europe and Japan than in North America, given lower average daily driving levels. 100 km (62 miles) to 150 km (93 miles) may be a typical target range in the near term.

PHEVs	EVs
Consumer adoption: • Many consumers may be willing to pay some level of price premium because it is a dual-fuel vehicle. This needs further research. • People interested in PHEVs may focus more on the liquid fuel efficiency (MPG) benefits rather than the overall (liquid fuel plus electricity) energy efficiency. Metrics should encourage looking at both. • Electric range should be set to allow best price that matches the daily travel of an individual or allow individuals to set their own range (e.g., providing variable battery capacity as a purchase option).	Consumer adoption: • Early adopters may be those with specific needs, such as primarily urban driving, or having more than one car, allowing the EV to serve for specific (shorter) trips. More research is needed to better understand driving behaviour and likely EV purchase and use patterns. • With involvement from battery manufacturers and utilities, consumers may have a wider range of financing options for EVs than they have for conventional vehicles (e.g., battery costs could be bundled into monthly electric bill). • EVs will perform differently in different situations (e.g., weather) and locations (e.g., Colorado versus California); therefore utility and operating costs may vary significantly.
Fuel standards: • SAE J1711 (Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles) and UN-ECE R101 (Emissions of carbon dioxide and fuel consumption) are possible candidates for the standard for measuring PHEV fuel economy.	Fuel standards: • SAE J1634 (Electric Vehicle Energy Consumption and Range Test Procedure) is currently undergoing review, and UN-ECE R101 (Emissions of carbon dioxide and fuel consumption) is a possible candidate for a testing procedure for EVs.

Batteries: The key technology for EVs and PHEVs

Major technology challenges

Although few serious technical hurdles remain to prevent the market introduction of EVs and PHEVs, battery technology is an integral part of these vehicles that still needs to be significantly improved. Both current and near-term (i.e., lithium-ion (Li-ion) batteries) battery technologies still have a number of issues that need to be addressed in order to improve overall vehicle cost and performance. These issues include:

- Battery storage capacity – Batteries for EVs need to be designed to optimise their energy storage capacity, while batteries for PHEVs typically need to have higher power densities. These differences may lead to the development and use of different battery technologies for EVs and PHEVs. However, economies of scale may favour the development of a single battery type, ultimately resulting in some compromises on other parameters (e.g., lower peak power for PHEVs, with the gap filled by an increased complementary use of an ICE).
- Battery duty (discharge) cycles – Batteries for PHEVs and EVs have different duty cycles. PHEV batteries are subject to deep discharge cycles (in all-electric mode), in addition to frequent shallow cycles for power assist and regenerative braking when the engine is in hybrid mode (similar to conventional ICE-HEVs). Batteries for EVs are more likely to be subjected to repeated deep discharge cycles without as many intermediate or shallow cycles. In both cases, these demands are very different than those on batteries being used on conventional ICE-HEVs, which experience almost exclusively shallow discharge/recharge cycling. Current battery deep discharge durability will need to be significantly improved to handle the demands of EVs and PHEVs.
- Durability, life expectancy, and other issues – Batteries must improve in a number of other

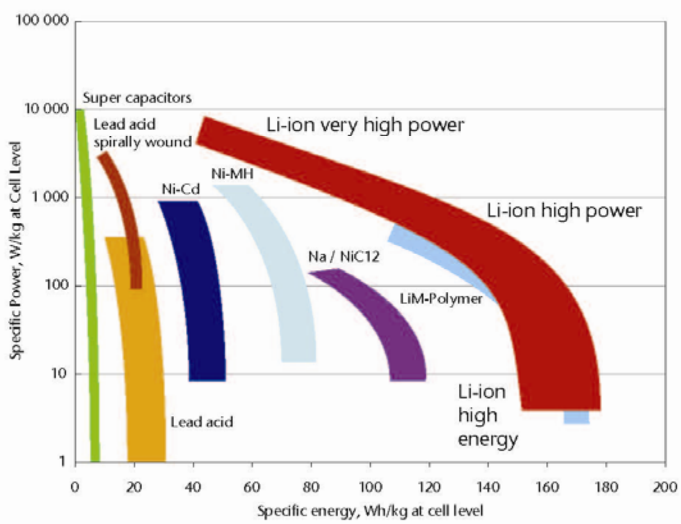
respects, including durability, life-expectancy, energy density, power density, temperature sensitivity, reductions in recharge time, and reductions in cost. Battery durability and life-expectancy are perhaps the biggest technical hurdles to commercial application in the near-term.

Since the above issues are inter-related, a central challenge is to create batteries that are better in all of the above respects without completely trading off one for another. For example, battery durability must include reliability over a wide range of operating conditions as well as have a consistently long battery life, which may be adversely affected by the number of deep discharge cycles. In addition, all of these remaining technology issues must be addressed in ways that ultimately reduce battery costs, or at the very least, do not add to cost.

Comparison of battery technologies

Figure 1 shows a general comparison of the specific power and energy of a number of battery technologies. Although there is an inverse relationship between specific energy and specific power (i.e., an increase in specific energy correlates with a decrease in specific power), lithium-ion batteries have a clear edge over other electrochemical approaches when optimised for both energy and power density.

Figure 1: Specific energy and specific power of different battery types



Source: Johnson Control – SAFT 2005 and 2007.

KEY POINT: ***Among battery technologies, lithium-ion batteries have a clear edge over other approaches when optimised for both energy and power density.***

Within the lithium-ion family, there is a range of different types and configurations of batteries. These vary in terms of characteristics such as battery life, energy, power, and abuse tolerance.

A summary of five battery chemistries and the strengths and weaknesses along these dimensions is shown in Table 2.

Table 2: Lithium-ion battery characteristics, by chemistry

	Lithium cobalt oxide ($LiCoO_2$)	Nickel, cobalt and aluminum (NCA)	Nickel-manganese-cobalt (NMC)	Lithium polymer ($LiMn_2O_4$)	Lithium iron phosphate ($LiFePO_4$)
Energy Wh/kg or L	Good	Good	Good	Average	Poor
Power	Good	Good	Good	Good	Average (lower V)
Low T	Good	Good	Good	Good	Average
Calendar life	Average	Very Good (if charge at 4.0 V)	Good	Poor	Poor above 30°C
Cycle life	Average	Very good (if charge at 4.0 V)	Good	Average	Average
Safety*	Poor	Poor	Poor	Average	Good
Cost/kWh	Higher	High	High	High	High
Maturity	High	High	High	High	Low

Source: Guibert, Anne de (2009), "Batteries and supercapacitor cells for the fully electric vehicle", Saft Groupe SA.

The future of battery technology

In the near-term, the existing suite of lithium batteries, and a few other types, will be optimised and used in PHEVs and EVs. In the longer-term (i.e., after 2015), new battery chemistries with significantly higher energy densities need to be developed to enable the development and use of PHEVs and EVs with a longer all-electric range. It is expected that new chemistries can outperform existing chemistries by incorporating high-capacity positive electrode materials, alloy electrodes, and electrolytes that are stable at five volts. The United States Department of Energy is currently supporting exploratory research on several new lithium-ion battery chemistries; programmes investigating lithium alloy/high-voltage positive, lithium-sulphur, and lithium-metal/lithium-ion polymer. Additional support for the development of advanced batteries will likely speed rates of improvement and help accelerate deployment.

Ultimately, new battery chemistries with increased energy density will facilitate important changes in battery design. Increased energy density means energy storage systems will require less active material, fewer cells, and less cell and module hardware. These improvements, in turn, will result in batteries, and by extension EVs/PHEVs, that are lighter, smaller and less expensive.

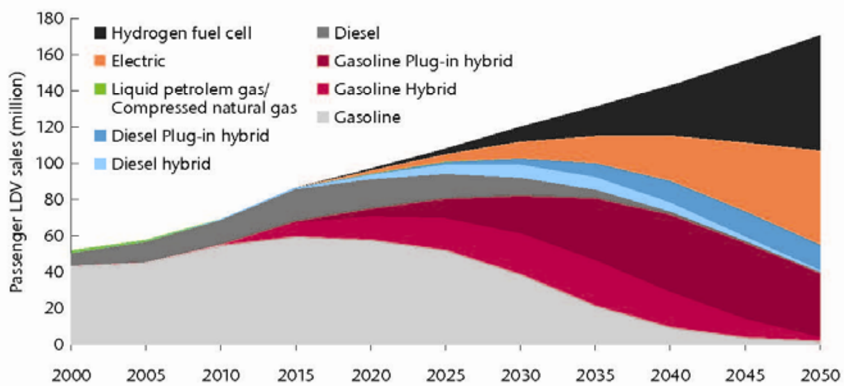
EV/PHEV Deployment: Market Impact Projections and CO_2 Abatement Potential

Overview of BLUE Map scenario targets and assumptions

The *Energy Technology Perspectives (ETP) 2008* BLUE Map scenario sets an overall target of a 50% reduction in global energy-related CO_2 emissions by 2050 compared to 2005 levels. In the BLUE Map scenario, transport contributes to this overall reduction by cutting CO_2 emissions levels in 2050 to 30% below 2005 levels. This reduction is achieved in part by accomplishing an annual sale of approximately 50 million light-duty EVs and 50 million PHEVs per year by 2050, which is more than half of all LDV sales in that year.[4] The EV/PHEV roadmap vision reflects the future EV/PHEV market targets set by the BLUE Map scenario.

Achieving the BLUE Maps requires that EV/PHEV technologies for LDVs evolve rapidly over time, with very aggressive rates of market penetration once deployment begins (see Figure 2). PHEVs and EVs are expected to begin to penetrate the market soon after 2010, with EVs reaching sales of 2.5 million vehicles per year by 2020 and PHEVs reaching sales of nearly 5 million by 2020 (see Figure 3, Figure 5 and Table 3). By 2030, sales of EVs are projected to reach 9 million and PHEVs are projected to reach almost 25 million. After 2040, sales of PHEVs are expected to begin declining as EVs (and fuel cell vehicles) achieve even greater levels of market share. The ultimate target is to achieve 50 million sales of both types of vehicles annually by 2050.

Figure 2: Annual light-duty vehicle sales by technology type, BLUE Map scenario



Source: IEA 2009.

KEY POINT: *This roadmap sees rapid light-duty vehicle technology evolution over time.*

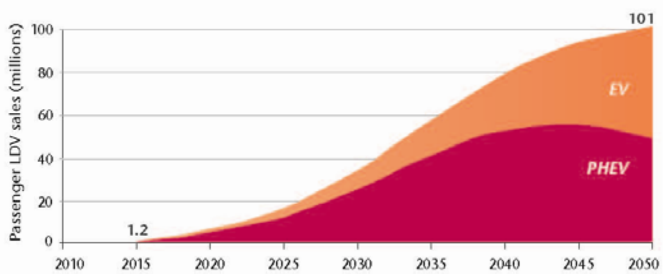
4 A slightly revised BLUE Map scenario for transport has been developed for *Transport, Energy and CO_2: Moving Toward Sustainability* (IEA, 2009). This scenario retains the important role for EVs and PHEVs in meeting 2050 targets that is depicted in ETP 2008, but in addition to focusing on LDVs, also acknowledges that some electrification will likely occur in the bus and medium-duty truck sectors.

Table 3: Global EV and PHEV sales in BLUE Map, 2010–2030 (millions per year)

	2012	2015	2020	2025	2030	2040	2050
PHEV	0.05	0.7	4.7	12.0	24.6	54.8	49.1
EV	0.03	0.5	2.5	4.4	9.3	25.1	52.2

Source: IEA 2009.

Figure 3: Annual global EV and PHEV sales in BLUE Map scenario



Source: IEA 2009.

***KEY POINT:** EV/PHEV sales must reach substantial levels by 2015 and rise rapidly thereafter.*

It is important to note that for the near- to medium-term (2010 to 2020) data in the figures above, the BLUE Map scenario was revised in 2009 to account both for the economic crisis that began in 2008, which decreased projected car sales, as well as for PHEV/EV product plans announced since the ETP was published, which suggest the possibility of a higher level of EV sales through 2020 (IEA 2009). This is an ambitious but plausible scenario that assumes strong policies and clear policy frameworks, including provision of adequate infrastructure and incentives.

While it may be possible to reach CO_2 targets in other ways, if this target level of EVs and PHEVs relying on low-carbon electricity is not introduced, then other low CO_2-emitting solutions will be needed. Altering the BLUE Map strategy in this way will likely result in an equally or even more difficult challenge.

BLUE Map assumptions

There are two particularly important assumptions in the BLUE Map projections for EV/PHEV sales and resulting CO_2 reduction impacts:

- **Vehicle model types and sales growth rates**
  It is assumed that a steady number of new models will be introduced over the next ten years, with eventual targeted sales for each model of 100 000 units per year. However, it is also expected that this sales rate will take time to achieve. During 2010 to 2015, it is assumed that new EV and PHEV models will be introduced at low production volumes as manufacturers gain experience and test out new designs. Early adopter consumers are expected to play a key role in sales, and sales per model are expected to be fairly low, as most consumers will wait to see how the technologies and market develop. As a result, it is assumed that from 2015 to 2020, the existing number of models and sales per model will increase fairly dramatically as companies move toward full commercialisation.

- **Vehicle efficiencies** – EVs are assumed, on average, to have a range of 150 km (90 miles) and PHEVs' all-electric ranges are assumed to start at 40 km (25 miles), rising on average over time due to improvements in battery technologies and declining costs. Both types of vehicles are assumed to have an average in-use fuel efficiency of about 0.2 kWh/km (0.3 kWh/mile). While vehicles could potentially be made more efficient, which would increase the range for a given battery capacity or decrease battery capacity requirements, the chosen efficiency assumptions reflect a more probable outcome.

Other important assumptions included in these projections involve battery range and cost. The scenario assumes an average 150 km-range EV and 40 km-range PHEV, and simplifies the likely range of variation around these averages.

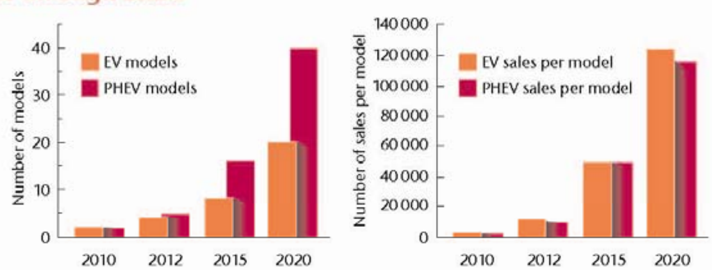
For PHEVs, the percentage of kilometres driven on electricity is assumed to rise over time as recharging times diminish, electric recharging infrastructure spreads, and the number of opportunities to recharge the battery during the day increases[5]. The cost of batteries for EVs is assumed to start at about USD 500 to USD 600/kWh at high volume production (on the order of 100 000 units), and drop to under USD 400/kWh by 2020. Higher per-unit battery costs are assumed for PHEVs, due to higher power requirements. PHEV batteries are assumed to start around USD 750/kWh for high-volume production and then drop to under USD 450 by 2020. These cost reductions depend on cumulative production and learning, so if production levels remain low over the next ten years, it reduces the probability of gaining the target cost reductions and hence reaching BLUE Map deployment targets.

Market growth projections in model types and model sales

In order to achieve the deployment targets in Table 3, a variety of EV and PHEV models with increasing levels of production is needed. Figure 4 demonstrates a possible ramp-up in both the number of models offered and the annual sales per model. This scenario achieves 50 000 units of production per model for both EVs and PHEVs by 2015, and 100 000 by 2020. This rate of increase in production will be extremely challenging over the short time frame considered (about ten years).

However, the number of new models for EVs and PHEVs in Figure 4 easily fits within the total number of new or replacement models expected to be offered by manufacturers around the world over this time span (likely to be hundreds of new models worldwide) and typical vehicle production levels per model. A bigger question is whether consumer demand will be strong enough to support such a rapid increase in EV and PHEV sales.

Figure 4: EV/PHEV number of models offered and sales per model through 2020



Source: IEA projections.

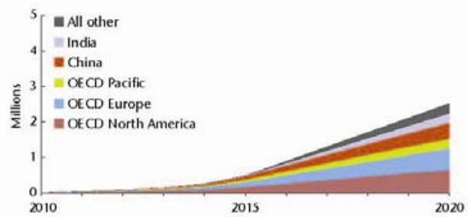
KEY POINT: *Sales per model must rise rapidly to reach scale economies, but the number of models introduced must also rise rapidly.*

5 A paper by D. M. Lemoine, D. M. Kammen and A. E. Farrell explores this in depth for California, and looks at a range of factors that might push PHEV use towards more electric or more liquid fuel use. The paper can be found at: http://www.iop.org/EJ/abstract/1748-9326/3/1/014003

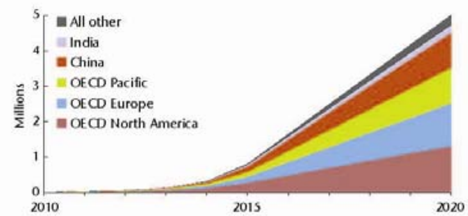
On a regional basis, Figure 5 offers a plausible distribution of EV/PHEV sales by region, consistent with this roadmap's global target of achieving an annual sale of approximately 50 million light-duty EVs and PHEVs by 2050. Regional targets reflect the expected availability of early-adopter consumers and the likelihood that governments will aggressively promote EV/PHEV programmes. EV and PHEV sales by region are also based on assumed leadership by OECD countries, with China following a similar aggressive path. Sales in other regions are assumed to follow with a market share lag of five to ten years.

Figure 5: EV/PHEV total sales by region through 2020

EV Sales



PHEV Sales



Source: IEA projections

KEY POINT: *In this roadmap, EV/PHEV sales increases are seen in all major regions.*

Although the ramp-up in EV/PHEV sales is extremely ambitious, a review of recently announced targets by governments around the world suggests that all of the announced targets combined add up to an even more ambitious ramp-up through 2020, particularly for Europe (see Table 4 and Figures 6A and 6B). Additionally, most of these announcements considered were made in the past 12 months, demonstrating the high priority that developing and deploying EV/PHEV technology has on an international level. If all announced targets were achieved, about 2 million EVs/PHEVs would be sold by 2015 and about 4 million by 2020 (see Figure 6A). These figures are not far from IEA targets in Figure 5. However, if countries who announced pre-2020 targets are able to meet their national targets, and then sales continue to increase to 2020 at a consistent pace, annual EV/PHEV sales would reach a level of about 3 million by 2015 and 10 million by 2020 (Figure 6B). This is possible but would be very challenging and suggests that the rates of EV/PHEV sales growth might have to drop in some countries after meeting their initial targets.

A key question is whether manufacturers will be able to deliver the vehicles (and battery manufacturers the batteries) in the quantities and timeframe needed. As mentioned, the IEA scenario has been developed with consideration for providing time for vehicle demonstration and small-scale production so manufacturers can ensure that their models are ready for the mass market. To achieve even the 2050 sales targets, a great deal of planning and co-ordination will be needed over the next five to ten years. Whether the currently announced near-term targets can all be achieved, with ongoing increases thereafter, is a question that deserves careful consideration and suggests the need for increased coordination between countries.

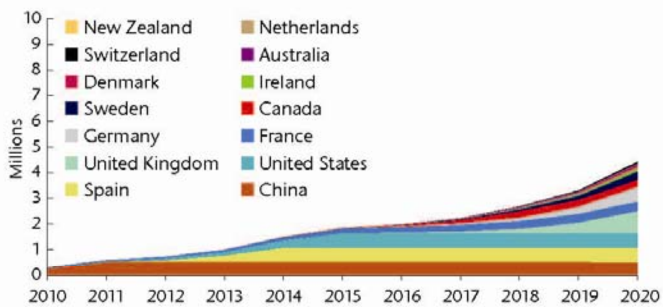
Table 4: Announced national EV and PHEV sales targets

Country	Target	Announcement / Report Date	Source
Australia	2012: first cars on road 2018: mass adoption 2050: up to 65% stock	04 Jun 2009	Project Better Place Energy White Paper (referencing Garnault Report)
Australia	2020: 20% production	10 Jun 2009	Mitsubishi Australia
Canada	2018: 500 000	Jun 2008	Government of Canada's Canadian Electric Vehicle Technology Roadmap
China	2011: 500 000 annual production	1 Apr 2009	"government officials and Chinese auto executives", per *The New York Times*
China	540 000 by 2015	8 Jul 2009	Pike Research
China	2008: 21 000 000 electric bike stock	27 Apr 2009	*The Economist*
China	2030: 20% to 30% market share	Oct 2008	McKinsey & Co.
Denmark	2020: 200 000		ENS Denmark
France	2020: 2 000 000	Oct 2009	Jean-Louis Borloo, Minister of Ecology
Germany	2020: 1 000 000	Nov 2008	Nationale Strategiekonferenz Elektromobilität
Ireland	2020: 350 000	28 Apr 2009	Houses of the Oireachtas
Ireland	2020: 250 000 2030: 40% market share	26 Nov 2008	Minister for Energy Eamon Ryan and Minister for Transport Noel Dempsey
Israel	2011: 40 000 EVs 2012: 40 000 to 100 000 EVs annually	9 Sep 2008	Project Better Place
Japan	2020: 50% market share next-generated vehicles	Jul–Aug 2008	Prime Minister Yasuo Fukuda
Netherlands	2015: 10 000 stock in Amsterdam 2040: 100% stock in Amsterdam (~200 000)	28 May 2009	Marijke Vos, Amsterdam councilmember
New Zealand	2020: 5% market share 2040: 60% market share	11 Oct 2007	Prime Minister Helen Clark
Spain	2010: 2 000	24 Feb 2009	Instituto para la Diversificación y Ahorro de la Energía
Spain	2014: 1 000 000	31 Jul 2009	Industry Minister Miguel Sebastian

Country	Target	Announcement / Report Date	Source
Sweden	2020: 600 000	May 2009	Nordic Energy Perspectives
Switzerland	2020: 145 000	Jul 2009	Alpiq Consulting
United Kingdom	2020: 1 200 000 stock EVs + 350 000 stock PHEVs 2030: 3 300 000 stock EVs + 7 900 000 stock PHEVs	Oct 2008	Department for Transport, "High Range" scenario
United States	2015: 1 000 000 PHEV stock	Jan 2009	President Barack Obama
United States	610 000 by 2015	8 Jul 2009	Pike Research
Worldwide	2015: 1 700 000	8 Jul 2009	Pike Research
Worldwide	2030: 5% to 10% market share	Oct 2008	McKinsey & Co.
Worldwide	2020: 10% market share	26 Jun 2009	Carlos Ghosn, President, Renault
Europe	2015: 250 000 EVs	4 Jul 2008	Frost & Sullivan
Europe	2015: 480 000 EVs	8 May 2009	Frost & Sullivan
Nordic countries	2020: 1 300 000	May 2009	Nordic Energy Perspectives

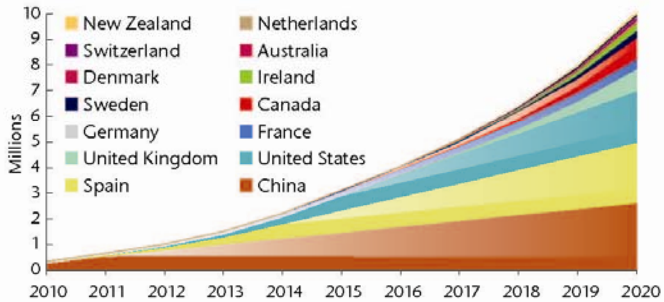
Source: Individual Country Roadmaps and Announced Targets, as listed in the references.

Figure 6A: National EV and PHEV sales targets based on national announcements, 2010-20[6]



6 The rate of growth up to each country's announced sales target is assumed to follow a technology s-curve along a logistical sigmoid described by: % target achieved = 2 / (1 + e^{T-t}), where T is the length of the period from 2010 to the target date and t is the annual progress toward that target date.

Figure 6B: National EV/PHEV sales targets if national target year growth rates extend to 2020



Source: Individual Country Roadmaps and Announced Targets.

Note: Opaque wedges are announced national targets; semi-transparent wedges are EV/PHEV sales if rate of growth in the year the national target is achieved is extended through 2020.

***KEY POINT:** If national EV/PHEV targets lead to on-going sales growth, totals in 2020 exceed the targets in this roadmap.*

Electric vehicle markets in emerging economies

China

Twenty million electric vehicles are already on the road in China in the form of two-wheeled electric bikes (e-bikes) and scooters (*The Economist* 2009). The number of e-bikes has grown from near-zero levels ten years ago, thanks to technological improvements and favourable policy. Improvements in e-bike designs and battery technology made them desirable, and the highly modular product architecture of electric two-wheelers (E2Ws) resulted in standardization, competition and acceptable pricing. Policies favour e-bikes by eliminating the competition; gasoline-powered two-wheeled vehicles are banned in several provinces. Shanghai, for example, banned gasoline-powered two-wheeled vehicles from 1996 (Weinert 2009).

Sales volumes for four-wheeled vehicles are much smaller. In August 2009, the Ministry of Industry and Information published a directory of "new energy vehicle[s]," listing five four-wheeled electric vehicle models, only two of which are mass market models: ZhongTai 2008EV (a small SUV) and Build Your Dream's (BYD) F3DM (a sedan) (Gao 2009). To date, about 80 F3DMs have been sold. These sales volumes are miniscule in comparison to overall LDV sales in China, which have increased by 320% – from 700 000 to 3.1 million – between 2000 and 2005 (IEA 2009). Production capacity and sales volumes are expected to increase, as evidenced by the arrival of new players in China's electric-drive vehicle industry. The Renault-Nissan Alliance entered a partnership with the Ministry of Industry and Information Technology of China (MIIT) to bring electric vehicles to China in early 2011 (Nissan 2009) and Chinese automaker Chery recently introduced the all-electric model S18.

The Chinese government has enacted programmes to promote vehicle electrification on a national scale. In late 2008, Science and Technology Minister Wan Gang initiated an alternative-energy vehicles demonstration project in eleven cities. 500 EVs are expected to be deployed by late 2009 and total deployment should reach 10 000 units by 2010 (Gao 2008). The national government also provides an electric-drive vehicle subsidy of RMB 50 000 (USD 7 300) that was launched in December 2008, but the F3DM is the only vehicle that currently qualifies (Fangfang 2009).

Both industry and government have lofty goals for the near future. The ten largest automotive companies formally targeted an electric-driven future in July 2009, when they established an "EV Industry Alliance" to work together to set EV standards, including standards of key vehicle parts (Chinese Association of Automobile Manufacturers 2009). According to government officials and Chinese auto executives, China is expected to raise its annual production capacity to 500 000 plug-in hybrid or all-electric cars and buses by the end of 2011 (Bradsher 2009), with plans to eventually export EVs. Although China has set a number of electric-drive vehicle goals for the next few years, it has not set any compulsory targets.

India

Electric-drive vehicles have already achieved mass production scale in India in the form of two-wheeled bikes and scooters, and four-wheeled vehicle production capacity should reach a similar point by 2010. Yo Bykes, a producer of electric bikes and scooters, has an installed capacity of 250 000 units per year (Electrotherm 2009). The Indian manufacturer Reva, which has already put 3 000 electric cars on the road worldwide, is expanding its current annual production capacity from 6 000 to 30 000, with a new plant to open next year (Pepper 2009). The company has also just announced two new models, one of which will feature an advanced lithium-ion battery (Cleantech 2009).

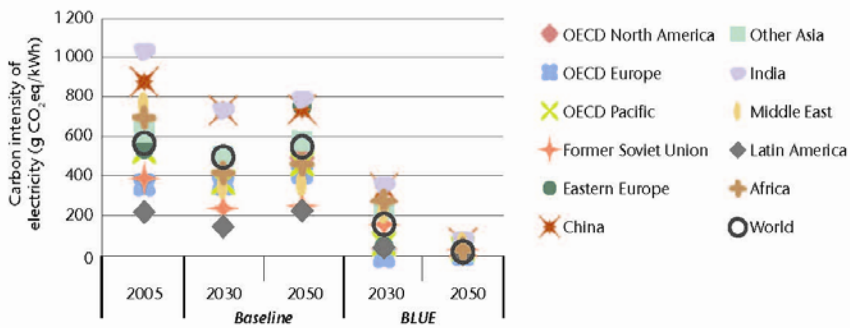
Despite global recognition of India as a growing centre of EV production, most Indian EV manufacturers contend that low volumes and the present duty structure make manufacturing unviable. Electricity supply and reliability may also raise concerns. The Society of Manufacturers of Electric Vehicles, incorporated in September 2009, estimates that two-wheeler makers and importers sold about 100 000 units last year – a 10% market share – and the vast majority of the electric scooters sold in India last year were imported (Srivastava 2009). Sales are also low for electric cars; Reva sold only 600 last fiscal year. Manufacturers suggest that these low sales figures are the product of high costs, attributable to high taxes. Reva estimates that it pays INR 35 000 to 40 000 (USD 720 to USD 825) extra in excise tax (10% of its vehicles' INR 400 000 [USD 8 250] price). Value-added tax (VAT) is another point of contention. Indian electric vehicle manufacturers jointly requested to reduce VAT to 4% from 12.5% in early 2009. Additionally, few public charging stations have been installed due to the high upfront cost, estimated to be about INR 50 000 (USD 1 030) per station, not including land costs.

While, as of 2009, India has no national policy or targets regarding EV manufacturing, some municipalities do. Delhi supports EV sales by giving buyers a 15% rebate on the price of the vehicle. In states such as Madhya Pradesh, Kerala, Gujarat and West Bengal, VAT rates for EVs have been brought down to 4%, resulting in a substantial increase in sales. Other cities refund road tax and registration charges (Centre for Science and Environment 2008).

Impacts on fuel use and CO_2 emissions

The estimates of EV and PHEV sales and use in this roadmap are based on achieving the BLUE Map scenario's 2050 CO_2 reduction targets, which can only be met with the enactment of aggressive policies. CO_2 reductions also depend heavily on changes in electricity generation; BLUE Map targets require the nearly full decarbonisation of electricity generation around the world by 2050. As shown in Figure 7, the CO_2 intensity of electricity generation in the BLUE Map scenario drops steadily over time until, by 2050, all regions have nearly decarbonised their electricity. This steady decrease is an important assumption; if the achievement of low CO_2 electricity generation around the world does not occur in the 2030 to 2050 timeframe, the CO_2 benefits of EVs and PHEVs will be much lower. The IEA is also developing roadmaps on achieving BLUE Map electricity CO_2 intensity targets.

Figure 7: CO_2 intensity of electricity generation by region, year and scenario



Source: IEA ETP 2008, IEA 2009.

KEY POINT: *The BLUE Map scenario targets strong GHG intensity reductions for electricity generation by 2030 and 2050.*

For PHEVs, CO_2 reduction levels will depend on the proportion of miles driven using battery electricity from grid recharging in lieu of petroleum consumption from an ICE. While it will take time to understand the relationship between the PHEV driving range as a function of the battery capacity, it is likely even a modest battery power range (e.g.,40 km) will enable many drivers to cut petroleum fuel use by 50% or more, as the battery will cover their first 40 km of driving per day. In countries where average driving distances per day are relatively short (e.g., Japan), a higher percentage of driving distance is expected to be covered by battery power than in countries with longer average driving distances (e.g., the United States).

Overall, given the BLUE Map scenario projections for the numbers of EVs and PHEVs deployed in the locations specified, and assuming that these vehicles replace conventional gasoline vehicles (which themselves improve over time in the baseline), about 0.5 billion tonnes of CO_2 are projected to be saved per year worldwide in 2030, and about 2.5 billion tonnes are projected to be saved worldwide in 2050. With a BLUE Map target of close to 500 million EVs on the road in 2050, and a CO_2 reduction of 2 tonnes (on a well-to-wheels basis) per vehicle per year compared to displaced gasoline ICE vehicles, EVs would provide about 1 billion tonnes of CO_2 reduction in that year. Approximately 800 million PHEVs would provide an additional 1.5 billion tonnes reduction.

Vehicle and battery manufacturer partnerships and production targets

Given the importance of batteries for EVs and PHEVs, most major vehicle manufacturers have announced partnerships with battery companies. While these partnerships help position each manufacturer and increase the reliability of battery supplies in the future, they could also impact the rate of innovation in the market. A list of vehicle/battery company liaisons announced in the media as of July 2009 is provided in Table 5. BYD Auto, which is working on both vehicles and batteries internally, is a notable exception to the pairing trend, as they were originally a battery manufacturer, but have since expanded into automobile manufacturing.

Although all of the listed battery manufacturers plan to start production and should eventually announce targets, as of July 2009, only a few manufacturers had announced production targets for EVs or PHEVs, totalling far less than 1 million units per year by 2020. Going forward, it will be important to track manufacturer plans for vehicle production against the production targets announced by governments and those contained in this roadmap.

Table 5: Manufacturers of EVs/PHEVs and partnering battery manufacturers, with production targets where available

Car manufacturer	Battery manufacturer	Production targets (vehicles per year)
BYD Auto	BYD group	
Fiat-Chrysler	A123 Systems, Altairnano	
Ford	Johnson Controls-Saft	5 000 per year
GEM	Sanyo/Panasonic	
GM	LG Chem	
Hyundai	LG Chem, SK Energy, and SB LiMotive	500 000 by 2018
Magna Group	Magna Steyr	
Mercedes-Benz	Continental , Johnson Controls-Saft	
Mitsubishi	GS Yuasa Corporation	5 000 in 2010; 15 000 in 2011
Nissan	AESC	EV Capacity: 50 000 in 2010 in Japan 100 000 in 2012 in U.S.
REVA	Indocel Technologies	
Renault	AESC	150 000 EV/year by 2012
Subaru	AESC	
Tata	Electrovaya	
Th!nk	A123 Systems , Enerdel/Ener1	
Toyota	Panasonic EV Energy	
Volkswagen	Volkswagen and Toshiba Corporation	

Sources: Various, compiled by IEA July 2009.

Elements of an EV business model

There are a number of obstacles that must be overcome for EVs to succeed commercially. Successful business models will need to be developed to overcome the following obstacles:

Battery cost – the up-front cost of batteries, that may be USD 10 000 per vehicle or more in the near-term, will be difficult to overcome unless these costs to the consumer can be spread over several years. An advantage of amortizing battery costs is that these costs could, in theory, be bundled in with monthly payments for electricity, taking advantage of the relatively low cost of electricity compared to gasoline fuel. Thus the fuel savings of EVs can be used to offset the battery costs in a manner that may be much more acceptable to consumers than facing high up-front vehicle costs.

Vehicle range – a car with a limited driving range (e.g., 150 km) will need to have plenty of opportunities to recharge. Recharge stations will be needed at high-traffic locations such as train stations, shopping malls, and public parking areas. Rapid recharge or battery swapping systems may also be important, particularly on highways and along other routes where a quick recharge will be needed.

A successful battery swapping system will require standardized battery specifications, batteries designed for rapid charge, and swapping centres with sufficient capacity to serve all arriving cars within a few minutes.

Driver information – another key feature for any public infrastructure will be for drivers to easily locate stations. With the widespread use of GPS technology, this challenge is being addressed. EVs can be sold with GPS systems specially designed to show available recharging centres – even the available number of parking spaces at particular locations. This will reduce much of the uncertainty and stress that limited refuelling infrastructure can have on individuals.

Critical mass and economies of scale – strategic planning, which concentrates vehicles and infrastructure in certain areas can help gain operating densities and economies of scale, rather than attempt too wide a range of coverage at the start. Initially targeting fewer cities with more infrastructure and vehicles may be a more successful approach. Scale economies must also be sought in terms of total vehicle and battery production – once a plan is developed, it should be executed relatively quickly. The faster that manufacturers can get to 50 000 or even 100 000 units of production (e.g., for a particular model of EV), the faster costs will come down. The same holds true for batteries (which can gain in scale from using identical or similar battery systems in multiple vehicle models) and for infrastructure (e.g., common recharging architectures across cities will help lead to scale economies and more rapid cost reductions).

Project *Better Place* is one example of a business model that addresses these obstacles. It puts a strong emphasis on developing an EV presence on selected cities and countries; minimising up-front costs; ensuring adequate public recharge facilities are installed early; including rapid recharge and battery swapping concepts; ensuring that drivers have the means to find stations easily, and otherwise focusing systems to ensure ease of use for drivers. (Project Better Place, http://www.betterplace.com/)

Technology Development: Strategic Goals, Actions and Milestones

The discussions during the IEA EV/PHEV Roadmap Workshop and the recommendations that have come out of that workshop have helped to define the following strategic goals for the development and commercialisation of EVs and PHEVs. These goals cover the development of the EV/PHEV market worldwide through 2020, and include recommended milestones and actions that align with the long-term 2050 targets of the IEA ETP BLUE Map scenario.

This roadmap identifies six strategic goals for accelerating EV/PHEV development and commercialisation:

1. **Set targets for electric-drive vehicle sales.**
2. **Develop coordinated strategies to support the market introduction of electric-drive vehicles.**
3. **Improve industry understanding of consumer needs and behaviours.**
4. **Develop key performance metrics for characterising vehicles.**
5. **Foster energy storage RD&D initiatives to reduce costs and address resource-related issues.**
6. **Develop and implement recharging infrastructure.**

1. Set targets for electric-drive vehicle sales

To meet the aggressive vision of 50 million light-duty EVs and PHEVs sold annually by 2050, countries need to achieve as many EV and PHEV sales as possible by 2015 and 2020. Increasing the number of vehicle models, reasonably heightening production rates by model, and ensuring the availability of an adequate recharging infrastructure that is designed to work well with the types of vehicles being introduced are all issues that must be addressed. Other considerations include costs and the need to avoid placing EVs in areas with unreliable or high-CO_2 electricity generation. Vehicle manufacturers, battery manufacturers, electric utilities and other stakeholders will need to work together to make this happen and governments will need to lead this coordination effort and provide a supportive policy framework.

This roadmap recommends the following milestones and actions:

- By 2050, achieve a combined EV/PHEV sales share of at least 50% of LDV sales worldwide.
- By 2020, achieve at least 5 million EV and PHEV combined global sales per year, or more if possible (the BLUE Map suggests 7 million in 2020).[7]
- By 2020, roll out the first EV/PHEV sales in regions and urban areas that have the best chance to deliver adequate infrastructure and low-GHG electricity, have adequate government support and planning, and potentially are home to sufficient early adopter target customers to reach target levels.

2. Develop coordinated strategies to support the market introduction of electric-drive vehicles

Electric-drive vehicles are unlikely to succeed in the next five to ten years without strong policy support, particularly in two areas: making vehicles cost-competitive with ICEs and ensuring adequate recharging infrastructure is in place. Each country interested in successfully introducing EVs and PHEVs to the market will need to first identify and develop adequate policies to achieve these conditions.

Governments need to coordinate the launch and ramp-up of EV and PHEV sales, the development of the recharging infrastructure and transition of electricity supply to carbon-free generation. This need for coordination is a primary reason for developing a detailed roadmap – to ensure everyone

7 Targets are subject to constraints in terms of rates of investment, manufacturing capability, recharging infrastructure and consumer demand.

sees and conducts the roll-out plans in a similar way. National and local governments, the auto industry, electric utilities, relevant NGOs and academic researchers need to continually communicate, work together and coordinate their efforts. Additionally, the development of national roadmaps can help individual countries recognise their internal constraints and establish national goals to clearly lay out the roles for automobile manufacturers, suppliers, researchers, and the government itself in facilitating a transition to electric mobility as quickly and smoothly as possible.

The successful market introduction of electric-drive vehicles also requires the identification of a "break-even" metric – the point at which EVs pay for themselves (or become sufficiently attractive to consumers relative to the replaced ICE vehicle). It is at this point that the achievement of target sales levels becomes possible. The importance of non-cost attributes such as range, refuelling/recharge time, environmental impact, and vehicle-to-grid (V2G) opportunities should be included in this metric. Variation across different consumer groups should also be explored. Once this metric has been identified, incentives will likely be needed to reach break-even points for most consumers in the near-term. The extent of incentives will depend in part on how much (if any) premium consumers are willing to pay for electric-drive vehicles.

When EVs and PHEVs gain a sufficient long-term market share, increased taxation on electricity may be needed to maintain state revenues currently lifted by taxation on fossil fuels. This may be partly counterbalanced by cost reductions resulting from technological advances and learning. Countries may also shift toward different taxation systems, possibly based on factors such as GHG emissions, infrastructure use, pollutant emissions, noise, and/or the occupation of public land. Additional analysis should be carried out in order to figure out how electric-drive vehicles would perform in different taxation scenarios.

This roadmap recommends that, as soon as possible, the following milestones and actions should be achieved:

- Improve national and regional market potential estimates.
- Ensure that national targets and auto company production planning are coordinated.
- Identify a "break-even" metric and implement policies to make vehicles cost-competitive with ICEs.
- Identify and implement policies to ensure that adequate recharging infrastructure is in place at the time of, or slightly before, vehicles that will rely on the infrastructure enter service.
- Coordinate the launch and ramp-up of EV and PHEV sales, the provision of recharging infrastructure, and the changes in electricity supply. Coordination should include national and local governments, auto industry, electric utilities, relevant NGOs and academic researchers, and – very importantly – consumers.
- Evaluate the near- and expected medium-term cost competitiveness of EV/PHEVs in the context of potential evolution of required support, and develop comprehensive policies to ensure a smooth transition phase is undertaken with a view toward achieving commercial viability of EVs and PHEVs as soon as possible.

3. Improve industry understanding of consumer needs and behaviours

Consumer acceptance of EVs and PHEVs is a key factor determining the ultimate success or failure of EV technologies. Estimation methods that help predict battery cost and ownership and potential EV/PHEV sales depend on a thorough understanding of consumer needs, desires and choice making behaviours with respect to EVs, PHEVs and competing vehicle types. Consumer willingness to change travel behaviour and accept different types of vehicles and, perhaps, driving patterns is an important area of uncertainty. Identification of potential early adopters and mainstream consumers requires good information on consumers broken out by demographics and other characteristics that can be related to the sizes of different population subgroups. Such information (at least on a public basis) is lacking or inadequate in most potential EV markets.

To effectively understand consumer needs and behaviours, industry must answer questions such as the following:

- How do demographics of car buyers vary in different markets (e.g., older customers in developed countries versus younger customers in developing countries)?
- What are the typical characteristics of those who buy car types that EVs may compete with (such as smaller urban vehicles)?
- How important is the multi-car family (e.g., electric-drive vehicles as second cars)? How many multi-car families are there in different countries?
- Will electric-drive vehicles' appeal to low- to medium-mileage drivers? (Range limits may make it difficult to drive EVs and PHEVs far enough to pay for vehicle costs through fuel savings.)
- What is the distribution of driving (e.g., in km per day) for different types of consumers, in different locations? How does this distribution impact electricity demand, and oil or CO_2 reductions?
- How many and what type of consumers may be willing to pay a premium for EVs or PHEVs? How many may be willing to purchase such vehicles with various levels of incentives?
- What role might businesses play in becoming early adopters? Are there large fleets that may be interested in making bulk purchases?

This roadmap recommends the following actions be undertaken at a national and municipal level as soon as possible:

- Collect better data, especially on markets and consumer behaviour; utilise metrics for gauging consumer aspects and market potential (see Table 6).
- Actively include consumers in the planning process of government and industry and ensure that consumers' needs and desires are met.
- Develop good outreach and information programmes to help consumers understand the benefits of EVs and PHEVs, and increase their interest in adopting them.
- Get good feedback systems in place to allow early adopters to provide feedback that helps planners optimize infrastructure and other EV/ PHEV-related systems.

Table 6: Metrics for gauging consumer aspects and market potential

Metric	Possible targets and notes
Consumer willingness to pay for EVs and PHEVs	Net higher cost for electric-drive vehicles (first cost and/or total life-cycle cost) that consumers are willing to pay compared to competing ICE vehicles; willingness to pay a premium likely to be more for early adopters than mainstream consumers. Fleet and private customer needs to be treated separately.
Driving behaviour – daily driving distance	Distribution of driving distance per day (important both for setting PHEV optimal range and for determining maximum needed range for electric-drive vehicles).
Driving behaviour – actual in-use vehicle efficiency and range	Vehicle energy use per km based on actual in-use data, with indications of variation based on driving style and driving conditions.
Recharging behaviour	When and for how long will consumers recharge on average? Metrics on recharging distributions (load profiles) by 24-hour period, day of week, for both PHEV and EV customers.

4. Develop performance metrics for characterising vehicles

EVs and PHEVs will need to meet various performance-related criteria in order to maximise their market potential. Identifying specific performance metrics can help in this regard. Vehicle attributes that likely will be important for the success of EVs and PHEVs include vehicle first cost, efficiency and annual fuel cost, maintenance cost, electric driving range, speed of recharging, performance (such as acceleration), reliability, safety, and CO_2 and pollutant emissions. EVs and PHEVs should, to the extent possible, achieve levels and values for these attributes that are comparable to similar sized and purposed ICE vehicles. However, some attributes will inevitably be different, such as driving range and emissions. Some metrics will matter more for one than the other – for example, the percentage of driving on electricity versus liquid fuel and the fuel efficiency on each fuel are important metrics for PHEVs but irrelevant for EVs.

Metrics also need to be developed to ensure that EVs and PHEVs meet applicable emissions and safety standards. Certain safety standards specific to EVs and the way they are used should be factored into these metrics to ensure their use is not unnecessarily impeded. Driving cycles specific to EVs/PHEVs should be studied and test procedures developed as necessary, since EV/PHEV driving patterns may be different than for today's ICE vehicles. Such test procedure development is underway at both the Society for Automotive Engineers (SAE) and the UN Economic Commission for Europe (UN-ECE). Standard metrics for safety aspects such as recharging security are also needed (especially high voltage).

This roadmap recommends the following actions be completed in the near-term:

- Establish common, consistent metrics for characterizing EVs and PHEVs around the world.
- Using these metrics, consider and set needs and desirable levels of attributes for EVs and PHEVs separately.
- Take into account interactions and tradeoffs among vehicle attributes when identifying targets.
- Utilise and, as needed, refine the metrics recommended in this roadmap (see Table 7).

Table 7: Metrics for characterising EV/PHEVs

Metric	Possible performance metric and notes
Driving range on electricity	More market research is needed to better inform targets and limits; the 100 km range is considered a possible minimum for mainstream EVs; anywhere from 20 km to 80 km may be appropriate for PHEVs (possibly scalable – customers choose their range).
Performance (e.g., acceleration)	Should match or exceed that for similar ICE vehicles.
Safety (passive and crash)	Should match or exceed that for similar ICE vehicles, though some differentiated standards may be needed (e.g., for small EVs).
Reliability (e.g,. average maintenance cost and service requirements per year)	Should match or exceed that for similar ICE vehicles.
Efficiency (kWh/km; L/100 km – equivalent)	Depends on vehicle size and purpose; 0.1 kWh/km appears to be close to the limit for regular-use cars; average may be much higher, especially in-use. Achieving 0.2 kWh/km should be sufficient to give EVs a significant fuel cost advantage over ICEs. (This is about equivalent to 2 litres (L)/100 km gasoline-equivalent). However, 0.2 kWh/km means 20 kWh storage for a 100 km range, which could be quite expensive in terms of battery cost.

Metric	Possible performance metric and notes
Fuel cost per km	Depends on efficiency and fuel prices; EVs will need a significant fuel cost advantage to make up for higher first cost. Possible near-term scenario: EV (0.2 kWh/km at USD 0.15/kWh translate to a fuel cost per km of USD 0.03/km); comparable gasoline ICE (8 L/100 km at USD 0.75/L translates to a cost of USD 0.06/km); and comparable diesel ICE (7.2 L/100 km at USD 0.75/L translates to a cost of USD 0.05/km). Higher oil prices would increase the difference in cost per km while improved ICE efficiency (e.g., hybrids) and higher taxes on electricity would reduce the cost per km differential.
Average travel per vehicle	May be lower for EVs than "comparable" ICE vehicles due to range limitations, which would reduce their impacts on energy use and their cost-effectiveness. But empirical data is needed to better understand this issue.
Vehicle resale value	Affects pricing strategies and willingness of people to purchase EVs (market size).

5. Foster energy storage RD&D initiatives to reduce costs and address resource-related issues

Battery cost reduction is critical to achieve EV break-even cost with ICEs. Estimated achievable lithium-ion battery costs under mass production in the near-term (2012 to 2015) range from USD 300 to USD 600 per kWh of storage capacity (possibly higher for PHEVs if they will require power-oriented batteries). For EVs with 20 kWh of capacity (the minimum requirement for a pure EV), this yields a battery cost per vehicle of USD 6 000 to USD 12 000. Moving toward the lower end of this range as quickly as possible will greatly help to achieve commercialisation. There is hope that this can occur via large battery production scales and learning, but it is uncertain. In the next two to three years, key battery technology performance should be verified via in-use testing, after which companies may be able to quickly go to mass production to achieve cost reductions. Model years 2010 to 2012 appear key for proof of concept and moving toward mass production of batteries. Appropriate performance metrics should be established, especially for battery energy/power density and specific energy targets, to ensure adequate battery and EV/PHEV performance.

Resource requirements for electric vehicles and batteries also need to be understood, and secure supply chains established. Today there are very few world-class battery manufacturers; most of them have strong strategic partnerships with original equipment manufacturers (OEMs). Governments should strongly encourage and support promising start-up battery manufacturers, particularly those with innovative approaches. This support includes ensuring that investment cost and risk are not obstacles to construction of battery manufacturing plants and capacity expansion. The supply of batteries (and materials to make them) needs to be sufficient to align with incremental EV/PHEV production and capacity expansion. Access to necessary inputs must be ensured for all manufacturers. Lithium and possibly rare earth metal supply/cost are also medium-term areas of concern and should be monitored, to ensure that supply bottlenecks are avoided. Conducting effective RD&D to foster greater use of advanced (e.g., light-weight) materials and innovative designs, can also help reduce the need for resources in building electric and other types of vehicles. Supply chains of materials required for vehicle manufacture should also be optimised. For example current battery supply chains and battery shipping can be very expensive (e.g., due to high weight and relatively low volumes). Production locations close to assembly locations may help cut such costs.

Batteries could be useful after their retirement from service in vehicles, mainly as stationary energy devices. New business models and battery designs may help decrease total cost, by extending battery life via multi-stage battery use. However, secondary uses should not detract from the first and primary purpose of the battery – energy storage on-board vehicles. Batteries should have minimal life-cycle environmental impacts, including production and disposal. Maximising recycling is a key way to ensure minimal impacts and resource recovery; systems and rules dictating its use and implementation need to be established early on.

To ensure the continued improvement of electric-drive vehicle batteries and battery systems, strong RD&D programmes for advanced energy storage concepts should continue. Flywheels and ultracapacitors continue to improve and should not be ignored; a "next-generation" of energy storage beyond current Li-ion battery concepts must be sought.

This roadmap recommends the following milestones and actions by 2015 or sooner:

- Reduce battery costs via large scale production, optimisation and improved logistics.
- Develop innovative vehicle/battery cost and financial models for vehicle ownership.
- Establish appropriate metrics and empirically verify battery performance via in-use testing.
- Develop and optimise supply chains and ensure sufficient battery and hybrid electric system supply through incremental production capacity expansion aligned with EV/PHEV vehicle volume.
- Incentivise battery manufacturers to achieve large-scale production and adopt advanced designs in a timely manner, in concert with expected roll-out of vehicles.
- Establish strategies for retiring batteries from vehicle use (e.g., secondary use or recycling programmes).
- Continue to support and accelerate innovative energy storage research.
- Develop standards for battery construction and disposal, with emphasis on recycling, for use around the world.
- Utilise the key metrics included in this roadmap (see Table 8).

Table 8: Cost-relevant metrics and targets

Metric	Possible targets and notes
• Energy density per unit weight, volume	Proposed targets include an energy density of approximately 150 Wh/litre to 200 Wh/litre (potential improvement ratio of 1.5 to 2) and specific energy of approximately 100 Wh/kg (potential improvement ratio of 1.5 to 2).
• Power density per unit weight, volume	The United States is considering a target for specific power of 460 W/L and increasing to 600 W/L
• State of charge (percentage of full battery charge) limits	Designs should allow for repeated deep discharges with minimum battery deterioration
• Battery recharge time and rate	Slow recharge is acceptable for overnight (e.g., home recharging). For recharging during the day, faster recharge rates are desirable. Fast recharging on highways may be the most important. Possible target: 10 minutes charging for 100 km of range.

Metric	Possible targets and notes
• Battery cost per kWh capacity	Estimated achievable lithium-ion battery costs under mass production in the near-term (2012 to 2015) for pure EVs range from USD 300 to USD 600 per kWh of storage capacity. For EVs with 20 kWh of capacity (probably the minimum requirement for a pure EV) this yields a vehicle cost of USD 6 000 to USD 12 000. Manufacturers will need to shift to the lower end of this range as quickly as possible to achieve commercialisation. Costs per kWh of battery will be somewhat higher for PHEVs, given smaller battery packs with higher power requirements. PHEVs will be able to tolerate somewhat higher unit costs since battery energy storage requirements will be much smaller.
• "Round trip" battery efficiency	Measured as energy out of battery divided by energy in; should achieve (90% to 95%) in in-use conditions, over battery life. Plug efficiency is also important, which is the energy out of battery divided by metered energy out of wall plug and into battery.
• Battery life (total charge-discharge cycles; calendar life)	Two metrics include the number of deep discharge cycles and total calendar life. Reasonable targets are 2 000 to 3 000 discharge cycles and calendar life of 10 to 15 years. (For reference, the US Department of Energy uses: 300 000 power assist cycles for plug-ins plus 1 000 full discharges).
• Battery performance deterioration over time	Minimising battery performance deterioration over life is essential. Maximum 20% deterioration in key performance metrics (e.g., capacity) over ten years is a good target.
• Battery performance deterioration, depending on ambient conditions	Targets must hold over a wide range of conditions, such as the typical range of weather and temperature conditions in inhabited parts of the planet. Reliable operation under a range of drive cycles and road conditions must also be ensured.
• Battery safety	At least as safe, in use, as current liquid fuel systems.
• Battery disposal and recycling	Need nearly full recovery of battery components, especially toxic components; need clear methodologies for measuring battery life-cycle environmental impacts.

6. Develop and implement recharging infrastructure

Reliable electricity supply must be available for EV/PHEV recharging, with convenient access to recharging stations. For PHEVs, overnight recharging appears to be the main initial requirement, whereas for pure EVs, recharging opportunities away from home are a more critical concern to achieve widespread demand for and use of vehicles.

The likely impact of a given number of EVs and PHEVs in use, on total and time-of-day electricity demand, generation, and capacity must be understood. The role of day/night recharging is a key issue. The role of electricity pricing (e.g., differential day/night, real time pricing) to meet both consumer and producer needs must be fully explored.

The standardisation of the vehicle-to-grid interface will also be necessary, at least within continents, but it is also important to avoid over-regulating in order to allow for innovation. The International Standards Organisation (ISO), the International Electrotechnical Commissions (IEC), SAE, the Underwriters' Laboratories (UL), and other organisations can play important roles in coordinating and setting standards. Likely areas for early standardisation are:

- Plug types.
- Recharging protocols.

- Communications protocols between cars and recharging infrastructure.
- Regulations for public recharging that ensure safety with minimal administrative challenges.
- Battery recycling standards and regulations.
- Utility regulations conducted by state/provincial authorities to ensure orderly participation in this market.

Infrastructure cost is estimated to run on the order of USD 1 000 to USD 2 000 per car.[8] However, governments and industry need to determine who will pay these costs, at what point during EV expansion should different investments be made, and how investments will be recovered. PHEVs may need less recharging infrastructure, at least to gain viability, than pure EVs. A low-cost strategy could rely on initial sales and stock accumulation of PHEVs to build-up the night-time recharging market, help lower battery costs, and encourage initial investments in public recharging infrastructure. Pure EVs could then be phased in as more daytime infrastructure becomes available. For each country, a clear PHEV versus EV roll-out scenario will help determine infrastructure requirements.

EV and PHEV expansion will be primarily driven by infrastructure investment. National governments can help coordinate early adoption sites, targeting large cities and urban areas that have ample recharging access. By 2012 or sooner, it should be determined which local and regional units of government are welcoming electric-drive vehicles through such efforts, and they should be coordinated to ensure a transition toward a national system. Governments should also ensure local electrical capacity and systems to accommodate whole areas plugging in their electric-drive vehicles at night; the development of local grid/distribution plans will help. Another key issue is determining how and when to join up cities for EVs by developing recharging opportunities on intra-city travel routes. Ultimately, to enable long-distance travel by EVs and access to all parts of a country, easily accessible, fast-charging facilities will be needed on motorways.

Innovative electricity recharging systems should be considered. Battery exchange systems can provide very rapid replacement of depleted batteries with those that are fully charged, although many questions remain in regard to cost, extra required battery supply, compatibility of the battery systems used by different original equipment manufacturers (OEMs) and replacement of new batteries with potentially older batteries. Battery technologies and licensing systems would also need to be compatible. Additionally, fast charging will be important for battery exchange systems, since it increases the effective supply and lowers the number of batteries that must be kept in reserve to meet peak demand.

Grid powering from batteries could be very useful for provision of peak power and load balancing, but needs to be controllable by vehicle owners. There could be important limitations on how much depletion in battery capacity that vehicle users will tolerate (e.g., the driver must be able to leave the car parked at work and be able to get home again). Adverse impacts on battery life must also be understood and minimised.

The role of smart metering should be fully explored via trials, with good information sharing. All forms of advanced charging systems (e.g., vehicle-to-grid power flow, day/night price differentials, restricted charging during peak demands) will require smart metering systems. But different levels of technology will involve different costs. Optimisation and standardisation will eventually be necessary.

Lastly, the role of utilities and regulators should be clearly established. Utilities will be expected to play a lead role in investing recharging infrastructure; regulators must ensure that utilities have incentives that allow them to earn a fair return on their investments. Utilities will need to work closely with cities, regions and vehicle OEMs in order to achieve a coordinated roll-out strategy that centres on consumer needs.

This roadmap recommends the following milestones and actions:

- Analyse each region to better estimate the relationship between EV/PHEV electricity supply and demand, especially during a fast growth phase after initial introduction (the system should anticipate the possibility of large numbers of vehicles in the 2020 time frame; simulation model tools are available and should be used in each region to determine the optimal location of charging points and timing of installation).

8 This estimate is for all recharging infrastructure; it is therefore likely to be much lower for simple home recharging.

- Establish appropriate codes and standards for recharging, electricity supply and smart metering.
- Draft national EV/PHEV infrastructure roll-out strategies that identify infrastructure priorities and priority areas, timelines, and funding.
- Define the roles and responsibilities of different actors (governments, regulators and utilities, vehicle OEMs, consumers) clearly and develop cooperative and collaborative strategies among multiple levels of government along with electric utilities and OEMs.
- Prioritise home recharging, but plan to bring in commercial recharging centres rapidly as vehicles accumulate (early build-up of commercial recharging may be less important for a PHEV-led transition strategy; urban centres may take priority over intercity recharging facilities).
- Explore the viability of various approaches to rapid recharge systems (e.g., battery exchange systems).
- Evaluate the role for and system designs of vehicle-to-grid electricity provision, including the need for next-generation infrastructure, such as smart metering technologies. Assess willingness of drivers to sell electricity back to the grid under various circumstances.
- Utilise the metrics recommended in this roadmap (see Table 9).

Table 9: Electricity supply and prices, and recharging infrastructure

Metric	Possible targets and notes
• EV market potential	Indications of potential market size overall and among different demographic groups; early adopter market size versus mainstream (maximum potential) market size; impacts of relevant vehicle costs, other vehicle attributes and policy-related variables.
• Impacts per unit infrastructure investment (or per unit investment overall), measured in value of net benefits to society	In order to avoid massive risky investments, early investments should provide a clear impact/benefit. PHEVs are the near-term focus in US because massive infrastructure investments are not required.
• Supply-related metrics	Number of models available, production capacity, trends in production over time (average and maximum rates of expansion).
• Infrastructure-related metrics	Recharging opportunities (percent of plug-capable homes; number of and density of public recharging facilities; and ratio of recharging facilities to numbers of vehicles). One data point from roadmap workshop – both the US and a number of large European countries appear to have about 50% of homes that are EV plug-capable at zero or low cost.

Additional Recommendations: Actions and Milestones

The successful implementation of this roadmap will only be possible when policy framework supporting technology development and dissemination is in place, and governments have established methods for coordinating their efforts domestically and internationally.

Use a comprehensive mix of policies that provide a clear framework and balance stakeholder interests

A comprehensive policy framework should be established through 2020 in order to give stakeholders a clear view of the road ahead, enable early decisions to be made, and reduce investment risks. Governments need to establish a consistent and dependable incentive framework to support the implementation of electric-drive vehicles. OEMs are currently seeking to secure near- to medium-term markets through policy agreements that ensure adequate volumes for OEM returns. Overall policy goals should be established (e.g., energy security, low CO_2 emissions) with appropriate incentives so manufacturers can tailor their production to achieve these policy goals.

To the extent possible, policies should not favour particular technologies but promote good performance (e.g., low CO_2 emission vehicles, fuel diversification and improved energy security). Thus, CO_2 and other exhaust emission-based standards, taxes, etc., are generally superior to ones that directly promote the use of EVs/PHEVs. However, some "technology picking" policies may be unavoidable, such as supporting the provision of EV/PHEV recharging infrastructure.

Policies should aim towards achieving first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles, at least during the transition period aimed at building sufficient confidence from all stakeholders (e.g., customers, battery and vehicle manufactures and recharging grid investors). Based on empirical data, some consumers (especially early adopters) may tolerate some level of ownership cost increment for EVs/PHEVs as compared to ICEs, but the smaller this increment, the larger the likely market size for EVs/PHEVs.

To limit policy (and taxpayer) cost of encouraging electric-vehicle development and deployment, governments can set market penetration targets, cost reduction targets, maximum spending caps or time limits for programmes. However, there is a risk of ending programmes before they succeed. Any limits should be clear to all stakeholders so these can be factored into decision making (both for investors and potential EV/PHEV buyers).

Policies must be based on policy-relevant metrics, including:

- Geography of incentives, or "net value" of incentives to consumers.
- Consumer behaviour (e.g., average driving distance).
- Reliability of electricity, especially in developing countries.
- Sales in fleets versus Households.
- Types of purchase contracts.
- Life-cycle CO_2 emissions

Policy elements should target fleet markets, which are among likely early adopters of EVs/PHEVs. Necessary infrastructure and purchase contract issues may be quite different from the personal vehicle market. Governments can also spur markets by acquiring EVs/PHEVs for official use. Large, coordinated vehicle purchases can help ensure minimum levels of demand to encourage commencement of vehicle production. Implementation of recharging infrastructure should also be coordinated with expected vehicle purchases. Governments will need to lead such coordination efforts.

Government-industry partnerships can support education and demonstration to increase consumer awareness of the availability and benefits of EVs/PHEVs. Labelling programmes and high-visibility trials (e.g., taxi fleets) can raise awareness. There is also a need for accurate information on in-use performance (e.g., range, recharging times, recharging grid location information and expansion plan) to raise consumer confidence.

Policies are also needed to promote R&D, especially for advanced energy storage; these can include corporate tax incentives and direct spending on R&D programmes.

This roadmap recommends the following milestones and actions be completed by national governments (and in some cases local/regional governments), as soon as possible:

- Establish clear national policy frameworks through 2020, complete with establishment of clear market incentives, evidence of commitment, and well-bounded timeframes.
- Maintain technology neutrality, to the extent possible.
- Use policies to achieve first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles during a fixed transition period.
- Combine a mix of policy elements that are harmonised and not in internal conflict, and adjust existing policies to remove any potential conflicts.
- Incorporate caps to limit the costs of policies, and indicate the time extent of policies (e.g., sunset provisions), but do so clearly and give adequate time for market development.
- Base CO_2-related policy incentives on life-cycle CO_2 emissions.
- Encourage regional strategies through multi-level governance.
- Develop infrastructure development plans in cooperation with government and industry.
- Encourage business/government fleets to serve as early adopters.
- Develop information campaigns via government-industry partnerships.
- Make a strong commitment to ongoing public RD&D programs.
- Utilise the metrics recommended by this roadmap (see Table 10).

Table 10: Policy-relevant metrics

Metric	Possible targets and notes
• Policy impact: net cost differential between EVs and similar ICE vehicles	The result of all various policy elements in terms of their impacts on first cost and annual vehicle ownership cost on EVs, in comparison to competing vehicles (perhaps converted to an annual average using amortisation where necessary). A good metric should also include quantification of "hedonic" factors such as non-cost attributes and policies giving preferential treatment (e.g., access to city centres) to electric-drive vehicles.
• Policy cost: net level of public subsidy per vehicle	The net public (tax) dollar cost per vehicle per year for all policy support.
• Policy benefit: net social benefits	Net impacts on CO_2, oil use, pollution emissions, traffic congestion, and noise reduction can be compared to policy cost.

The preceding discussion on policy recommendations focused on the goals of the policies. These goals can be accomplished through a variety of policy elements. Table 11 summarises the types of policies and policy elements that could play a role in incentivising electric-drive vehicles. Optimally, governments would use a mix of policies that is least-cost and provides just enough incentive to build the market at the target rate. This roadmap does not attempt to analyse specific sets of policies.

Table 11: Types of policies and policy elements that could play a role in incentivising electric-drive vehicles

Vehicle-fuel price related	Not cost-related
• Favourable financing terms – e.g., battery leasing to minimise up-front and monthly cost. • Feebate (vehicle fee/rebate) system at time of vehicle purchase, based on performance (e.g., life-cycle CO_2 emissions). • Differential CO_2-based fuel taxes. • Reductions in highway tolls and other vehicle fees (annual registrations). • Incentives for providing recharging infrastructure in commercial/public areas. • Subsidisation of the cost of recharging infrastructure for households/apartment buildings.	• Differential treatment for EVs/PHEVs in terms of regulations, such as access to otherwise vehicle-restricted zones in city centres, preferential parking spots with charge points. • Guarantees for re-sale values, battery replacements. • Additional credits under regulatory systems (e.g., in EU vehicle CO_2 regulations, EVs/PHEVs are considered zero emissions, so automakers get an advantage for producing them; similar credits exist in the US Corporate Average Fuel Economy (CAFE) law). • Electric-drive vehicles would be favoured by strong regulations addressing pollutants (apart from CO_2). • Initial introduction of EVs by government fleets to help spur manufacture. • Public transport vehicles, two/three-wheeled vehicles – exploit EVs in these segments to promote EVs for individual consumers and increase battery production scales. • Direct provision of recharging infrastructure in public areas.

Source: IEA EV/PHEV Workshop, January 2009.

Engage in international collaboration efforts

Governments around the world must work together to ensure sufficient coordination of activities and avoid working at cross purposes, as well as to accelerate technology development and adoption in the most efficient way. There are a number of key areas for information sharing and collaboration:

- Research programmes.
- Codes and standards.
- Vehicle testing facilities.
- Setting of market development targets, such as vehicle sales.
- Alignment of infrastructure, charging and vehicle systems as appropriate.
- Policy development and experience in implementing different approaches.

A number of activities can help improve international collaboration and information sharing. Governments should maximise the use of websites to publically share information and learning, and identify best practices. Regular international meetings can help governments learn from experiences in other countries and increase contacts. Multi-stakeholder workshops – among governments, utilities, OEMs and others – are also important to improving collaboration and sharing best practices in areas such as, standardisation, recharging types/sites, customer driving profiles and demand patterns. Information should also be shared about policies that are particularly effective or ineffective to avoid duplication of mistakes and encourage repeat successes across countries. Early involvement of developing countries in international collaboration and information sharing should be ensured (especially emerging economies with large vehicle markets, e.g., Brazil, Russia, India and China). Some developing countries may be early adopters or market leaders (e.g., China). In any case, EVs/PHEVs may begin to be resold to developing countries by 2015 to 2020 and these countries need some preparation to handle this.

Technology and research should also be shared. Hardware and software relating to analysis, recharging infrastructure, and other aspects should be shared to harmonise approaches. Expertise sharing and exchanges of experts should be explored. Common research agendas can address shared problems (e.g., supplies of lithium, rare earth materials and battery materials). Global recycling system for batteries, common electricity demand, and GHG impact methodologies will all be needed.

The IEA Secretariat can play a role in convening workshops and in coordinating activities, including planning, data collection, international analysis and research methodologies.

- Through its roadmapping efforts, the IEA can help coordinate planning in linked areas, including EV/PHEV development, smart grid development, and planning for low-CO_2 electricity generation around the world.
- The IEA Implementing Agreement on Hybrid and Electric Vehicles plays an important role in running joint research programmes. Countries and private organisations can join for specific projects. Currently eight specific projects ("Annexes") are operating.
- The IEA is a member of the "Global Fuel Economy Initiative", which can provide a framework for engaging governments on the adoption of advanced technology vehicles such as EVs and PHEVs, and help them develop strategies and adopt targets and principles as outlined in this roadmap.
- There are several other potential and active forums for international collaboration on EVs/PHEVs, e.g., the Electric Drive Transport Association (EDTA) and the Asia-Pacific Economic Cooperation (APEC) agency.

This roadmap recommends the following milestones and actions:

- Achieve standardised safety and performance regimes.
- Develop websites and have regular international meetings for information and research sharing (includes hardware and software sharing).
- Identify countries (including developing countries) that are candidates to become early adopters, and help to get them involved.
- Convene workshops and coordinate activities.
- Publish periodical reports and "scorecards" on progress; report on best practices, issues arising and how these can be overcome.

Encourage governments to address policy and industry needs at a national level

Several countries have already initiated the development of their own national roadmaps for EVs and PHEVs. Canada, for example, initiated the "Canadian Electric Vehicle Technology Roadmap (evTRM)" in mid-2008, which included conducting a series of workshops to define the national outlook on the future of electric-drive vehicles in Canada and to set a target for future EV/PHEV market penetration. The United Kingdom also released a high-level roadmap called "Ultra-low Carbon Vehicles in the UK" that includes high-level short-, medium- and long-term goals for transport. Additionally, Japan and the United States have issued several documents to date, the combination of which form roadmaps that include goals for EV/PHEV-critical technologies like batteries, converters, and motors, and quantify characteristics such as cost, power density, and energy density.[9] Other countries have announced ambitious targets regarding future EV/PHEV penetration (see Figures 6A and 6B).

Like this roadmap, national roadmaps can show how stakeholders can better set appropriate targets, guide market introduction, understand consumer behaviour, advance vehicle systems, develop energy, expand infrastructure, craft supportive policy, and collaborate where possible. In addition to making recommendations about how national governments, researchers, and automobile manufacturers and suppliers can identify their route to significant EV/PHEV penetration by 2050, this roadmap strongly encourages stakeholders to formally develop and share their own national roadmaps. By formulating common goals, the global community can work toward an electric-drive transport future.

9 A summary of the Japanese and American roadmaps can be found in the Appendix.

Conclusion: Near-term Actions for Stakeholders

This roadmap has responded to the G8 and other government leaders' requests for more detailed analysis regarding future deployment of EVs and PHEVs. It outlines a set of strategic goals, milestones, and actions to reach a high level of EV/PHEV market penetration around the world by 2050.

The existence of a roadmap document is not enough. This roadmap is meant to be a process, one that evolves to take into account new developments from research breakthroughs, demonstration projects, new types of policies, and international collaborative efforts. The roadmap has been designed with milestones that the international community can use to ensure that EV/PHEV development efforts are on track to achieve the GHG emissions reductions that are required by 2050. As such, the IEA will report regularly on the progress that has been made in achieving the roadmap's vision.

To ensure co-ordination and harmonisation of activities, there needs to be a clear understanding of the roles of different stakeholder groups, along with commitments to achieving various objectives and targets over time. Table 12 identifies near-term priority actions for the full set of stakeholders that will need to be taken to achieve this roadmap.

The IEA has benefited from major inputs from representatives from government agencies, the automobile and electric utility industries, and other experts and NGO representatives. These groups should continue to collaborate, along with others, to work together in a harmonised manner in the future. Specifically, the IEA proposes to develop an EV/PHEV Roadmap Implementation and Monitoring committee that would work together in an ongoing fashion. The committee could undertake various data collection and monitoring activities, as well as coordination activities. It could build on (and include participants from) existing structures, such as the IEA Hybrid and Electric Vehicle Implementing Agreement.

For more information about the ongoing roadmap process and progress in implementation, visit www.iea.org/roadmaps/index.asp.

Table 12: Near-term actions for stakeholders

Stakeholder	Action item
Economics/ finance ministries	• Incentivise battery manufacturers to achieve large scale production quickly and adopt advanced designs in a timely manner. • Evaluate the long-term cost competitiveness of EVs/PHEVs in the context of potential evolution of the taxation structure. • Develop innovative vehicle/battery cost and financial models for vehicle ownership. • Explore the financial viability of various approaches to rapid recharge systems (e.g., battery exchange systems). • Identify a "break-even" metric and implement policies to make vehicles cost-competitive with ICEs. • Use policies to achieve first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles during a fixed transition period.

Stakeholder	Action item
Environment/ energy/ resource ministries	• Target a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050. • By 2020, achieve at least 5 million EV and PHEV combined global sales per year or more, if possible. • Improve and refine regional and national market potential estimates. • Draft national EV/PHEV infrastructure roll-out strategies that identify infrastructure priorities and priority areas, timelines and funding. • With automobile manufacturers and suppliers, ensure that all national targets can be matched to auto company production planning, and vice versa. • Coordinate the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Collect better data, especially on markets and consumer behaviour. • Develop good outreach and information programmes to help consumers to understand the benefits of EVs and PHEVs and increase their interest in adopting them. • Develop websites and have regular international meetings for information sharing. • Establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Establish standards for battery construction and disposal, with emphasis on recycling. • Achieve standardised safety and performance regimes. • Clearly define the roles and responsibilities of different actors (governments, regulators and utilities, vehicle OEMs and consumers); develop cooperative and collaborative strategies among multiple levels of government along with electric utilities and OEMs. • Base CO_2-related policy incentives on life-cycle CO_2 emissions. • With utilities, cooperatively develop infrastructure development plans. • With science ministries, design, implement and make a strong commitment to ongoing RD&D programmes.
Training/ science ministries and universities	• Reduce battery costs for EVs to USD 300/kWh or below by 2015. • Establish appropriate metrics and empirically verify battery performance via in-use testing. • Continue strong energy storage research. • Conduct research, testing and benchmarking to establish standards for battery construction and disposal, with emphasis on recycling. • Conduct research, testing and benchmarking to establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Explore viability of various approaches to rapid recharge systems (e.g., battery exchange systems). • Design, implement and make a strong commitment to ongoing RD&D programmes.

Stakeholder	Action item
Automobile manufacturers and suppliers	• Improve and refine regional and national market potential estimates. • With governments, ensure that all national targets can be matched to auto company production planning, and vice versa. • Identify and implement policies to ensure adequate recharging infrastructure is in place at the time of, or slightly before, vehicles enter service that will need it. • Governments and industry must include consumers in the planning process and ensure that their needs and desires are met. • Develop good outreach and information programmes to help consumers understand the benefits of EVs and PHEVs, and increase their interest in adopting them. • Consider and set needs and desirable levels of attributes for EVs and PHEVs separately. • Develop innovative vehicle/battery cost and financial models for vehicle ownership. • Optimise the supply chain and ensure sufficient battery and hybrid electric system supply through incremental production capacity expansion aligned with EV/PHEV vehicle volume. • Help identify business/government fleets that can serve as early adopters.
Electric utilities	• Ensure adequate recharging infrastructure is in place at the time of, or slightly before, vehicles enter service that will need it. • Include consumers in the planning process and ensure that their needs and desires are met. • Help develop innovative vehicle/battery cost and financial models for vehicle ownership. • Work with business/government fleets as early adopters. • Establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Explore role for and system designs of vehicle-to-grid electricity provision, including the need for "next-generation infrastructure," such as smart metering technologies; explore willingness of drivers to sell electricity to the grid under various circumstances. • Governments and utilities should cooperatively develop infrastructure development plans.
State, provincial and local governments	• Target regions and urban areas that have the best chance to deliver adequate infrastructure and low-GHG electricity by 2020 for initial EV/PHEV sales. • Focus initial recharging infrastructure development on home recharging, but with plans for bringing in commercial recharging centres rapidly as vehicles accumulate. • Incentivise battery manufacturers to achieve large scale production quickly and adopt advanced designs in a timely manner. • Maintain technology neutrality to the extent possible. • Encourage regional strategies (multi-level governance). • Share hardware, software and research.

Stakeholder	Action item
Non-governmental organisations	• Encourage, coordinate, and facilitate the sharing of hardware, software and research. • Study and make recommendations regarding the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Document efforts and make recommendations regarding coordination among national and local governments, auto industry, electric utilities, relevant NGOs and academic researchers. • Establish strategies for retiring batteries from vehicle use, e.g., secondary use or recycling programmes.
Supranational organisations (e.g., the IEA)	• Co-ordinate sharing of hardware, software and research among countries. • Co-ordinate and monitor the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Identify countries (including developing countries) that are candidates to become early adopters, and help to get them involved. • Convene workshops and coordinating activities. • Publish periodical reports and "scorecards" on progress; report on best practices and issues arising (including how to overcome them).

A Comparison of National Electric-Drive Vehicle Roadmaps

UNITED STATES

Year	2009	2010	2011	2012	2013	2014	2015	2016	2020	2025	2030	2050	2080	2100
Motor	Build and test integrated motor/ generator													
Motor Cost		19 USD/kW		12 USD/kW					8 USD/kW					
Motor Specific Power		> 1.06 kW/kG					> 1.2 kW/kG		> 1.4 kW/kG					
Motor Power Density		> 2.6 kW/L					> 3.5 kW/L		> 4.0 kW/L					
Motor Efficiency		> 90%					> 93%		> 94%					
Converter														
Converter Cost		< 75 USD/kW					< 50 USD/kW		< 25 USD/kW					
Converter Specific Power		> 0.8 kW/kG					> 1.0 kW/kG		> 1.2 kW/kG					
Converter Power Density		> 1.0 kW/L					> 2.0 kW/L		> 3.0 kW/L					
Converter Efficiency		> 92%					> 95%		> 96%					
Battery														
Battery Capacity		30 kWh					40 kWh		40 kWh					
Battery Cost		USD 20/km					< 150 USD/kWh		100 USD/kWh					
Battery Power Density							460 W/L		600 W/L					
Battery Energy Density							150 Wh/kg		200 Wh/kg					
Battery Life		15 years					10 years		10 years					
EV Range														
Market Penetration														
Recharging Infrastructure														

JAPAN

Year	2009	2010	2011	2012	2013	2014	2015	2016	2020	2025	2030	2050	2080	2100
EV PHEV sales (gov. target) [sales%]									15 to 20[1]		20 to 30[1]			
EV Battery Energy density [Wh/kg]		100					150		250		500	700		
EV Battery Energy density [Wh/L]		250					400		600		1000	1500		
EV Battery Power density [W/kg]		1000					1200		1500		1000	1000		
EV Battery Power density [W/L]														
EV Battery Calender life [years]		5 to 8					8 to 10				10 to 15			
EV Battery Cost [JPY/kWh]		100k to 200k					30k		20k		10k	5k		
EV Battery Type						Li-ion						Revolutionary battery (e.g. Metal-air)		
HEV Battery Energy density [Wh/kg]		70					100		200					
HEV Battery Energy density [Wh/L]		200					250		500					
HEV Battery Power density [W/kg]					2000				2500					
HEV Battery Power density [W/L]														
HEV Battery Calender life [years]		5 to 8					8 to 10		10 to 15					
HEV Battery Cost [JPY/kWh]		100k to 200k					30k		20k					
HEV Battery Type						Li-ion								
Motor		efficiency improvement							SR motor					
Motor							In-wheel motor							
Inverter		Ultra Low Ron SiC device Low parastic impedence High power density assy.								High frequency HFET				
Infrastructure									Charger (normal) 2 million units[1] Charger (quick) 5k units[1]					
Infrastructure		Connector standardisation												
Infrastructure							Charge from house (200V) Discharge to grid (V2G)							

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Appendix II. Abbreviations and Acronyms

AER	PHEV all-electric range
BLUE Map	The energy policy scenario in IEA's Energy Technology Perspectives analysis that aims to achieve a 50% reduction in global CO_2 emissions from 2005 levels by 2050
BYD	Build Your Dreams
CAFE	corporate automotive fuel economy
CCS	carbon capture and storage
CO_2	cabon dioxide
E2W	electric 2-wheeler
ETP	IEA's Energy Technology Perspectives publication
EU	European Union
EV	battery electric vehicle
FCV	fuel cell vehicle
GHG	greenhouse gas
H_2	hydrogen gas
HEV	hybrid electric vehicle
ICE	internal combustion engine
IEA	International Energy Agency
IEC	International Electrotechnical Commissions
INR	Indian rupee
ISO	International Standards Organisation
LDV	light-duty vehicle
Li-ion	lithium-ion
MIIT	Ministry of Industry and Information Technology of China
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
R&D	research and development
RD&D	research, development and demonstration
RMB	Chinese yuan
SAE	Society of Automotive Engineers
SUV	sport utility vehicle
UL	Underwriters Laboratories
UN-ECE	United Nations Economic Commission for Europe
USD	United States dollars
V2G	vehicle-to-grid
VAT	value added tax

Units

kg	kilogram
km	kilometre
kWh	kilowatt-hour
L	litre
MPG	miles per gallon
W	watts

APPENDIX E. DELOITTE

Deloitte.

Gaining traction
A customer view of electric vehicle mass adoption in the U.S. automotive market

Opening

Is this the time for the electric car? Who is likely to buy these vehicles? ("If we build them, will buyers come?") What will Original Equipment Manufacturers (OEMs) need to do to make these vehicles acceptable for the mass market? These are challenging questions given the substantial investments automakers and suppliers will have to make in order to bring electric vehicles to the mass market. To answer these questions and others, Deloitte recently completed a proprietary market study that includes primary and secondary customer research and interviews with executives from major automotive OEMs, clean-tech start-ups, dealers, and energy companies. Our findings are presented in this report.

As the industry begins to recover from the effects of the 2008/2009 recession, quite a few factors are converging to make the idea of an electric vehicle (EV) more attractive than ever. Government tax credits, emission regulation and fuel economy standards, and unstable oil prices are contributing to a shift in both focus and attitude among industry leaders. Most of the major global OEMs have announced plans for vehicles powered by an electric motor with an on-board battery pack. Also, several start-up companies have announced their intentions to bring "pure" electric vehicles to market in the next 12 to 18 months. These announcements have generated great enthusiasm in the media and at recent auto shows.

Indeed, the future of the electric car looks good. But there are challenges. So far, most EVs have been powered by internal combustion engines (ICE) with supplemental electric motors and battery storage — in other words, they are not the true electric cars of the popular imagination. As a result, the size of the market opportunity has been difficult to gauge. How big is the potential demand? Who are the likely buyers of the electric car? At the same time, certain barriers need to be overcome before market adoption could achieve critical mass. These topics were the focus of our research:

- Market opportunity
- Target customers
- Barriers to adoption
- Market forecast

As used in this document, "Deloitte" means Deloitte Consulting LLP, a subsidiary of Deloitte LLP. Please see www.deloitte.com/us/about for a detailed description of the legal structure of Deloitte LLP and its subsidiaries.

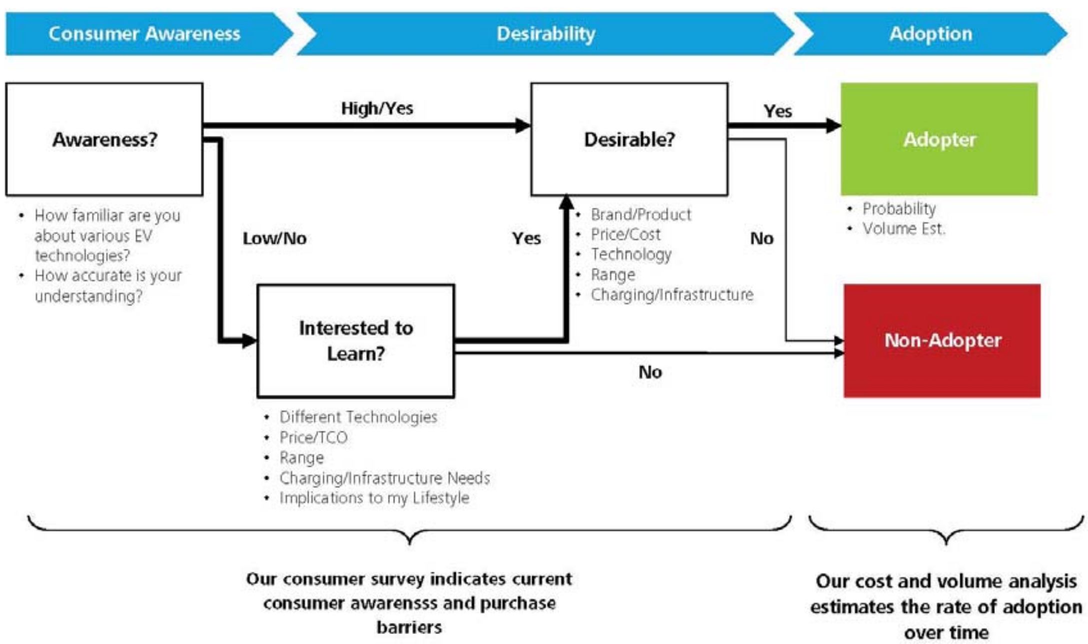
About our study

The analysis presented in this report comes from original primary and secondary research, including interviews with executives from major automotive OEMs, clean-tech start-ups, dealers, and energy companies, as well as a survey of nearly 2,000 current vehicle owners.

To this qualitative and quantitative data we applied Deloitte's Demand Driven Analytics Methodology (Figure 1) to assess the consumer's perspective about the future of electric vehicles in the U.S. market.

Assessing future demand for electric vehicles was somewhat challenging since it meant testing consumer preferences for a product with which they are largely unfamiliar. For this reason, we focused on uncovering consumers' familiarity with EV technologies and products; with their opinions around price, brand, range, charging, the infrastructure, and the cost of ownership; and with the consumer's imagined "fit" of an EV in his or her lifestyle given a range of demographic parameters.

Figure 1. Deloitte's demand driven analytics methodology

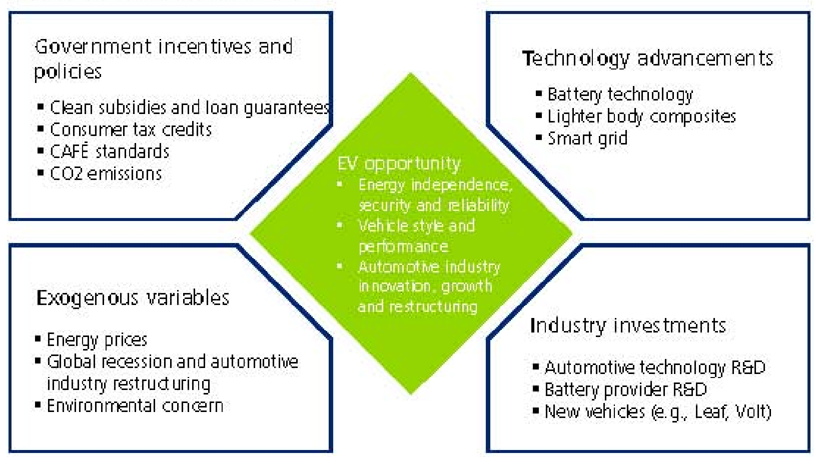


Market opportunity

Electric vehicles present a tremendous opportunity for the struggling, established automotive industry (Figure 2). They can enable the OEMs to respond to the growing public clamor for energy independence, security, and reliability since the grid is powered by multiple sources including coal, natural gas, nuclear power, and renewable sources. EVs are also introducing innovative body materials and styling, and today's electric motors deliver high performance and torque over a wide rpm range, which makes driving the new EVs a satisfying experience even when compared to traditional ICE vehicles.

But electric vehicles also pose a threat to OEMs, as they could lead to reconfigured value chains and massive industry restructuring. The threat is a complicated problem influenced by a wide range of factors including government policies and incentives, technology advancements in components such as batteries, and market forces including the price of gasoline.

Figure 2. Electric vehicle and activity drivers



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Target customers

Based on our research, we have created a profile of consumers most likely to buy electric vehicles (early adopters, see Figure 3) and those least likely to do so (non-adopters, see Figure 4) in the foreseeable future.

The early adopters will be a small number of buyers, nowhere near the volume needed for mass adoption. They will be young, high-income individuals who already own one or more vehicles. We expect early adoption to be centered in southern California primarily due to infrastructure investments already made in the region (and discussed later in this document).

On the other side of the spectrum are the non-adopters. These consumers tend to be highly insensitive to environmental matters and are rarely politically active. They live predominantly in suburban and rural areas and drive larger vehicles — SUVs and trucks — a relatively significant distance every week. Non-adopters are very price sensitive; with low household incomes (HHI), they view EVs as expensive. Since a relatively high percentage do not have garages, charging an EV could be difficult. These consumers would be poor targets for any EV marketing campaign and are unlikely to want to buy an EV unless prices dropped significantly and ranges expand to accommodate their typical driving distances.

Figure 3. Early adopter profile: 2011–2020

- Similar to early adopters of hybrids, early adopters of EV's will be young, very high income individuals — adoption is already being popularized by high-profile celebrities
- Average incomes are expected to be in excess of $200K HHI who already own one or more vehicles
- Early adoption will be concentrated around southern California where weather and infrastructure allow for ease of EV ownership

Source: Deloitte survey, interviews and analysis

Figure 4. Non-Adopter profile

EV perception	Top purchase influencer	HHI	Gender	Location	Garage	Miles per week
"Expensive"	Price	$54K	49% Male	Suburban and rural	36% no garage & power	600

The early majority

Eventually, mass adoption will be spurred by the development of competitive offerings. We refer to consumers coming on board at this time as the "early majority" and would include those individuals who are the most likely to buy immediately after the "early adopter" wave.

These consumers have a very distinct profile (Figure 5), beginning with a much higher-than-average HHI at $114K. They tend to reside in urban or suburban areas, but nearly 90 percent have garages with electrical power (which resolves the challenge of charging the EV). Their weekly mileage is low — about 100 miles. Environmentally sensitive, they perceive an EV as "green and clean;" they are concerned about U.S. dependency on foreign oil and are politically active. Finally, this group is willing to pay a premium for convenience.

Among the U.S. population, about 1.3 million people fall into this segment. Among these, the most likely "early majority" are men and women ages 40 to 44. This group is the most likely target for electric vehicles.

Figure 5. Early majority profile

EV perception	Top purchase influencer	HHI	Gender	Location	Garage	Miles per week
"Green and clean"	Reliability	$114K	67% Male	Urban and suburban	88% have garage & power	100

Early Majority Population & Volume Potential

- Given a few key demographic and psychographic attributes of the mass adopter segment we can approximate the segment's population size
  - Men represent 49% of the total population and 67% of this segment
  - 13.4% of men have an income of $100K or more
  - 12.3% of Households have an income between $100K to $150K
  - 44.9% of men vote, 44.5 % of women vote
- There are 1.3 million men and women in the U.S. who have the demographic characteristics in the Early Majority segment

Source: U.S. Census

Barriers to adoption

Our research indicates that a sizeable demographic segment of U.S. consumers would consider buying an electric vehicle; however, we also identified barriers to mass adoption.

In our survey we asked consumers which variables would encourage them to buy an electric car (Figure 6) and which would discourage them from doing so (Figure 7). The top four factors in the "pro" column are price, reliability, cost to charge, and convenience to charge. If these four are favorable, the consumer's attitude toward the EV would be positive. The top three variables in the "con" column are price, range, and size of the vehicle.

Figure 6. Factors encouraging Survey Respondent EV purchase

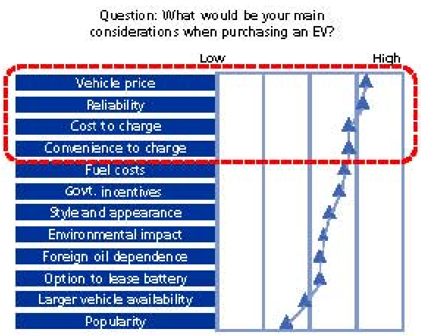
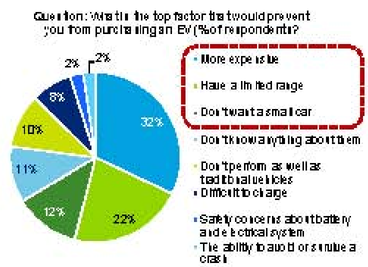


Figure 7. Factors discouraging Survey Respondent EV purchase



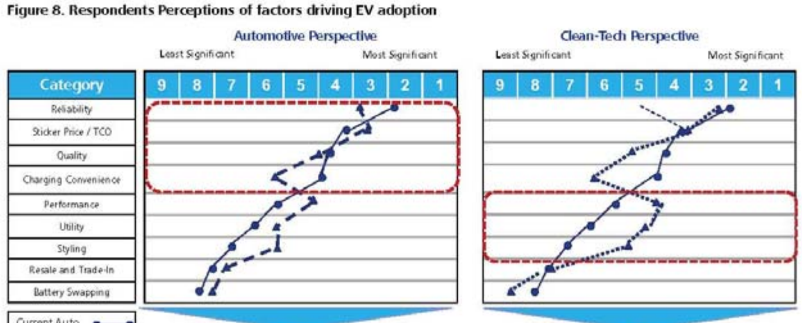
We also interviewed executives from major automotive OEMs, clean-tech start-ups, dealers, and energy companies. In these inquiries, we noticed an interesting trend: at this time, the leaders of traditional automotive OEMs seem to have a closer, clearer understanding of customer surveyed concerns than do executives from clean-tech start-ups surveyed (Figure 8).

For example, clean-tech executives surveyed think that quality and charging convenience are less important than performance and styling to consumers. But, our research indicates that, potential buyers aren't concerned with those factors at this point; right now, their concerns are more basic. Auto executives surveyed realize something clean-tech executives do not: U.S. consumers are accustomed to a certain type of automotive experience. For EVs to become popular, they must mimic the experience and performance that drivers have become accustomed to.

Synthesizing all this quantitative and qualitative data, we have identified six potential barriers to the mass adoption of electric vehicles:

- Familiarity
- Brand
- Range
- Charging
- Infrastructure
- Price and cost of ownership

Figure 8. Respondents Perceptions of factors driving EV adoption



- Automotive executives surveyed believe that charging convenience will become less significant in 5 years due to a more extensive charging infrastructure
- They are relatively aligned with customers

- Clean-Tech companies surveyed are less concerned about charging convenience than automobile companies
- They believe performance, utility and styling will be key drivers of mass adoption
- They are less aligned with customers

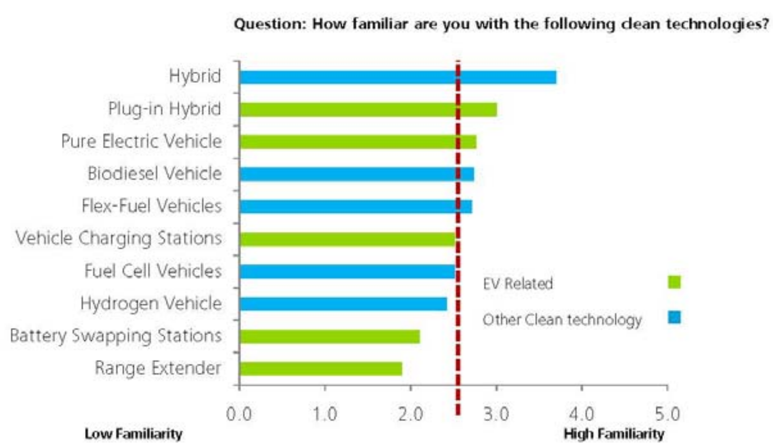
Barriers to adoption

A. Familiarity

We discovered that customers are largely unfamiliar with alternative fuel technologies other than hybrids (Figure 9). It's natural that they would be hesitant in their enthusiasm for something they know nothing about. Furthermore, their familiarity (and subsequent comfort) with "hybrid" vehicles comes from massive education efforts by a few automobile manufacturers — efforts already 10 years underway at a cost of more than $1 billion.

Electric vehicles represent an even more radical departure from ICE vehicles than did hybrids; public acceptance will require more education about issues such as charging, ranges, and the driving experience itself. Messaging will need to focus on "educating" and "correcting" because many people have wrong preconceptions about EVs. For these reasons, it's highly likely that educating customers on EV technologies will cost even more than it did for hybrids.

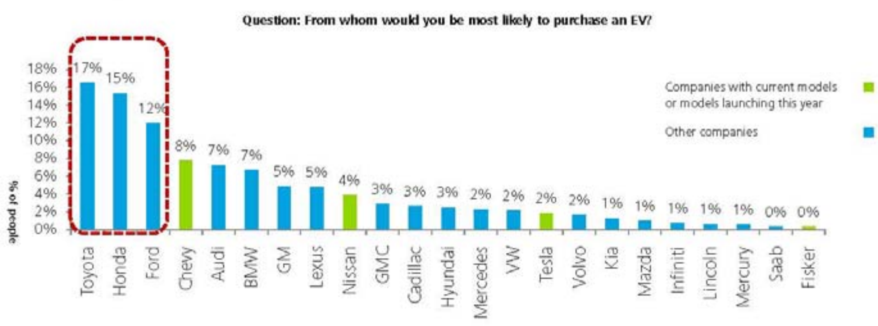
Figure 9. Customer Surveyed Familiarity



B. Brand

Experience tells us that when it comes to automotive purchases, consumers are brand-driven; we believe they will buy EVs only from a brand they trust (Figure 10). Our study indicates that Toyota, Honda, and Ford have brand "permission" in this space due in part to the "green equity" they have built with their hybrid vehicles. We think that EVs from these three OEMs will have the highest likelihood of success. As a corollary, Nissan and Chevrolet will likely face challenges in their upcoming EV launches. As first-to-market products, their vehicles will bear the cost and burden of educating consumers.

Figure 10. Brand preference

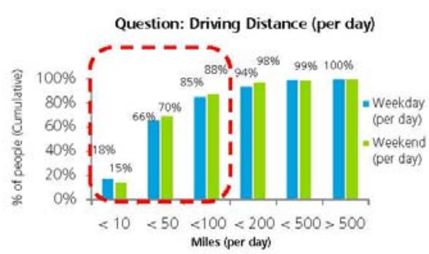


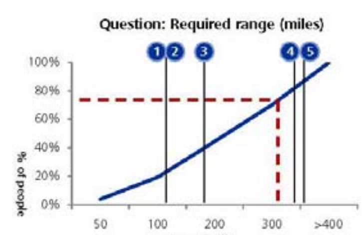
C. Range

Even though EVs meet the daily range requirements of most drivers, range anxiety is pervasive amongst our survey participants. Technically a 50-100 mile electric range would meet the daily driving requirements of most customers, a statistic that clean-tech executives focus on. But our research indicates that consumers aren't comfortable with that range. Most expect a minimum range of 300 miles before they would consider an EV (Figure 11).

Essentially, consumers want the equivalent range of an ICE vehicle on a tank of gas. This gap is important: customers want the freedom and convenience they associate with a full tank of gas. They want the convenience and peace-of-mind knowing they can make from point A to point B without the worry of running out of fuel/energy.

Figure 11. Survey Respondent's Driving distance, per day and required





Travel distance

- On weekdays and weekends, few consumers surveyed travel more than 100 miles per day
- EVs with a range of 50 miles could meet the daily needs of 66% of drivers on weekdays, and 70% on weekends

Range anxiety

- 70% of drivers surveyed would expect an electric vehicle to travel 300 miles before they would consider purchasing one
- Current EVS vary Considerably in their range
- Nissan Leaf: 100 miles (electric)
- Ford Focus: 100 miles (electric)
- Tesla Model S: 160 miles (electric)
- Chevy Volt: 40 miles (electric) + 300 (combustion)
- Fisker Karma: 50 miles (electric) + 300 (combustion)

D. Charging

Our survey results indicate that consumers want to be able to charge at home and have the convenience of rapid charging stations. Eighty-one percent of surveyed consumers would prefer to charge from home, but 61 percent don't have access to home-charging capabilities, such as a garage with an electric power source.

Relatively few (only 17 percent) would be willing to spend eight hours charging their vehicle at home (fully recharging depleted PHEV/EV batteries can take 2 to 8 hours, depending on the type of charging equipment and battery size). However, if the charging time is reduced from eight hours to four, consumer willingness doubles. Sixty-nine percent would be willing to pay up to $1,000 for a vehicle that charges faster (Figure 12), but no more than $1,000.

Further, 54 percent of surveyed consumers would not consider purchasing an EV until charging locations are widely available and as easy-to-locate as a gas station is today. Currently, there are fewer than 500 stations in the United States, with more than 80 percent of these in California (Figure 13). Clearly, increasing public and private infrastructure will be necessary before the EV can be widely adopted. In fact, widespread charging stations could be a key enabler to the EV. But the cost would be significant. A station that can service 100 customers in a 24-hour period at 50kWh per charge would cost $1.8 to $3.0 million. While the current climate is not strong enough to attract enough private investment, Pike Research predicts that the infrastructure will expand and that by 2015 there will be 5.3 million charging stations globally.

But the real question to us with regard to changing is this: Would consumers be willing to adapt to any charging time? As one auto executive we interviewed said, *"You need an electric car that can recharge in five minutes — that's how a gas station works."*

A proposed alternative to rapid charging stations is battery swapping stations; 79 percent of surveyed consumers would consider battery swapping as an alternative to charging their vehicle at home (Figure 14). But technical barriers and other challenges (Figure 15) make this a less-than-ideal option.

Figure 12. Charging time Survey Responses

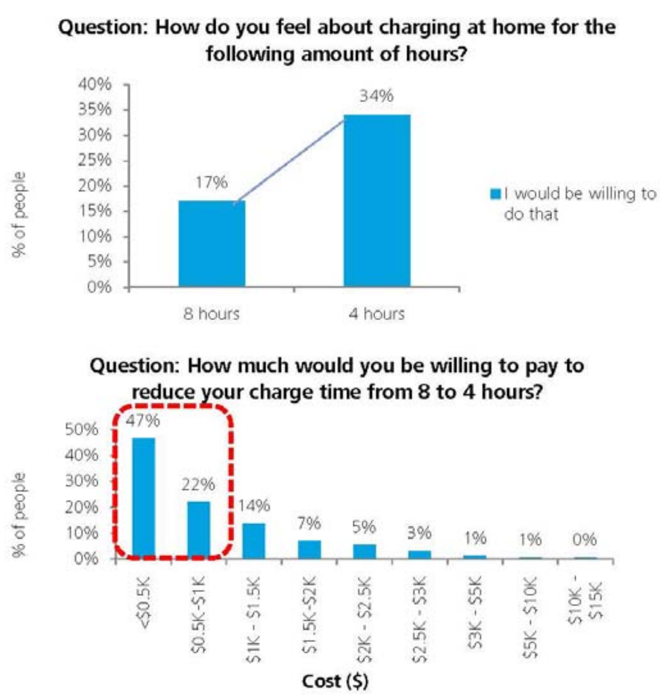


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Figure 13. Charging location Survey Responses

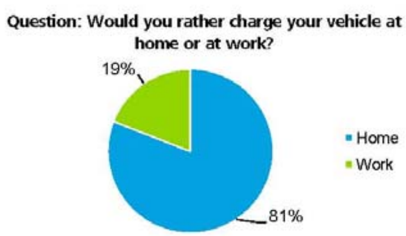


Figure 14. Battery swapping Survey Responses

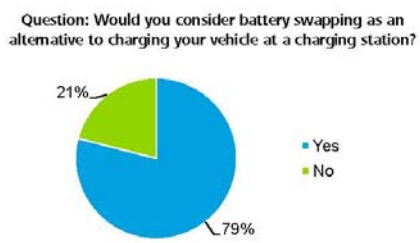


Figure 15. Barriers to battery swapping Survey Responses

Barriers to Battery Swapping

While consumers are open to battery swapping to avoid charging (79% of people surveyed): there are many limitations:

- **Cost:** Each battery swapping station may cost as much as $500K
- **Standardization:** Battery Swapping requires battery standardization
- **Tragedy of the Commons:** Consumers will have the incentive to treat their batteries poorly, knowing they will swap with someone else

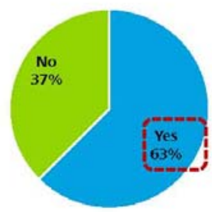
E. Infrastructure

Our research indicates that consumers are anxious about the availability and convenience of infrastructure to support electric vehicles (Figure 16). Another potential concern involves charging times, which tend to be between 6:00 p.m. and 10:00 p.m., potentially putting a heavy strain on the power infrastructure, particularly in areas not equipped to handle this type of load.

Yet, industry insiders we interviewed believe that improvements will be forthcoming. The government has shown willingness to fund the first $100 million of infrastructure [need to cite source], but building out more extensively will require a much larger investment. Power industry forecasts indicate that the smart grid, with digital real-time metering, should be ready by 2015. But the energy industry will need to do a better job of increasing customer awareness.

Figure 16. Survey Responses Concerns about the grid

Question: Are you concerned about the capacity and reliability of your local utility to support electric vehicle charging?



F. Price and cost of ownership

The greatest factor that will drive or prevent adoption is price.

Sixty-nine percent of consumers surveyed consider price the most important factor in a vehicle purchase, and most of them expect to pay less than $30K for an EV (Figure 17). Twenty-three percent say the price of gasoline would be a deciding factor, a finding that suggests the importance of more consumer education about EVs and their total cost of ownership. As one automotive executive we interviewed said, "Customers will buy an EV if the cost is comparable to an ICE vehicle; if it's more they won't buy it. People will not sacrifice themselves to save the environment."

When we did a sensitivity analysis on key costs (Figure 18), we discovered that the perceived operating benefits of an EV are sensitive to battery costs and gas prices. In fact, these are likely key parameters in determining the timing and degree of adoption.

For example, Figure 19 shows the projected cost per kWh for lithium ion batteries over time: technology is driving the cost down, but the decrease is slow. Battery costs will have to decrease 40 percent for EVs to be at par with ICEs in total cost of ownership. Since both gas prices and battery costs will inhibit adoption, OEMs will likely need to spend a lot in incentives to sell EVs in the next two to three years. At $3/ gallon for gas, ICEs are more economical to operate; the EV will not be comparable until battery costs are $600 or less per kWh (Figure 20), which could occur by 2014, at which time EV adoption will pick-up (assuming fuel costs remain stable).

Figure 17. Price in the purchasing decision of Respondents

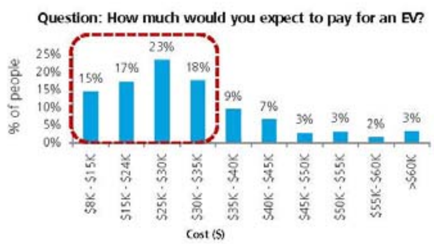


Figure 19. Li-ion Battery Cost/kWh

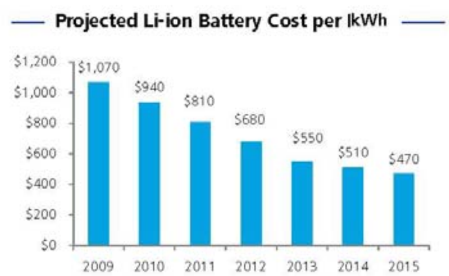
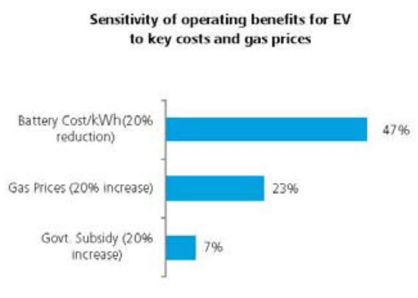


Figure 18. Sensitivity benefits vs. costs



Note: the base line values for the analysis are: Battery cost /kWh = $1100, Gas price = $3.00 per gallon), and Govt. Subsidy = $4000 per EV

Figure 20. Operating benefit over ICV

Approx. 2010 Battery Cost

Gas Price ($)	Battery cost / kWh ($): $1,000	$900	$800	$700	$600	$500
$3.00	-$1,675	-$1,175	-$675	-$175	$325	$825
$3.25	-$1,525	-$1,025	-$525	-$25	$475	$975
$3.50	-$1,375	-$875	-$375	$125	$625	$1,125
$3.75	-$1,225	-$725	-$225	$725	$775	$1,275
$4.00	-$1,075	-$575	-$75	$425	$925	$1,425
$4.25	-$925	-$425	$75	$575	$1,075	$1,725
$4.50	-$775	-$275	$225	$725	$1,225	$1,725
$4.75	-$725	-$125	$375	$875	$1,375	$1,875
$5.00	-$475	$25	$525	$1,025	$1,525	$2,025

EV has an Operating Benefit over ICV

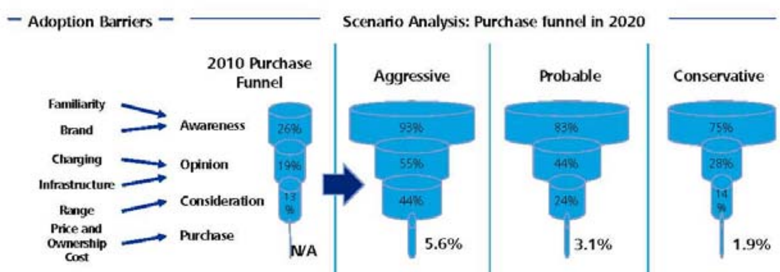
Market forecast

Based on our research, we estimate that in 2020 electric vehicles will account for 3.1 percent of total automotive sales in the U.S. market (Figure 21) or approximately 465K units.

We also expect with volume increasing, many OEMs will enter the market, and that consequently, the market share per OEM will shrink: assuming five OEMs in 2015 making electric vehicles, each OEM will sell only 12,000 units a year on an average. This volume does not appear to be sufficient to push the cost of the battery lower.

In 2020, even with the volume at 465,000 units, each OEM will have only about 93,000 units (Figure 22). If each of the five OEMs has three models, then EV production per model will be only 30,000. At this small volume OEMs will be challenged in recovering the cost of their infrastructure investments, and each OEM will face significant cost pressures.

Figure 21. Purchase funnel analysis for 2020 market

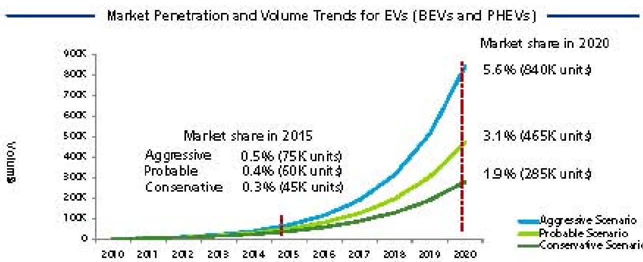


Purchase Price	Low ($25K)	Medium ($35K)	High ($45K)
Range	High (350 miles)	Medium (200 miles)	Low (100 miles)
Gas Price	High ($4.5/gal)	Medium ($3.5/gal)	Low ($3/gal)

NOTE: 1) Analysis considered BEVs and PHEVs only. 2) Current funnel is derived based on the customer survey. The 2020 purchase funnel is based on sensitivity of consideration to purchase price and range within customer clusters and the purchase funnel metrics for Hybrid adoption 3) The U.S. light vehicle volume for 2020 is assumed to be 15 million.

Sources: Deloitte analysis, primary research; GfK Automotive Purchase Funnel Benchmarks, Jan 2010

Figure 22. Market penetration and volume trends for EVs



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Sources: Deloitte analysis, primary research; GfK Automotive Purchase Funnel Benchmarks, Jan 2010

Conclusions

Electric vehicles are attractive to customers, the automotive industry, and the country. In the U.S., approximately 1.3 million consumers fit the demographic and psychographic profiles of potential "early majority" EV customers. The challenge to the industry at this point is overcoming the six barriers to adoption. We expect that mass adoption will be gradual — roughly 3 percent by 2020 — and that complementary technologies will continue to gain acceptance.

Consumer perspective

EVs bring performance and styling improvement opportunities for automakers. However, range anxieties will be a significant barrier to adoption until technology can address the issue. We conclude that the keys to mass adoption are 1) a reduction in price and 2) a driving experience in which the EV is equivalent to the internal combustion engine vehicle.

Automotive industry

Clean-tech investments are accelerating, supported by government incentives. Because of their investments in hybrids, three OEMs — Toyota, Honda, and Ford — appear to be well positioned in the emerging EV market. We expect that new EV introductions will broaden awareness, build excitement, and boost messaging/imaging. However, given our forecasted volume of 465,000 units across 15 brands/models in 2020, we believe achieving profitability and manufacturing efficiencies will be a challenge.

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APPENDIX F. THE RECOVERY ACT

DEPARTMENT OF ENERGY

THE RECOVERY ACT:

TRANSFORMING AMERICA'S TRANSPORTATION SECTOR

BATTERIES AND ELECTRIC VEHICLES

WEDNESDAY, JULY 14, 2010

Embargoed until 8:00 PM EDT

The Recovery Act:
Transforming America's Transportation Sector

Batteries and Electric Vehicles

The Obama Administration is investing in a broad portfolio of advanced vehicle technologies. These investments—investments in American ingenuity, innovation, and manufacturing—are driving down the costs associated with electric vehicles and expanding the domestic market. Investments in batteries alone, for example, should help **lower the cost of some electric car batteries by nearly 70 percent before the end of 2015.** What's more, thanks in part to these investments, **U.S. factories will be able to produce batteries and components to support up to 500,000 electric-drive vehicles annually by 2015**. Overall, **these investments will create tens of thousands of American jobs.**

As part of the Department of Energy's $12 billion investment in advanced vehicle technologies, the Department is investing more than $5 billion to electrify America's transportation sector. These investments under the American Recovery and Reinvestment Act and DOE's Advanced Technology Vehicle Manufacturing (ATVM) Loan Program are supporting the development, manufacturing, and deployment of the batteries, components, vehicles, and chargers necessary to put millions of electric vehicles on America's roads.

The Recovery Act included $2.4 billion to establish 30 electric vehicle battery and component manufacturing plants and support some of the world's first electric vehicle demonstration projects. For every dollar of the $2.4 billion, the companies have matched it at minimum dollar for dollar. Additionally, DOE's Advanced Research Projects Agency-Energy (ARPA-E) is providing over $80 million for more than 20 transformative research and development projects with the potential to take batteries and electric drive components beyond today's best technologies, and the Advanced Energy Manufacturing Tax Credit program is helping expand U.S.-based manufacturing operations for advanced vehicle technologies.

The Obama Administration has also provided nearly $2.6 billion in ATVM loans to Nissan, Tesla and Fisker to establish electric vehicle manufacturing facilities in Tennessee, California and Delaware, respectively.

Projects have now begun constructing new manufacturing plants, adding new manufacturing lines, building electric vehicles, and installing electric vehicle charging stations, creating thousands of new jobs across the country. These combined investments are helping the economy grow now, while positioning the U.S. for global leadership in the electric vehicle industry for years to come.

Recovery Act Investments in Electric Vehicles

Through the Recovery Act, the country is making comprehensive investments in each part of the electric vehicle ecosystem. In sum, the Act included approximately $4 billion to support domestic manufacturing and deployment for advanced vehicle and clean fuel technologies. To date, there have been over 70 awards, worth more than $2.5 billion, to promote electric vehicle technologies. This includes cost-shared projects at each level along the innovation chain – from battery and component manufacturing to commercial deployment of vehicles and charging stations to advanced research and development that will help identify the next generation of electric vehicle technologies.

- **Manufacturing –** 26 of 30 battery and component manufacturing plants have started construction, which includes breaking ground on new factories or installing new equipment in existing facilities.

    - 9 battery manufacturing projects, including a $249 million project by A123 to support the construction of 3 Michigan facilities to produce advanced batteries for vehicles, grid storage, and other applications. They have already started construction of a low-volume manufacturing facility in Livonia, which they expect to begin operations in September, and have begun planning for larger-volume facilities in Romulus and Brownstown, Michigan. Nine of the nine new battery plants opening as a result of Recovery Act investments will have started construction by tomorrow – and four of those will be operational by the end of the year.

    - 11 battery component manufacturing facilities, including Celgard LLC in North Carolina, who won a $49.2 million grant to expand its production capacity for separators, a key component in the lithium-ion batteries needed for the growing electric drive vehicle market. When Celgard completes expanding its facility in Charlotte, North Carolina, the company will be able to produce an additional 80 million square meters of separator per year—enough to support up to a million electric-drive batteries per year. Celgard is also building a new manufacturing facility in Concord, North Carolina to support additional increased demand for electric vehicle batteries.

    - 10 electric drive component manufacturing projects, including Delphi Automotive Systems, the largest North American supplier of power electronic components for electric vehicles. The company received $89.3 million in Recovery Act support to build a power electronics manufacturing facility in Kokomo, Indiana. The plant will have the production capacity to support at least 200,000 electric drive vehicles by the end of 2012.

- **Deployment –** 8 innovative demonstration projects, representing the world's largest electric vehicle demonstration to date. In total, these projects will lead to an additional 13,000 grid-connected vehicles and 20,000 charging stations in residential, commercial and public locations nationwide by December 2013**.**
    - Coulomb Technologies received a $15 million Recovery Act grant to support the ChargePoint America program, which will deploy 5,000 residential and commercial charging stations and 2,600 electric drive vehicles in nine major metropolitan areas around the country.
- **Advanced Research and Development** - More than 20 breakthrough research projects to support potential game-changing technologies like semi-solid flow batteries, ultracapacitors and "all-electron" batteries that could go well beyond today's best lithium-ion chemistries are being funded. **If successful, these breakthroughs could cut battery costs by as much as 90 percent and expand vehicle range three to six-fold.** In turn, this would decrease the upfront cost of electric cars to roughly that of gas-powered cars and give them a longer range, likely further increasing demand for the vehicles in the long-term.
    - Fluidic Energy won $5 million to pursue "metal air" batteries that could have 10 times the energy density of today's lithium-ion technologies, at a third of the cost. The Scottsdale, Arizona company is working with Arizona State University to develop ultra stable new materials, or "wonder fluids" that could allow metal-air batteries to be successfully developed and deployed for the first time, enabling widespread deployment of low cost, very long range electric vehicles.

Taken together, the impact of these investments is greater than the sum of their parts. The investments interact to stimulate both supply and demand for electric vehicles. The investments are lowering barriers to ownership: driving down the cost of batteries while improving their functionality and building a network of charging stations. Meanwhile, they are actively putting more electric cars on the road and supporting the long-term domestic production of low-cost, clean energy vehicles.

Federal investments in electric vehicles are being matched by private sector funding, helping to move private capital off of the sidelines. This combination of private and public investments in advanced vehicles is stimulating economic growth, creating jobs in both the short- and long-term, and increasing the country's global competitiveness.

These jobs represent a shift—the shift of important industries moving jobs back to American shores and the growth of a domestic battery industry. The Recovery Act is laying the groundwork for long-term, sustainable recovery by ensuring that the industries of the future are American industries. In 2009, the United States had only two factories manufacturing advanced vehicle batteries and produced less than two percent of the world's advanced vehicle batteries. By 2012, thanks in part to the Recovery Act, 30 factories will be online and the **U.S. will have the capacity to produce 20 percent of the world's advanced vehicle batteries. By 2015, this share will be 40 percent.**

This shift has additional benefits, too. Today, oil provides 95% of the power to move America's cars, trucks, ships, rail, and planes, and over half of America's oil is imported. Electric vehicles and other advanced vehicle technologies can reduce this dependence and help the country control its energy future.

Electric Vehicle Supply Chains and Networks

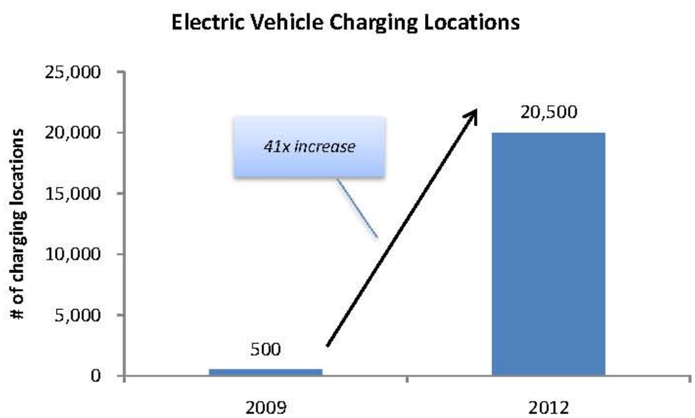
Through the Recovery Act and the ATVM program, DOE is invigorating a nationwide advanced vehicle supply chain centered in the Midwest. Michigan is an example of how clusters can multiply the impact of Recovery Act funds and create synergies within and across corporate walls. A concentration of Michigan's engineers, workers, and managers are innovating more quickly because they are near one another – and drawing in more and more advanced vehicle expertise each day.

The Recovery Act is supporting 14 vehicle awards in Michigan. This includes several large battery factories (e.g. A123, GM, Johnson-Controls, Dow-Kokam, and LG Chem), electric drive component factories (e.g. GM, Ford, Magna), and three workforce training programs (University of Michigan, Michigan Technological University, and Wayne State). Under the Department's loan program, DOE is supporting multiple Michigan-based factories that will hire the workers trained in these universities to assemble the batteries and components into some of the world's most advanced vehicles.

For example, a $105 million grant to GM is expanding a facility to package batteries for the Chevy Volt – the grant is creating hundreds of jobs at the Brownstown facility and invigorating a chain of local factories. GM will deliver batteries from Brownstown to a plant in Detroit. Here, hundreds of workers will assemble components made in Warren, Grand Blanc, and three factories in Flint. This network of Volt-related investments is attracting other companies to Michigan. To supply battery cells to the Brownstown facility, Compact Power, Inc. is building its first American factory in Holland, Michigan. The $151 million grant is helping Compact hire workers in Holland and purchase battery components and supplies from U.S. factories. Compact will purchase its separator material from Celgard, and is evaluating other Midwestern suppliers for its other components like cathodes, electrolytes, additives, and binders.

Meanwhile, under the Recovery Act's Transportation Electrification program, grantees will deploy 20,000 additional electric charging locations, up from 500 locations today. These 8 demonstration projects are also putting 13,000 electric vehicles on the road, including more than

4,700 Chevy Volts, across more than a dozen cities to show how electric cars perform under real driving, traffic and weather conditions.



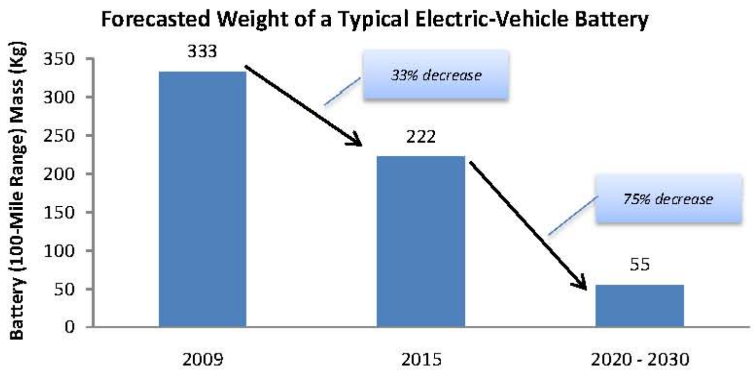
Innovation in Batteries

The Obama Administration's investments in advanced vehicles are creating a sustainable future for American industry and American workers. But investments in batteries demand special attention. The lack of affordable, highly-functional batteries has been a particularly high barrier to the widespread adoption of electric vehicles. When the Recovery Act passed, batteries were too costly, too heavy, too bulky and would wear out too quickly. Recovery Act investments are literally reshaping electric batteries and reshaping the economics of battery production and distribution.

More Affordable

Before the Recovery Act, the only highway-enabled electric vehicle on the road cost more than $100,000. This high cost resulted in large part from the high cost of batteries—a car with a 100 mile range required a battery that cost more than $33,000.

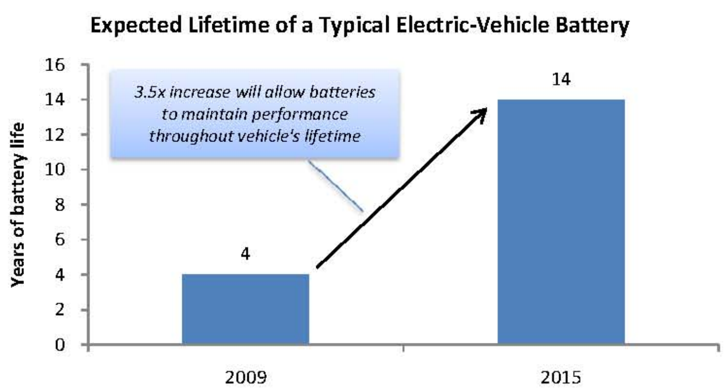
Between 2009 and 2013, the Department of Energy expects battery costs to drop by half as 20 Recovery Act-funded factories begin to achieve economies of scale. By the end of 2013, a comparable 100 mile range battery is expected to cost only $16,000. By the end of 2015, Recovery Act investments should help lower the cost of some electric car batteries by nearly 70 percent to $10,000. The same cost improvement applies to plug-in hybrids – cars that can travel roughly 40 miles on electricity before their gasoline engine kicks in. The cost of a 40-mile range battery is falling from more than $13,000 in 2009, to roughly $6,700 in 2013, to $4,000 in 2015.



Note: Assumes 3 miles per kilowatt hour and 100-mile range. Source: U.S. DOE Vehicle Technologies Program.

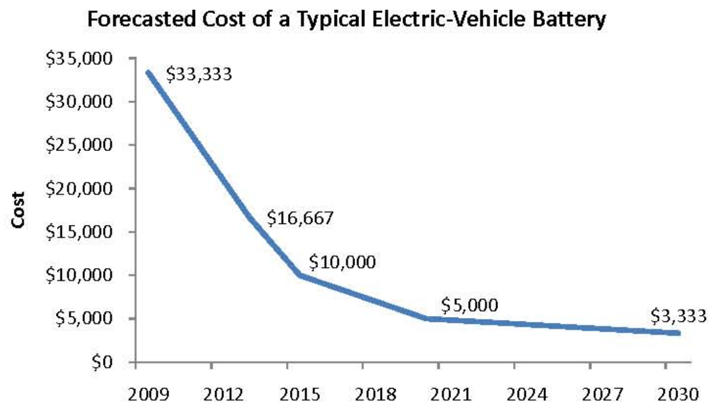
Longer Lasting

Batteries are also getting more durable. In the next few years, domestic manufacturers should be able to produce batteries that last up to 14 years. This should give consumers confidence that electric vehicle batteries will last the full life of the vehicle. In addition, longer lasting batteries reduce the potential for used batteries to become waste material.[1]



Note: Assumes drivers will charge their vehicles 1.5 times per week. Source: U.S. DOE Vehicle Technologies Program.

[1] Calendar life is assumed for advanced electric vehicle battery technologies. Current batteries for PHEV vehicles are designed to achieve significantly higher calendar life, but trade-off performance and cost to achieve that life.



Note: Assumes 3 miles per kilowatt hour and 100-mile range. Source: U.S. DOE Vehicle Technologies Program.

This dramatic drop in cost should result in more affordable, mainstream electric cars. Fisker, GM, Nissan, Tesla, and other automakers are introducing more affordable electric vehicles. At the end of this year, consumers will be able to purchase electric vehicles that cost between $25,000 and $35,000, after tax credits. In addition, drivers will save money over a car's lifetime. Using electricity to power a car is only about 30 percent of the cost of using three-dollar-a-gallon gasoline.

Lighter Weight

Low energy density, i.e. heavier batteries, significantly limits vehicle range and acceleration. Under the Recovery Act, DOE is supporting innovations to reduce battery weight and increase the energy density, which allows batteries to store more energy in a smaller, lighter package. These smaller, lighter batteries will pack **more power, performance, and range.**

Between 2009 and 2015, increases in energy density will reduce the typical weight of an electric vehicle battery by 33 percent. Meanwhile, ARPA-E projects are pursuing innovations that have the potential to improve battery density up to six times its current level.

WORK ORDER 15: OPERATION AND CONTROL ALTERNATIVES FOR THE PORT ARANSAS FERRY

INTRODUCTION

At the request of the Corpus Christi District of the Texas Department of Transportation (TxDOT), the Texas Transportation Institute (TTI) performed an analysis of alternative means to control pre-boarding management for Port Aransas Ferry operations. This analysis represents the second and final stage of several analysis steps intended to provide results and associated insights into the complete storage, management, and traffic control of vehicles approaching and using the ferry system on both the City of Port Aransas (Mustang Island) and mainland (Harbor Island) approaches to the Corpus Christi Channel.

A previous analysis (1) performed as part of this investigation examined traffic control options using the existing physical layout of landings on each side of the Corpus Christi Channel, as well as the impacts of the impending introduction of new, larger ferry boats into Port Aransas Ferry service. This phase of the investigation extends that analysis to reconfigure the pre-boarding storage areas within both the Harbor and Mustang Island landings, as well as examine the queue-storage impacts of providing a bi-level queuing scheme on Mustang Island.

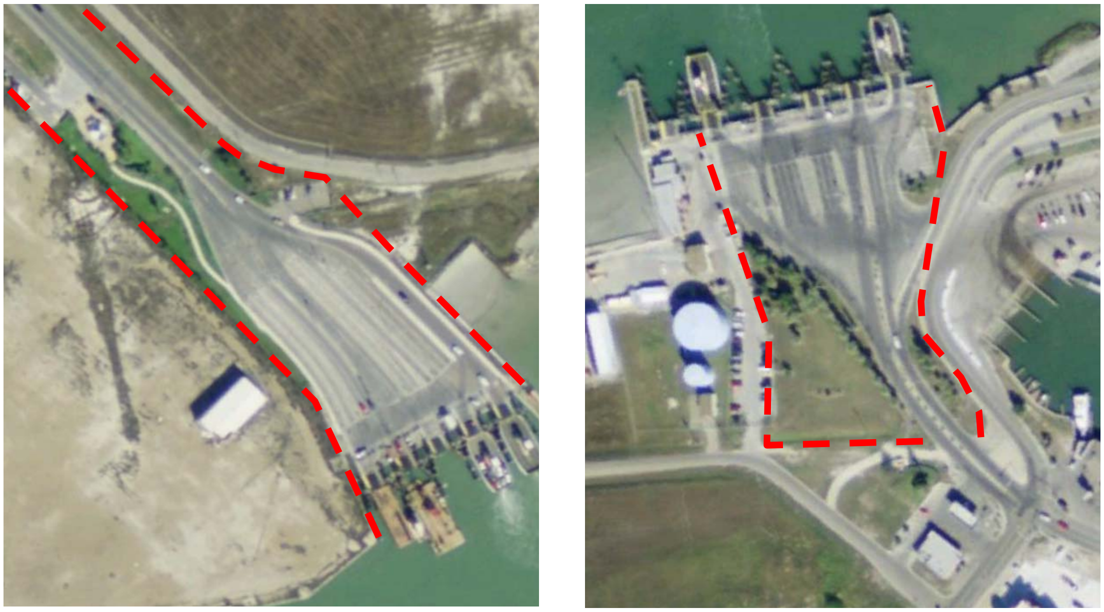
BACKGROUND

Figure 4 depicts the ferry landing and crossing environment for the Corpus Christi Channel. Details about ferry operations can be found in previous reports (1, 2, 3); of interest in the current phase of this investigation is the physical layout of the landings. Figure 5 provides a more detailed aerial view of each landing, and annotated lines show the rough boundary of property limits available for landing reconfiguration on each side of the channel.

Reconfiguration and semi-automation of the Port Aransas Ferry landing on Harbor Island has been proposed by the Traffic Operations Division of TxDOT; plan details are found in Figure 6. The new control plan arranges side-by-side signal approach and departure lanes for each ramp. Loading and unloading conflicts are removed from the ramp vicinity, as the paths of vehicles loading and unloading from any given boat do not cross one another or the paths of vehicles entering or exiting any other boat. Traffic signals are used to indicate to motorists when and which of the ramp pre-boarding lanes to enter, and when it is time to enter the ferry from the pre-boarding lanes. A merging area does exist as vehicles depart the exit lane for each ramp, as these vehicles cross paths with vehicles entering the pre-boarding lanes and must merge with vehicles departing other ferry exit lanes. The traffic signal controlling vehicle entrance to the pre-boarding lanes can be used to eliminate the entry/exit crossing conflict; the merge conflict with other departing vehicles could be managed by traffic director or additional signals.

Figure 4. Port Aransas Ferry/SH 361 at Corpus Christi Channel.

(Source: Google™ Earth; accessed 8/19/2010)



Harbor Island Mustang Island

Figure 5. Port Aransas Ferry Landings.

(Source: Adapted from Google™ Earth; accessed 10/28/2010)

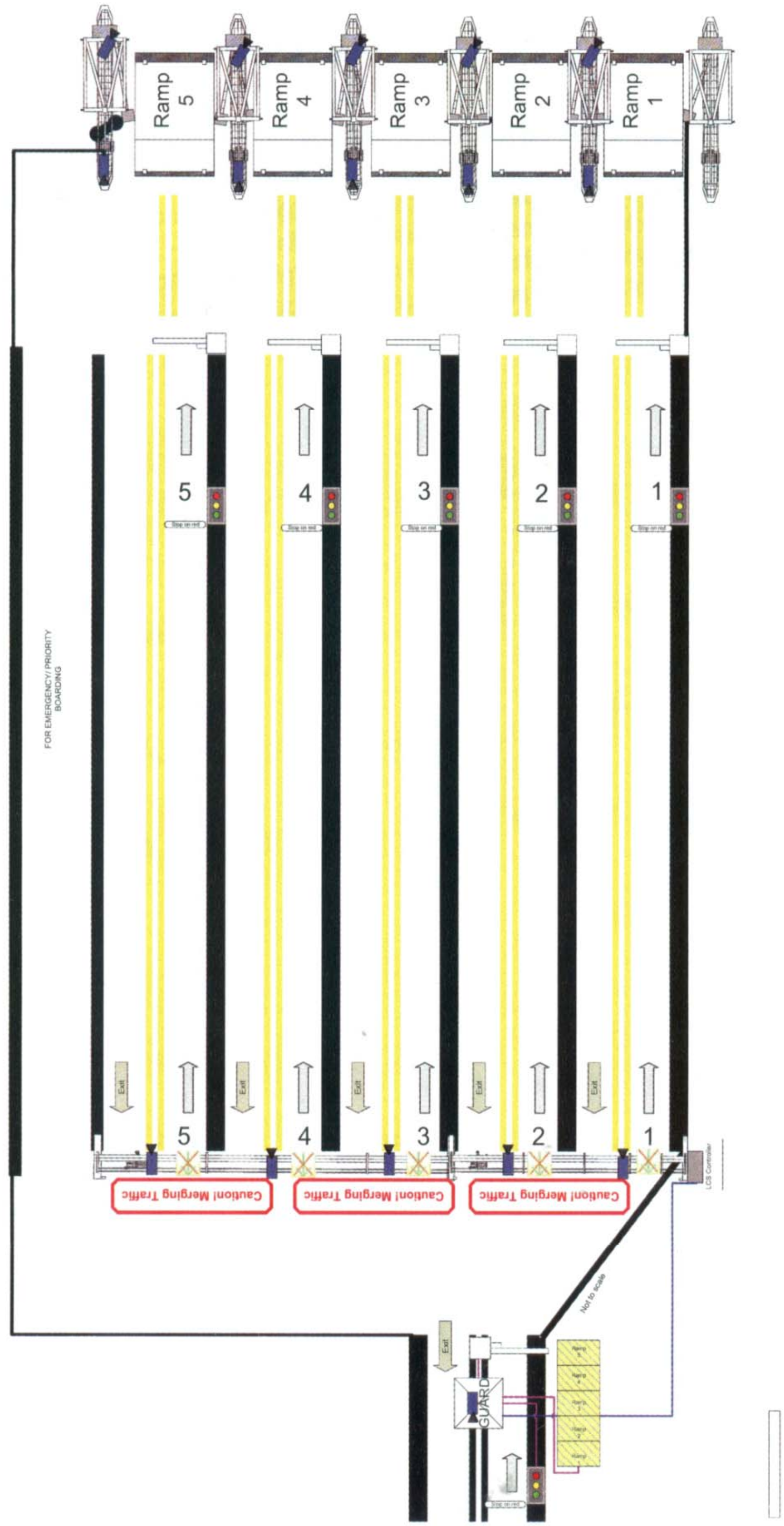


Figure 6. TxDOT-Proposed Semi-Automation Plan for Port Aransas Ferry Landings.

In addition to possible signal control of ferry loading, additional planned improvements are underway for improving the efficiency of the Port Aransas Ferry system. The first of these changes is the addition of two new and larger ferry boats in everyday operation. Rather than carrying a maximum load of 20 passenger vehicles, the new boats will be able to carry a maximum of 28 passenger vehicles (Figure 7). In addition, the new boats will have a "pass-through" design with three lanes storing eight vehicles each and a side pull-out lane capable of storing four additional vehicles. All lanes will be side-by-side on the new ferry, whereas the existing ferry fleet has a center tower supporting the wheelhouse that splits the loading lanes into two left and two right lanes. The first of the two new ferry boats is expected to be in operation in December 2010; the second new boat will follow roughly one year later.

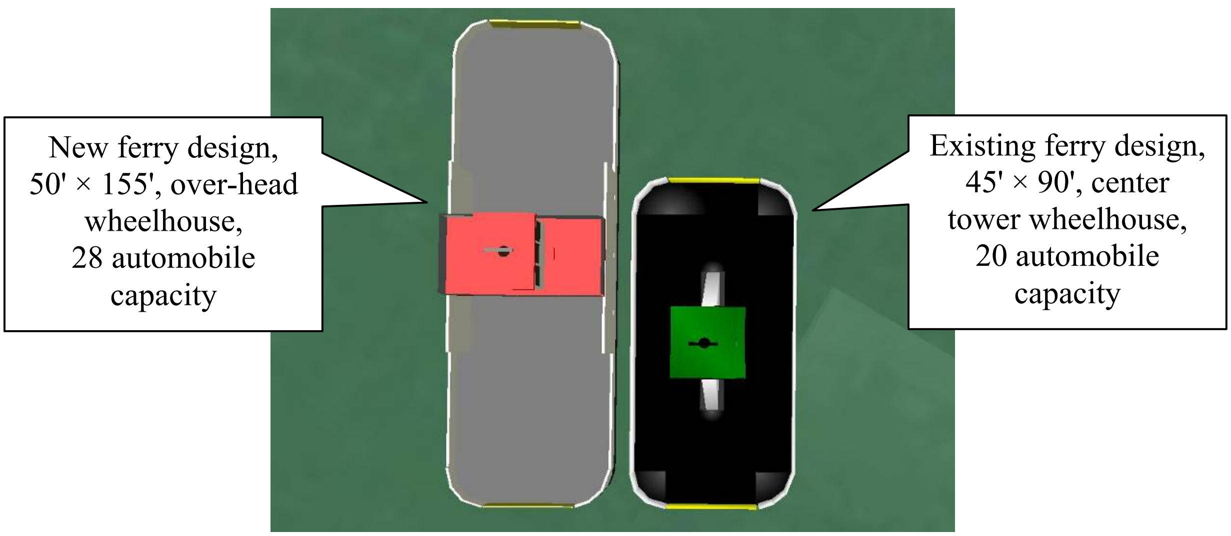


Figure 7. Old and New Ferry Boat Designs (as Modeled in VISSIM).

Another change being investigated for the ferry system is the addition of a more informative and broadly reaching traveler information system for ferry wait times. Currently, online images of the ferry landings are available through TxDOT and posted on the City of Port Aransas website at (http://www.cityofportaransas.org/ferrycam.cfm). Wait times and other status information regarding the Port Aransas ferry system can be found on the same website (http://www.cityofportaransas.org/txdot/status.pdf). System enhancements being considered include using roadside Bluetooth technology to monitor travel times through the ferry system in real time, calculate wait times from the travel time data, and post wait times on mobile device websites and roadside dynamic message signs at strategic locations along I-37.

METHODOLOGY

The current investigation will make use of the VISSIM (4) traffic simulation model developed during previous studies of ferry operation (1, 2, 3). The latest study (1), the companion investigation to the current study, updated the VISSIM model to account for the length of each vehicle allowed into the pre-boarding storage lanes for each ramp and added in the larger, new ferry boat design. These changes were made to more realistically account for the effect trucks have on ferry loading/unloading and to load a realistic number (and type) of vehicles on the new, larger boats. Visualization examples were created to demonstrate both human and signal control of ferry landing pre-boarding using the existing geometry of each ferry landing.

Performance results from the previous phase of this investigation (1) revealed that the replacement of one of the six existing 20-vehicle ferries with a new, 28-vehicle ferry boat during peak-demand conditions reduced the queue on the Harbor Island approach by over 1400 ft and on the Mustang Island approach by roughly 500 ft. The results also showed a 3.5 percent increase in ferry traffic volume and a 9.3 percent reduction in total vehicle delay. Average delay for a vehicle making a trip using the ferry system dropped by about 3 minutes, or 8 percent.

Changes to the control and operations environments on the ferry landings for the current investigation include implementation of the TxDOT signal control scheme (Figure 8) in a three-phased approach. In phase 1, the signal-controlled, single-lane pre-boarding/single lane direct unloading landing layout will be applied to the Harbor Island landing only. In phase 2, both the Harbor Island and Mustang Island landings will be controlled using this scheme. Note that extensive geometric modification to the Mustang Island landing was required for this phase, and that property beyond TxDOT right-of-way was necessary in order to enable this type of control at this landing. The last phase of this analysis involved the modified layouts for both the Harbor and Mustang Island landing and an elevated queue storage loop on Mustang Island to reduce ferry wait queuing into Port Aransas along Cotter Street and Cut-Off Road (i.e., the two primary roads approaching the ferry landing).

Figure 8 depicts the phase 1 implementation of the new TxDOT control scheme whereby each ferry ramp is directly loaded from a single pre-boarding lane, and each ramp is unloaded using a single-lane exit lane adjacent to that ramp's entry lane. Crossing conflicts no longer occur between the pre-boarding area and the ferry ramps since each ferry has its own loading and unloading lane, but conflicts do exist at the approach roadway between vehicles leaving each exit lane and vehicles arriving at the landing trying to access the pre-boarding lane.

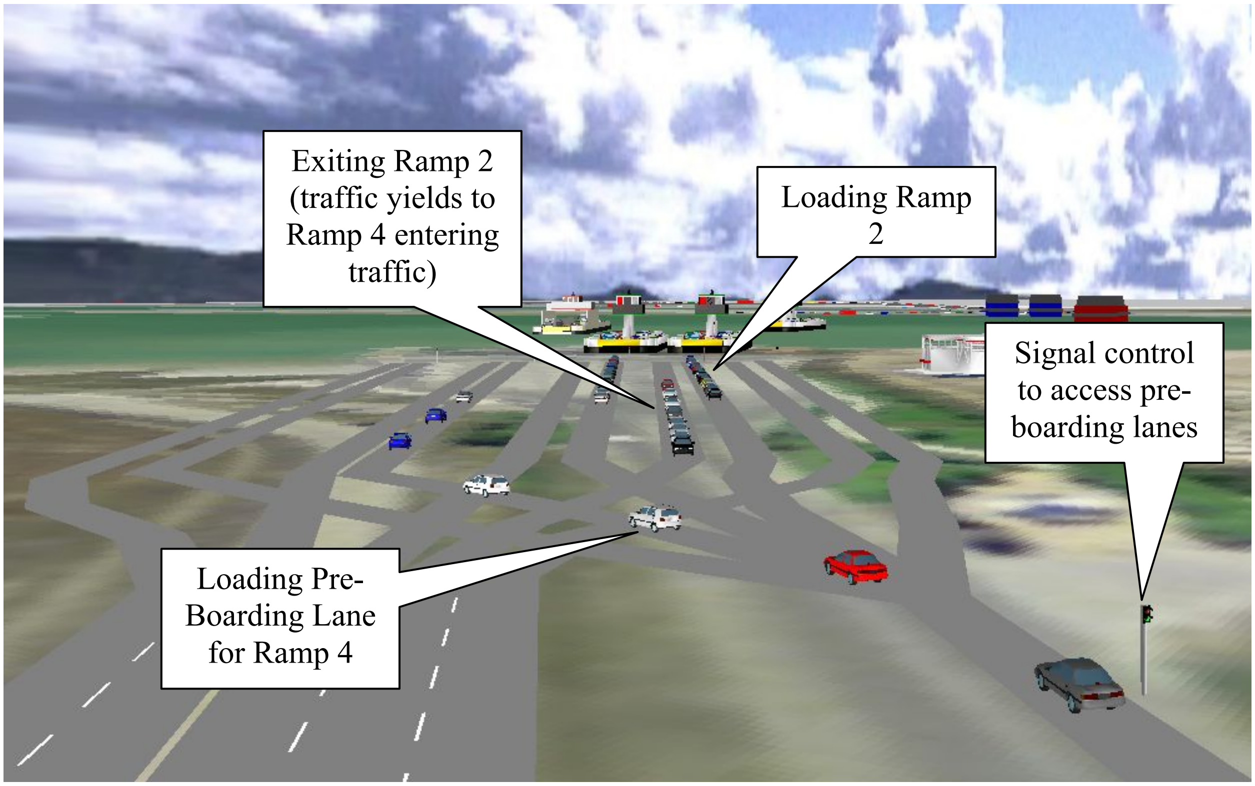


Figure 8. Model Representation of TxDOT Control Revisions – Harbor Island.

Reconfiguration of the Mustang Island landing to allow adjacent, single-lane pre-boarding storage and exiting on the Mustang Island side required not only existing TxDOT right-of-way (see red-outlined area of Figure 5 for Mustang Island), but also some additional property currently operated as a filling station in the west corner of the Cotter/Cut-Off Road intersection. This property was utilized merely for the purposes of providing adequate storage lane length for each ferry ramp and circulation roadway segments to exit the modified landing onto Cut-Off Road. The phase 2 control modification to the Mustang Island landing is shown in Figure 9. The lower right corner of the background image is the location of the signalized intersection of Cotter Road and Cut-Off Road. The lower left corner of the figure shows vehicles exiting the ferry landing onto Cut-Off Road. Note that this configuration was created for modeling purposes only to create the single-lane queue storage necessary for each ramp's pre-boarding area; a wide-range of alternatives exist for the design of this concept.

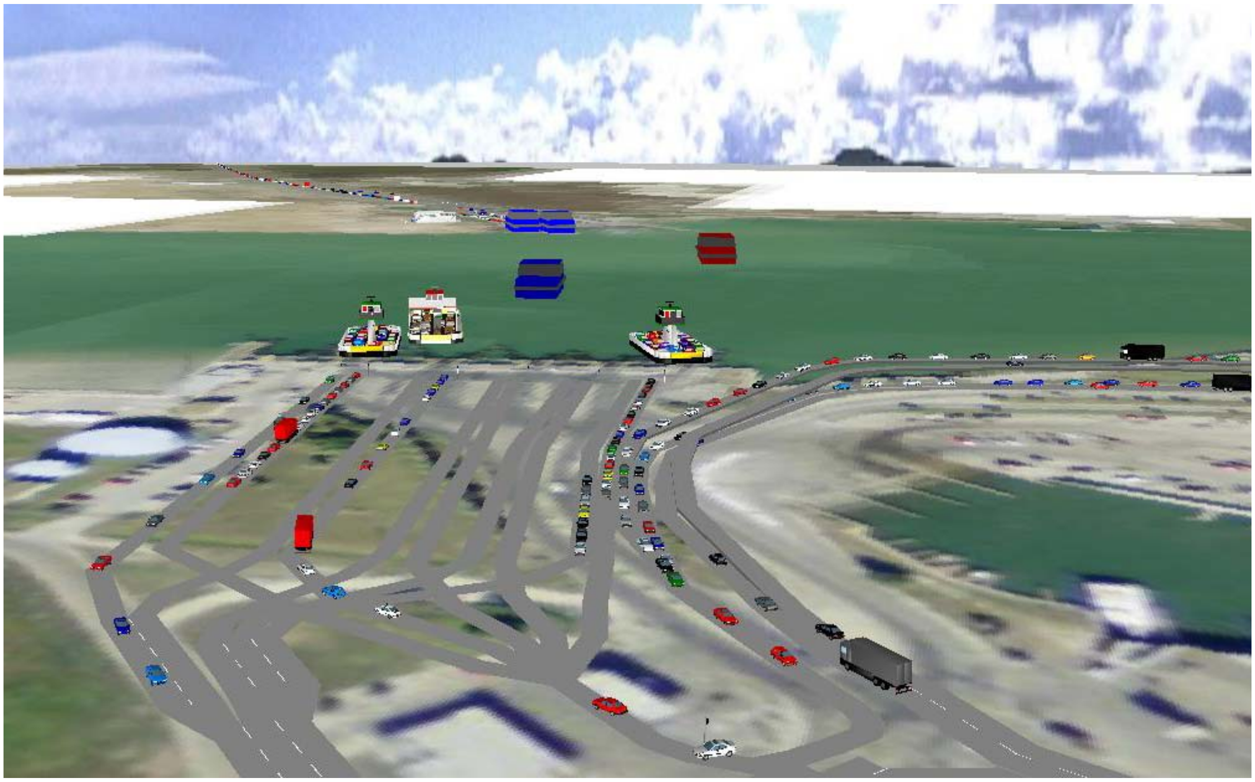


Figure 9. Model Representation of TxDOT Control Revisions – Mustang Island.

The final stage of the modeling analysis required the evaluation of the impacts of having a bi-level storage area on Mustang Island for the storage loop currently located on the east side of the ferry landing. In its current at-grade form, the storage loop and approach roadway back to the Cotter/Cut-Off Road intersection provide just under one-half mile of vehicle storage queuing distance. The landing modification and dual-level enhancement of the storage loop result in roughly one mile of queue storage, roughly doubling on-site queue storage for the ferry. Figure 10 provides a three-dimensional model-based view of the elevated storage loop concept for the Mustang Island ferry landing.

Figure 10. TxDOT Elevated Ferry Queue Storage Loop Concept for Mustang Island.

RESULTS

The VISSIM simulation analysis results for the longer-term changes to the Harbor and Mustang Island ferry landing approaches are presented in the following four figures. Figure 11 provides a graph of the model's analysis of ferry landing operations. Note that counts shown here are the exit counts from each landing (i.e., the PA – or Port Aransas – count shows traffic coming to Mustang Island, while the HI count on Harbor Island is for vehicles bound for the mainland). The graphs clearly show that efficiencies are gained both by introducing one of the new, larger ferry boats into a six-boat fleet and by expanding the fleet from six to seven boats (with two boats being larger, new ferries). The "Count@PA" shows that the new ferry landing and control layout (Figure 6) provides similar operation and efficiency for Harbor Island, while improving the landing on the Mustang Island side, which is reflected in the exit count on Harbor Island (Count@HI).

Figure 12 contains a system-wide average delay that is experienced by vehicles going through the ferry system. It is intended to provide a relative measure of the efficiency of the ferry system as a whole in scenarios where new, larger ferries are added to the ferry system and how the system responds to the new TxDOT control scheme as:

- Control improvements are made on Harbor Island (HI, phase 1).
- Control improvements are made on both Harbor and Mustang Islands (Both, phase 2).
- Both landings experience control improvements, and bi-level storage is provided on Mustang Island (Double Layer Loop, phase 3).

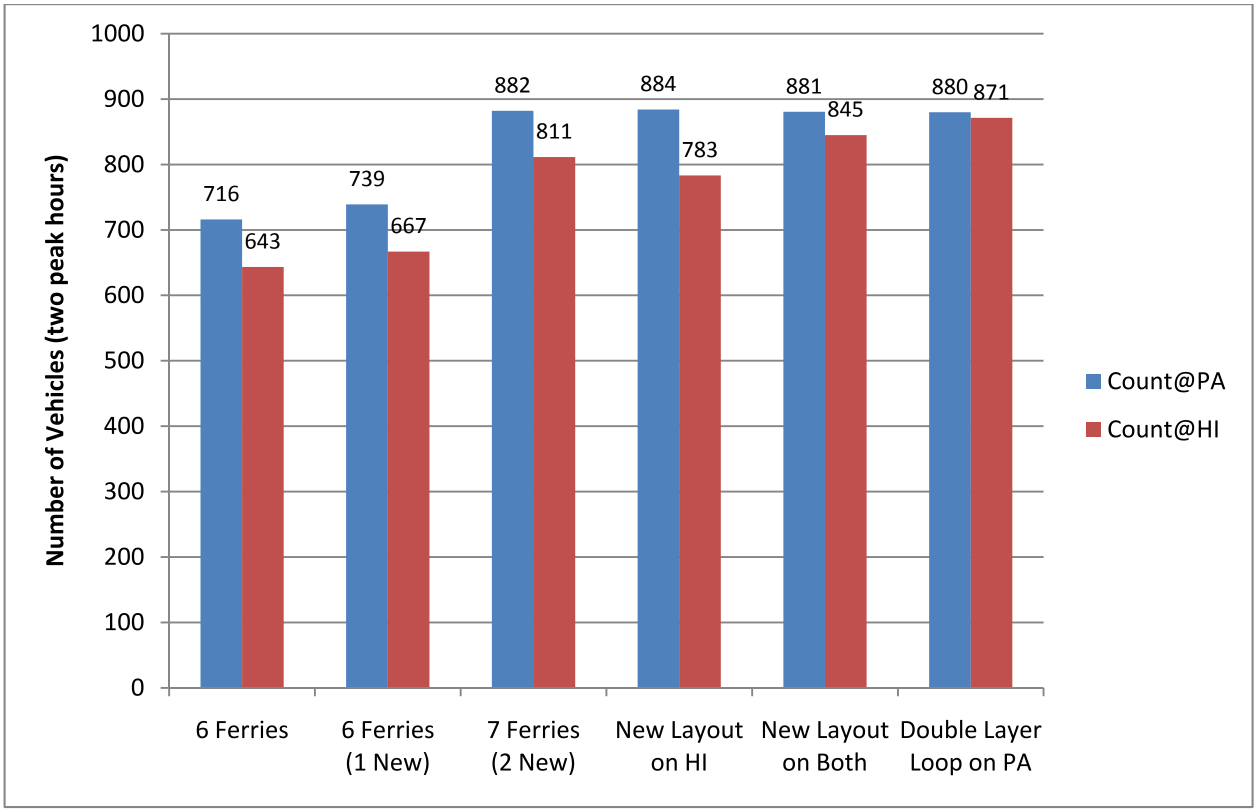


Figure 11. Exit Vehicle Count from Port Aransas Ferry Landings.

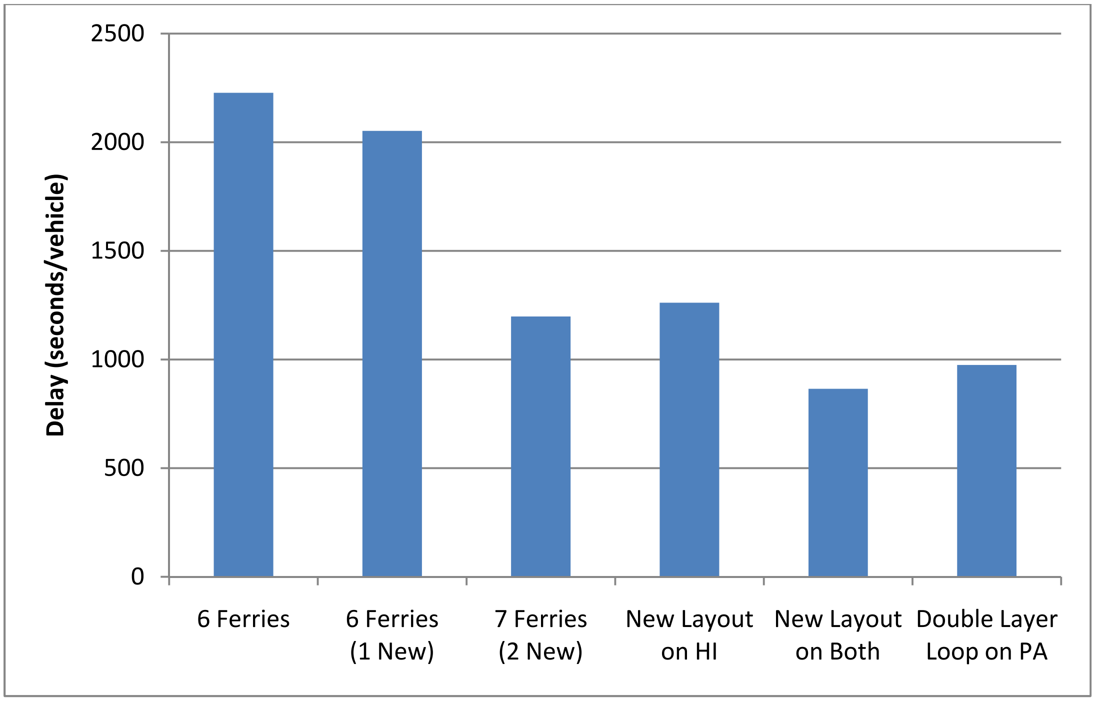


Figure 12. Ferry System-Wide Average Control Delay.

Figure 13 provides an indication of the queue length impacts based on changes in the ferry fleet. Under peak hour conditions during a high-volume holiday weekend, queue lengths are observed to be over a mile long using the existing fleet of six smaller ferries. Introducing one new, larger boat as a replacement for one existing ferry and adding a seventh larger ferry minimize queue length on Harbor Island and reduce by over two-thirds the queue length on Mustang Island under equivalent demand levels.

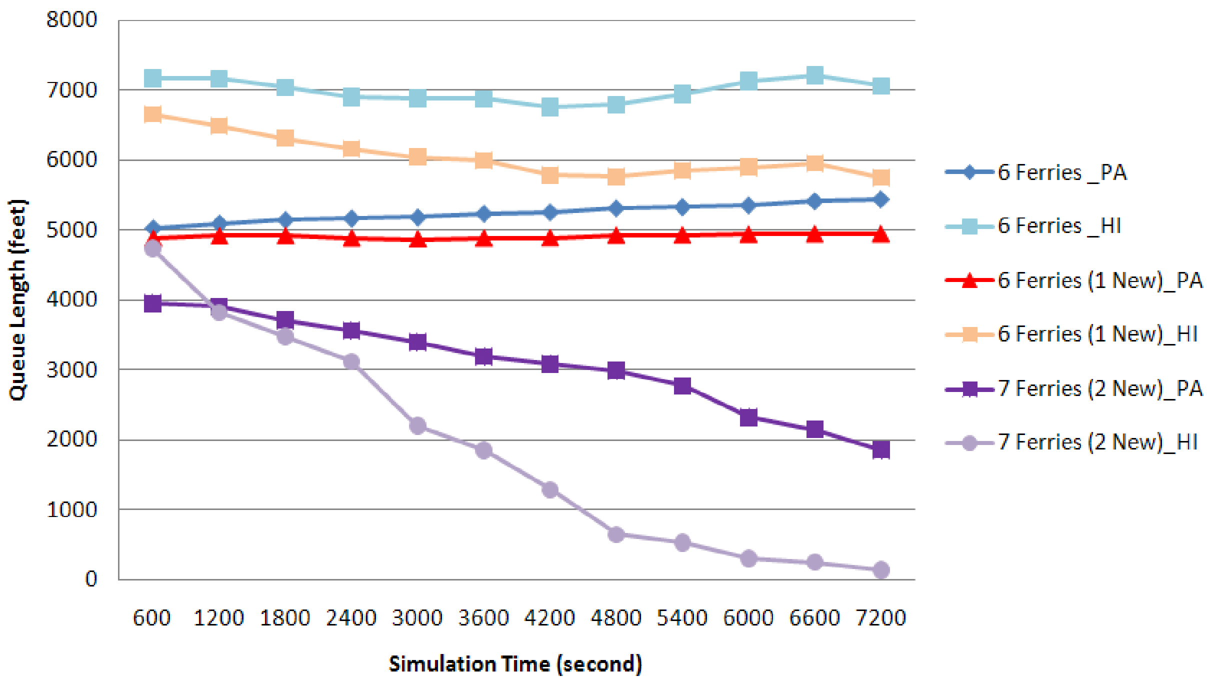


Figure 13. Ferry Option's Queue Length on Harbor Island (HI) and Mustang Island (PA).

Figure14 illustrates the queue storage impacts on both Harbor Island (HI) and Mustang Island (PA, or Port Aransas) of the phased ferry landing layout changes that introduce direct, single-lane loading, and unloading for each ferry ramp. For the Harbor Island approach, the majority of changes that improve operations are brought about by changes in the ferry fleet (i.e., seven boat fleet with two larger ferries). However, on the Mustang Island approach both the new layout control system and the storage loop improve space utilization (though right-of-way expansion is necessary to accomplish these schemes on Mustang Island) such that vehicle flow and landing efficiency are increased. Observe that Port Aransas/Mustang Island queue length without improvements on the Mustang Island side ("New Layout on HI_PA") is roughly 2000 feet long, while this queue is effectively minimized by the end of the simulation when control improvements and the double-layer storage loop are found on Mustang Island ("New Layout on Both_PA" and "Double Loop Layer_PA," respectively).

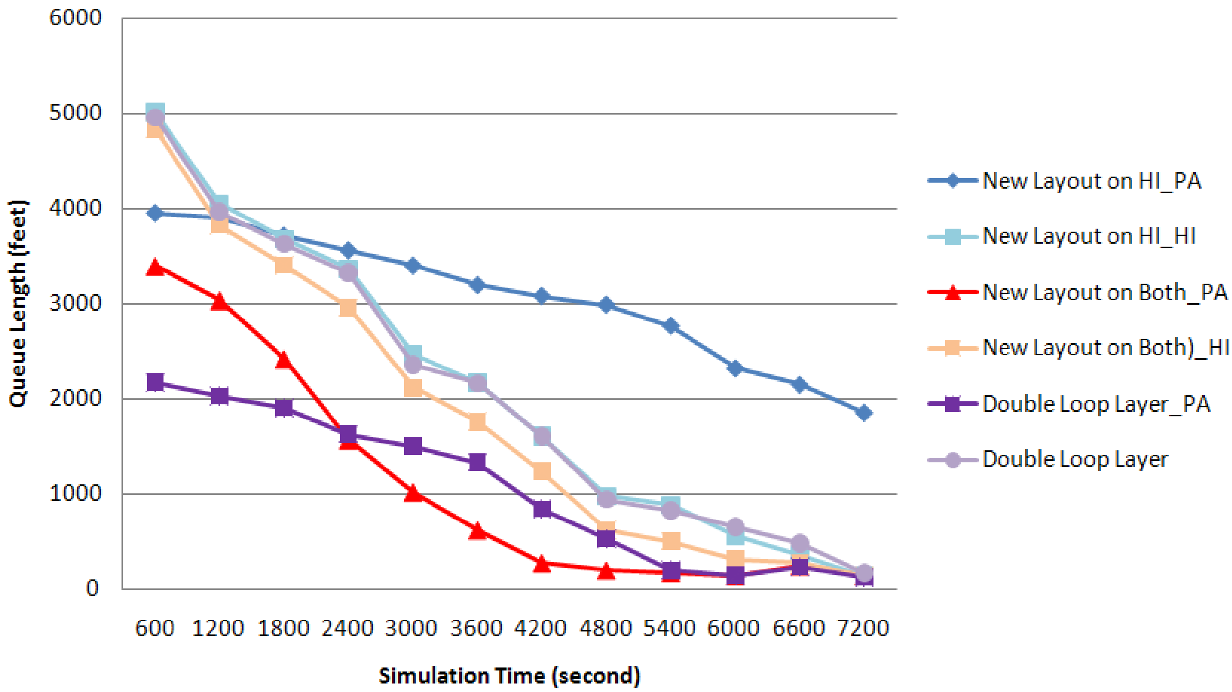


Figure 14. Impacts of Proposed Ferry Control and Queue Storage Changes.

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WORK ORDER 18: LOOP 410 PROJECT CONTEXT, ANALYSIS, AND ECONOMIC IMPACTS

Over the past 18 years, TxDOT has spent more than $900 million on over 18 separate infrastructure improvement projects along Loop 410 in north and west San Antonio. Projects like Loop 410 provide valuable test beds in determining how such improvements impact a region and the benefits they provide. This report approximates the economic benefits to San Antonio of the Loop 410 improvement project.

A BRIEF CONTEXT FOR THE LOOP 410 IMPROVEMENT PROJECT

This project is a 15.3-mile reconstruction project to upgrade and expand San Antonio's Loop 410 (see Figure 15). Essentially, the effort improves capacity by widening existing Loop 410 lanes. Specifically, capacity was enhanced from six to ten lanes. The Loop 410 project impacts service at the local level by adding:

- Ramp access changes to the San Antonio Airport.
- Two fully directional interchanges.
- Several direct connector ramps.

Since it is extensively connected to I-35, I-10, and US 281, improvements to Loop 410 have potentially significant impact on the area's traffic flow and economic development.

Loop 410 Improvement Project: Facts

- 15.3-miles long.
- Expanded capacity from 6 to 10 lanes.
- Improved diamond intersection.
- Reconfigured ramp access to SA Airport.
- Added connections to Bandera Road (SH 16) and I-10.
- Reconstructed inefficient interchanges at I-10, US 281, SH 16, and San Pedro Road.
- Construction cost: $753M.
- Total Project cost: $973M.

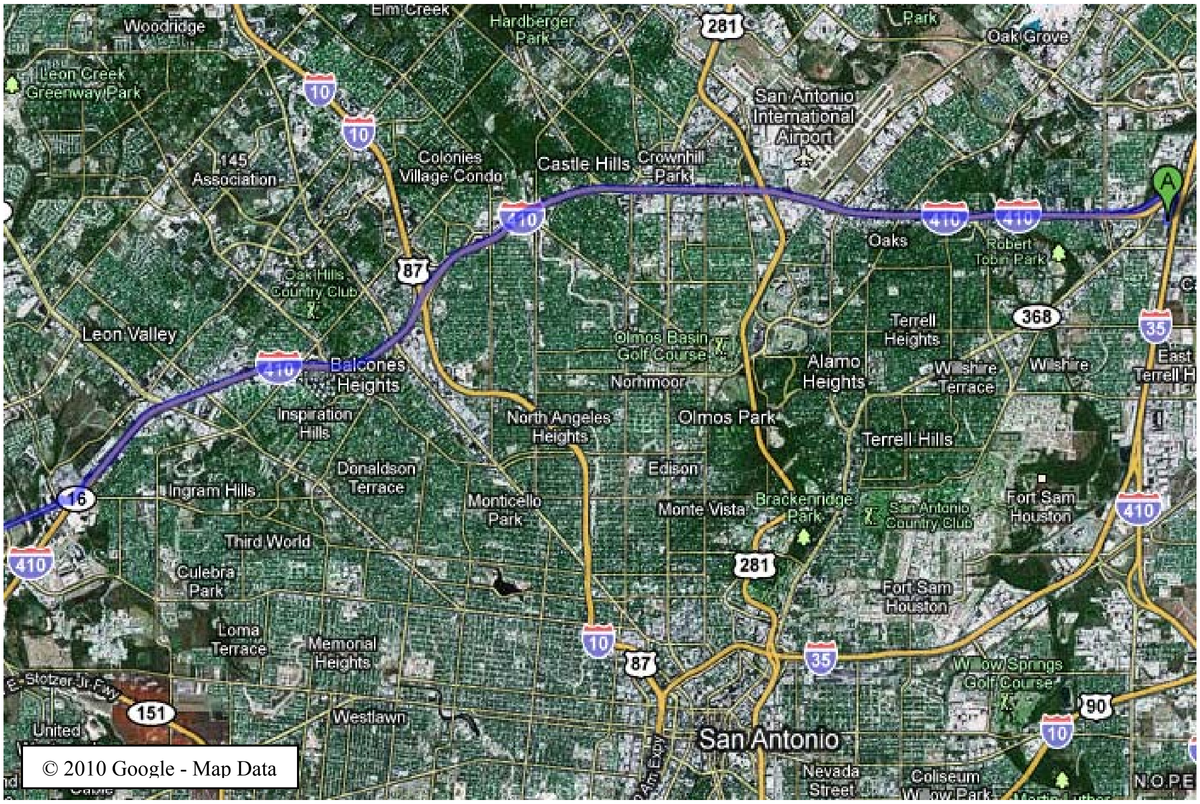

Figure 15. The Loop 410 Improvement Project.

STATE OF THE SAN ANTONIO ECONOMY

Despite the nationwide recession of the past few years, the San Antonio economy has proven remarkably resilient. In fact, it surpassed the other four major Texas metro areas in economic performance and is one of the few regions in the country with its economy performing better than eight years ago.[12] One manufacturing trade union noted that the city “is widely perceived in the industry as a low-cost place to do business and that the cost of living is 10 percent below the U.S. average.”[13]

The San Antonio economy is highly diverse, depending heavily on a flexible, dynamic transportation network. Top employment sectors include finance, government, biomedical and biotechnology, food service, manufacturing, and tourism. The service sector is the largest and fastest growing in the economy, largely due to increased demand for health care and business services.

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[12] Quarterly Economic Forecast, San Antonio Chamber of Commerce, July 2010.
[13] “The construction market in San Antonio has fared better than most, thanks to government spending and a diverse economy.” *Associated Equipment Distributors*, January 1, 2010.

San Antonio's highly regarded medical industry, which contributed approximately $11.9 billion to the area in 2003, includes the 900-acre South Texas Medical Center, employing approximately 25,000 people. The manufacturing sector employs over 50,000 employees and pays out over $2.2 billion annually in salaries. This industry has grown from $10 billion in 1996 to over $14 billion today, a 44 percent overall increase in just 14 years.[14] San Antonio's largest employers comprise a diverse industry sampling: USAA, H-E-B Grocery, Wells Fargo, Citibank, Valero Energy, ClearChannel Communications, and the Alamo Colleges System.[15]

WHY THE IMPROVEMENTS WERE NEEDED

In 1960, San Antonio's population was 587,718. Loop 410 was originally designed to handle 40,000 vehicles per day—twice the anticipated volume in the early 1960s. Loop 410, which opened to the public in 1966, was the first planned and constructed metropolitan loop in Texas.

When opened to the public in 1966, Loop 410 was originally designed to handle 40,000 vehicles per day. By 1995, traffic volume approached 200,000 vehicles per day.

By 1995, traffic volume approached 200,000 vehicles per day, or five times Loop 410's originally designed capacity. The typical San Antonio resident spent about one day of every year—24 hours—sitting in traffic. That year, TxDOT began what was then the largest freeway improvement project in South Texas history – expanding the Loop's capacity to 400,000 vehicles per day, or 10 times its original capacity, while modernizing the system's design standards.

In 2009, the Census Bureau estimated San Antonio's population to be more than 1.2 million people. By 2050, San Antonio's population is expected to top 2.0 million people. Population density, shown for 2000 in Figure 16, reflects the importance of Loop 410 to San Antonio. Population growth tends to cluster around Loop 410 and its ancillary roadways. Addressing the city's growing population's transportation needs by expanding capacity and improving access via Loop 410 has facilitated economic development and commute time prior to these issues reaching crisis levels.

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[14] San Antonio Chamber of Commerce, San Antonio Manufacturing Industry: 2006 Economic Impact.
[15] San Antonio Economic Development Corporation, *Major Employers and Support Organizations*, http://www.sanantonioedf.com/index.php?module=xarpages&func=display&pid=7, accessed September 2010.

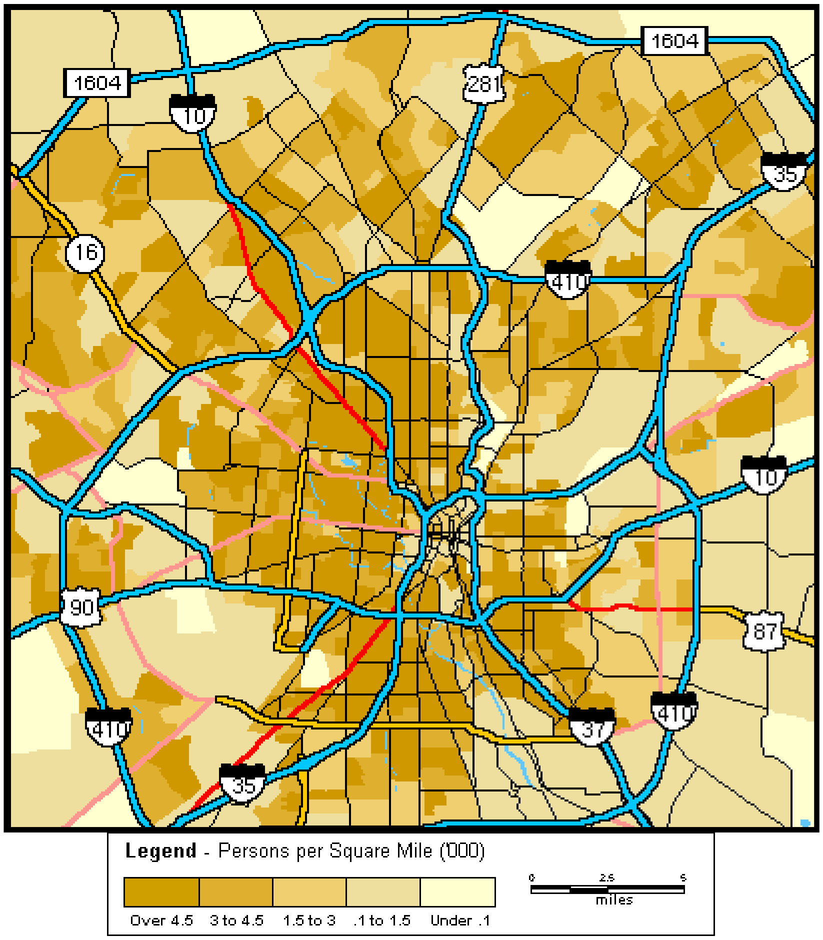


Figure 16. Population Density around Loop 410 (2000 Census).

HOW DO WE DETERMINE ECONOMIC IMPACT?

Trackable metrics show economic impact over time. Examples of trackable measures of local economic impact for a project like this include:

- Land use impacts (changes in use, value, developments, private investments stimulated).
- Fiscal effects stimulated from land use impacts.
- Impacts related to changes in sales.

Examples of trackable measures of regional economic impact include:

- Contributions to regional output and value added.
- Job-related impacts (e.g., construction-induced contributions of operating and maintenance expenses and as a combined result of improvements facilitated by the project).

How much activity a business generates can demonstrate the impact of improvements to the gross regional product. Over a project's life, community stakeholders—government, private sector, and the general public—can witness various economic impacts that grow in effect over time. For instance, land use impacts accrue to the larger community in a variety of ways, including to individuals who directly benefit from a larger range of choices and private investments. Fiscal effects accrue to the larger community where these resources are used to provide services to a growing region.

Impacts accruing to users and/or commuters are another direct source of impact. Since they are not trackable, these impacts are often estimated using predictive models. If these effects are negligible, economic impacts by the project are also likely to be small, limited to just the construction spending stimulus. Examples of these impacts are:

- Reduced travel time.
- Improved travel time reliability.
- Vehicle operating costs, including fuel consumption.
- Driving safety.
- Air quality.
- Accessibility.

APPROPRIATE TIME SPAN FOR DETERMINING ECONOMIC IMPACT

Longitudinal in nature, projects like this one assume that user benefits and induced economic impacts continue to grow through the project lifespan up to 25 years from the end of construction. For Loop 410, this suggests a potential terminal evaluation year of 2035. Therefore, researchers have projected benefits accruing from Loop 410 to that year.

In most evaluation studies of existing projects, economic impacts are usually evaluated from 3–5 years before start to a minimum of 5 years after completion. For Loop 410 improvements, this represents an evaluation period of 1992 to 2016. Given that these findings were produced in 2010, only a partial economic impact evaluation is possible. The research team recommends further study in the section below entitled "Where to Go from Here."

LOOP 410 PRIOR TO RECONSTRUCTION

Even before reconstruction began, commercial and residential development characterized this dense urban corridor. Digital imagery files like the ones shown in Figure 17 suggest pockets of undeveloped land along several parts of the corridor, particularly along its southern fringe near Culebra Road and interchanges nearby. The corridor's predominant use at the time focused on single-family, residential commuting. Although difficult to see in Figure 17, pockets of undeveloped land along the corridor, especially around Culebra Road, are evident.

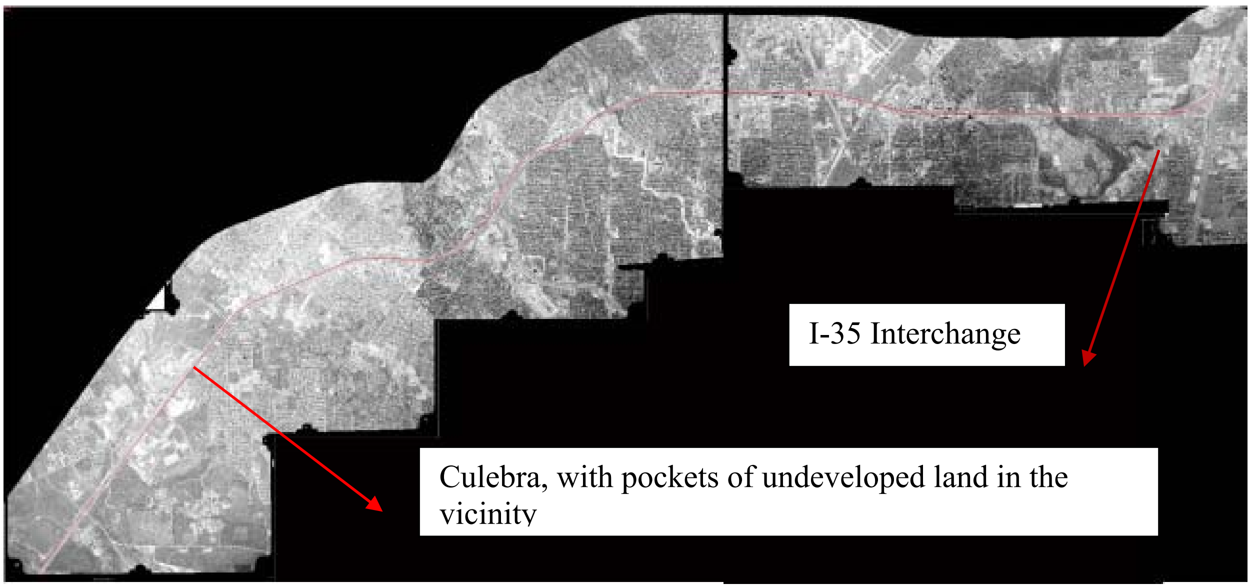


Figure 17. Conditions along Loop 410 Prior to Reconstruction (1986).

LOOP 410 AFTER RECONSTRUCTION – GENERAL OBSERVATIONS

During the early construction years (1996–2005), San Antonio experienced growth across the city, but the highest growth was recorded in the portions of Loop 410 corridor that were unimproved at that time.

By 2009, a significant portion of Loop 410 had been reconstructed. Contemporary aerial photography (see Figure 18) shows an even denser urban environment with increased development around the corridor, including south of Culebra Road. Increased land development, including the improvement of existing vacant areas and redevelopment in some areas, is also evident. Some development follows naturally from population growth in the region.

Until 1995, growth in the study corridor was much higher than the rest of Loop 410 with a 2010 tax base value that was nearly double the rest of the loop. During the early construction years (1996–2005), San Antonio experienced growth across the city, but the highest growth was recorded in the unimproved portions of the Loop 410 corridor.

These findings suggest that construction might have spurred growth and development in closely linked areas (like the rest of Loop 410 and outside the study area), since the region's increasing population would necessarily be absorbed by regions with greater land available for development. Furthermore, in 2006–2010 (the most recent years of construction, which also correlated with economic downturns), all regions show a decline in growth, though the unimproved portions of Loop 410 are the regions least in decline during this time. This growth is coupled with significant additions to the city tax base. Due to the current limited data and the fact that developments were only recently completed, however, it is too soon to draw direct links between the Loop 410 improvements and increased growth in the region.

Figure 18. Loop 410 Land Development (2009).

WHY THE RESULTS ARE PRELIMINARY

While the research team has identified interesting trends about the effects of Loop 410's reconstruction, the results are preliminary due to the limited post-construction data available. As time passes and more longitudinal data is gathered, researchers can better draw the link between construction and local growth, like the impact on local businesses.

WHAT WE KNOW SO FAR

TTI researchers have identified some trends and benefits resulting from the Loop 410 reconstruction project.

Benefit Type	Benefit Amount (all figures approximate)		
Return on Investment	$3 to every $1 spent		
Jobs Created	12,000 new jobs		
Cumulative Output Total Gained (wages + value added)	$1.3B		
Tax Base Contributions	2010	2020	
	$60M	$109M	
Tax Base – New Commercial / Industrial Investment	$1.2B		
Commuter Savings (cumulative value of time saved to year indicated in 2010 $)	2010	2020	2035
	$114M	$637M	$1.2B
Fuel Savings (cumulative value of fuel saved to year indicated in 2010 $)	2010	2020	2035
	$62M	$335M	$626M
Benefits to Businesses	$34M		

Overall Economic Benefits

Conservatively speaking, reconstruconction costs for Loop 410 have produced a return on investment of 3 to 1. In terms of jobs gained, the project has approximately 12,000 full-time equivalent jobs to the San Antonio economy in the construction, manufacturing, mining, retail, and service sectors. Most of those jobs are near term, resulting from the construction project itself, and account for approximately 60 percent of jobs gained. The remaining jobs are longer term and are the result of the economic benefits accrued to the local economy resulting from Loop 410's reconstruction. Cumulative wages for these jobs is approximately $388 million. Accounting for the value added, that number increases to $742 million. The cumulative output total is $1.3 billion. By 2020, the delay and fuel efficiencies should just about offset the cost of investment.

Contributions to the Tax Base

We cannot accurately assess true contributions to the tax base before 5+ years after completion of the project. However, we estimate that, by 2010, tax benefits are approximately $60 million (city and school districts). By 2020, this amount increases to $109 million. Regarding new commercial and industrial investment, we estimate benefits to the tax base approaching $1.2 billion in the immediate vicinity of Loop 410. This constitutes almost 15 percent of the overall city value for the same category during that period.

Travel Efficiencies and Commuter Benefits

Under typical settings, travel efficiencies are rarely tracked, though they are sometimes predicted using a variety of methods and demand models. Few studies have attempted to relate commuter delay (and the relief from delay) directly to construction. Determining the actual impact of the improvements requires discussing actual operating cost benefits like fuel consumption, related savings, and other vehicle operating cost changes.

Preliminary data indicate that following Loop 410 improvements, traffic today is moving about 31 percent faster than it would have had no improvements been made. This likely would have been even more pronounced had the San Antonio population grown at a lower rate than it has. By 2020, we estimate an equivalent savings of $637 million directly attributable to the Loop 410 construction's positive impact on commute time. By 2035, that savings accrues to $1.2 billion.

Estimated Fuel Savings to San Antonio

Year	Dollar Savings Equivalent (2010 $)
1998-2010	$62M
Through 2020	$335M
Through 2035	$626M

Fuel Savings Benefits

As mobility improves, the amount of fuel burned sitting idle in traffic decreases. Since we have determined significant mobility improvements as a result of the reconstruction, we can calculate fuel savings resulting from reduced congestion. We assumed a conservative fuel price of $2.00 per gallon and that traffic would move at a regular rate of 45 mph along the corridor.

THE WORD ON THE STREET: ESTIMATED ECONOMIC IMPACTS TO BUSINESSES

TTI researchers contacted local companies and businesses within nine zip codes along Loop 410 to assess their perceptions of improvements. Researchers received a total of 44 responses from the nine zip codes targeted by its survey. In general, respondents:

- Use Loop 410 more now than before improvements were made.
- Choose not to stay at work after hours to avoid heavy traffic more now than before Loop 410 improvements were completed.
- Spent less time waiting for traffic conditions to improve after work.

- Saw their morning and evening commute times decrease.
- Saw no change in employee turnover and employee tardiness.
- Were unlikely to relocate a business due to traffic congestion.
- Stressed the importance of access to Loop 410 for the viability of their business.
- Felt the improvements did not negatively impact their businesses.
- Were generally satisfied with Loop 410 after improvements were completed.

In general, respondents were positive in their assessments of the Loop 410 improvements, with many noting the improved commute times. Respondents also had some criticisms of the project, mainly regarding ramp relocations and the length of time required to build the improvement project. Suggestions for improvement included better enforcement of the minimum speed limit and improved visibility for safety.

The Importance of Access to Loop 410 to Businesses

Of the companies surveyed along the corridor, 73 percent had resided in their location for at least five years and 55 percent for at least 10 years. Forty-one percent of all businesses interviewed mentioned that access to Loop 410 is "very" or "extremely" important to the organization's decision to remain at its current location. All restaurant business owners interviewed said that access to Loop 410 is "very" important for the company to remain at its current location.

How Loop 410 Improvements Have Affected Commute Time

Of all the businesses responding, 60 percent noticed a decrease in commute time since completion of reconstruction. Respondents also mentioned that they spent less time waiting for traffic conditions to improve after work, citing the completed corridor's improved mobility as their reason. Overall, 54 percent of respondents claimed that their evening commute time had "decreased" or "slightly decreased."

Impacts on Employee Turnover or Tardiness

Reconstruction did not significantly impact the employee turnover rate for corridor businesses, according to 92 percent of respondents. Likewise, where employee tardiness is concerned, 76 percent of employers noted no change, though 21 percent claimed that it had decreased.

Likelihood of Business Owners to Move Their Business due to Traffic Concerns

As a result of traffic concerns, some 92 percent of respondents were "not at all" or "slightly" likely to relocate following finalization of the Loop 410 improvements.

Traffic on Loop 410: Better or Worse?

Overall, complaints about traffic on Loop 410 have dropped from 36 percent (pre improvements) to 12 percent (post improvements). Prior to reconstruction, 80 percent of the "Banking, Insurance, and Finance" companies said their employees complained about access to Loop 410 "sometimes." Since reconstruction, 80 percent of those same respondents said they "almost never" or "never" hear employees complaining about access to Loop 410.

Have the Improvements Helped Your Business?

Of those surveyed, 94 percent felt that the improvements had not negatively impacted their businesses, with 50 percent reporting a positive or slightly positive impact. Six percent cited a negative impact, and 44 percent had experienced no impact.

WHERE TO GO FROM HERE

This assessment was not a random sampling of the San Antonio business population. Thanks to readily available contact information through the San Antonio Chamber of Commerce (CoC), researchers sent surveys to businesses registered with the CoC. Given the financial and time constraints for this analysis, this approach was the most practical. The research team is confident that this research procedure has provided reliable results, which provide a well-developed snapshot of how reconstruction of Loop 410 has impacted San Antonio.

However, researchers suggest future research using a more comprehensive analysis that will yield a more accurate picture. In addition, more focus groups could provide a better assessment of the improvement impacts from Loop 410. Specifically, the study team recommends further research into the long-term job benefits and changes in land use directly attributable to the new construction, an assessment that can only be made after enough time has passed following the completion of construction. Thus, we recommend a reevaluation of Loop

410’s economic impact six to seven years from now, when those impacts are more accurately measurable.

PROJECT CONTEXT IMPROVEMENT PROJECT DESCRIPTION

The Loop 410 project is a 15.3-mile reconstruction project that upgrades and expands existing services in the transportation system serving San Antonio. It is essentially a capacity project widening existing Loop 410 and specifically includes the reconstruction of a three-lane directional, access-controlled facility to a modern five-lane directional facility with several accompanying modifications occurring in various parts of the study area.

The Loop 410 project has several improvements that impact service at the local level—these include ramp access changes to the San Antonio Airport, two fully directional interchanges, and the addition of several direct connector ramps. However, the project is essentially a corridor project, with potential significant network influence due to its connectivity and interchange with several interstate freeways and U.S. highways (I-35, I-10, US 281). The project location is shown in Figure 19a. The study limits are shown in Figure 19b.

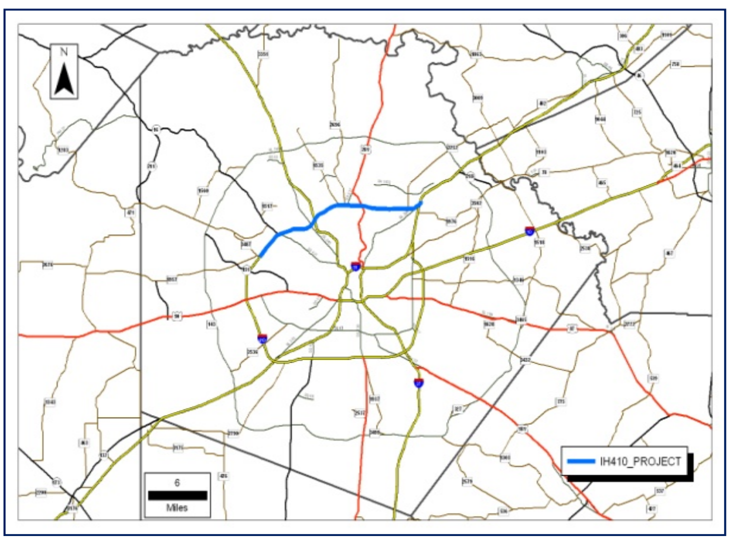


Figure 19a. Loop 410 Improvements (San Antonio, TX).

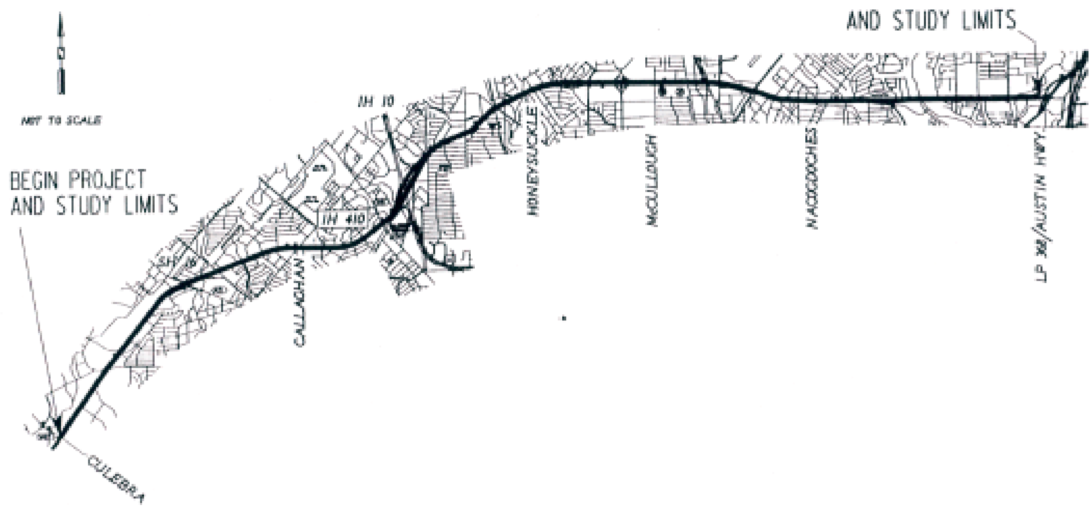


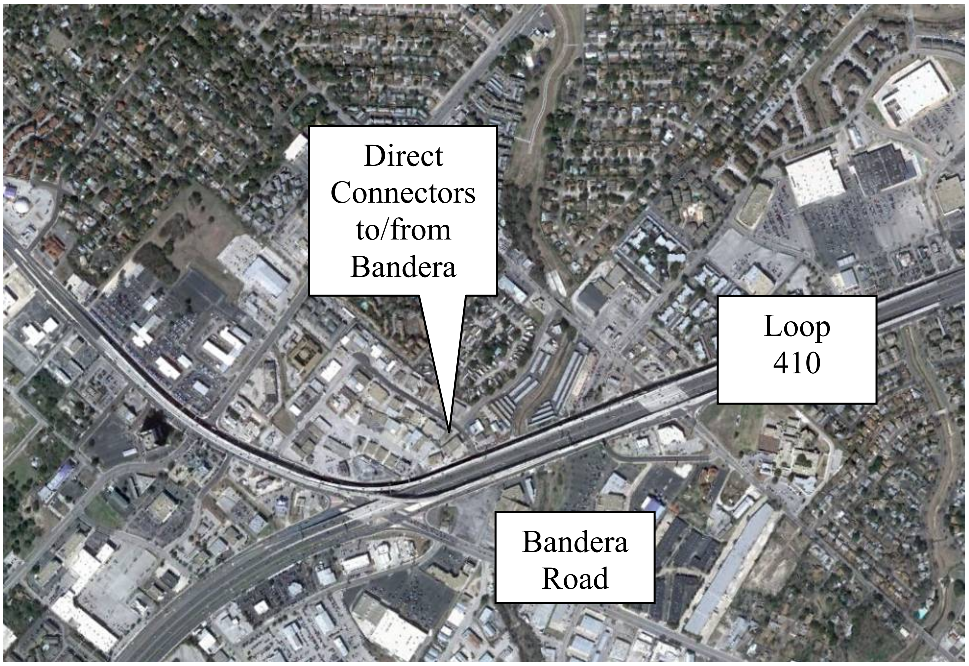
Figure 19b. Project Study Limits.[16]

Specific components of the Loop 410 improvements include:

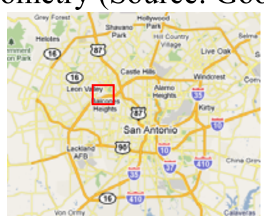
- Expansion of grade-separated, access-controlled primary travel lanes from three to five directional lanes for the majority of the Loop 410 corridor between Culebra and I-35, and along I-10 between Fulton and Loop 410.
- Construction of direct-connect ramps between Loop 410 and Bandera Road north of Loop 410.
- Reconstruction of the Loop 410/I-10 interchange from a hybrid direct/partial cloverleaf design to a fully directional interchange with pass-through frontage/collector-distributor lanes.
- Reconstruction of the Loop 410/San Pedro interchange from a cloverleaf design to a high-capacity diamond interchange with frontage pass-through lanes for Loop 410.
- Reconstruction of the Loop 410/US 281 interchange from an indirect access design (US 281 previously connected to Loop 410 via San Pedro to the north and Airport Boulevard to the south) to a fully directional interchange.
- Select frontage road improvements – including U-turn lanes for Loop 410 frontage roads – throughout the corridor.

[16] Environmental Assessment Reevaluation - Loop 410 from Culebra to Loop 368 (Austin Highway), December 2002.

Figures 20 through 24 describe the corridor improvements; location diagrams are provided to orient the reader to the improvement location within the Loop 410 corridor. The source for all current aerial imagery is Google™ Earth, while past imagery (1996) was downloaded from the Texas Natural Resources Information System (TNRIS).

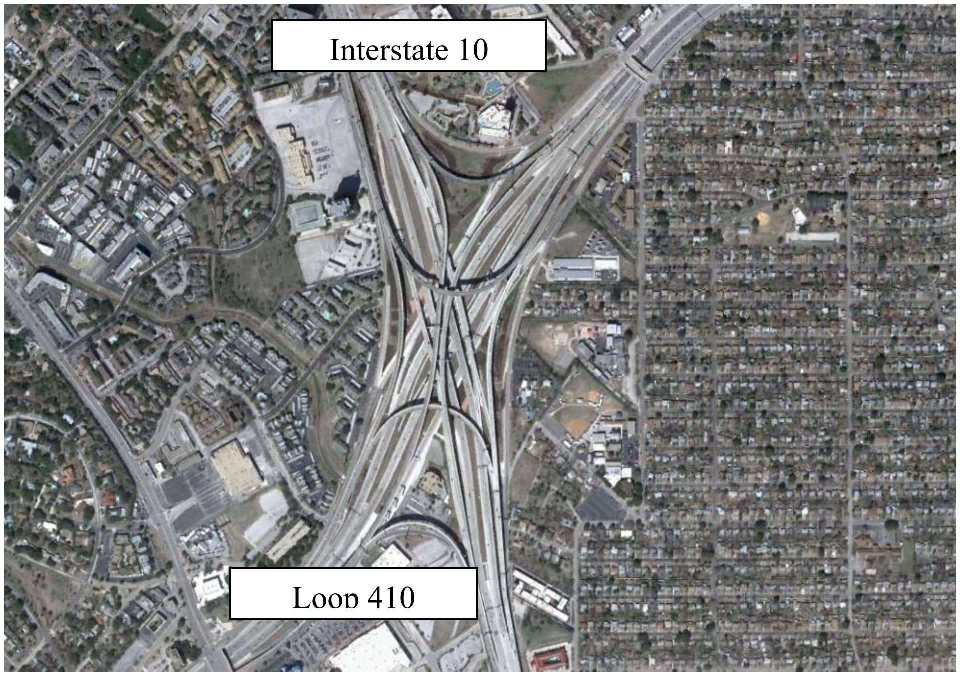


A. Improved Geometry (Source: Google™ Earth)



B. Previous Interchange Details (TNRIS, 1996 Color Infrared)

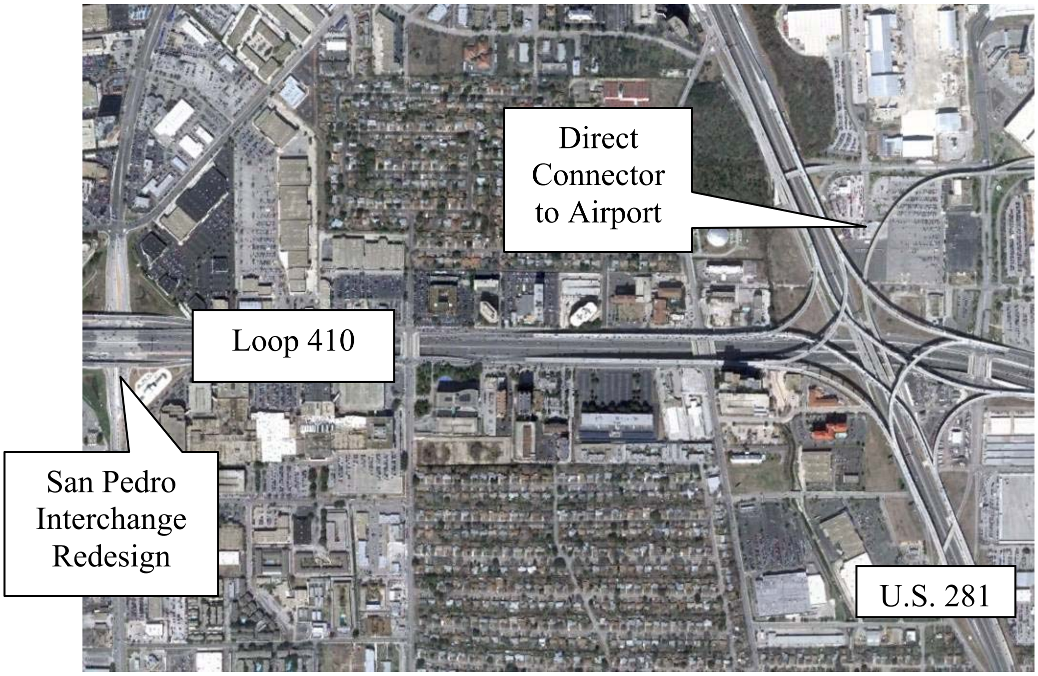
Figure 20. Loop 410 Direct Connectors at Bandera Road.



A. Improved Geometry (Source: Google™ Earth)

B. Previous Interchange Details (TNRIS, 1996 Color Infrared)

Figure 21. Reconstructed Loop 410/I-10 Interchange.

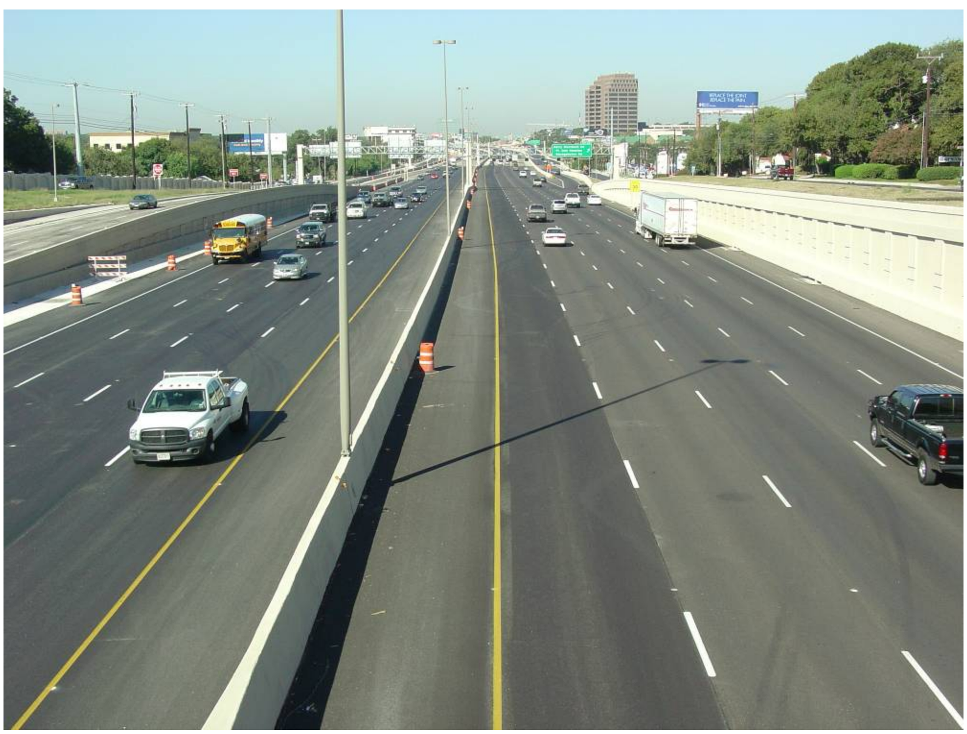


A. Improved Geometry (Source: Google™ Earth; annotations by authors)

B. Previous Interchange Details (TNRIS, 1996 Color Infrared)

Figure 22. Reconstructed Loop 410/US 281 Interchange.

Figure 23. Loop 410 at Vance Jackson
(Facing West; Loop 410/I-10 interchange in background).



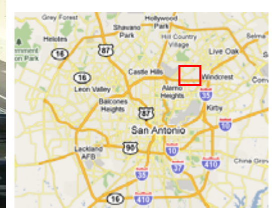


Figure 24. Loop 410 at Starcrest (Facing West).

CONSTRUCTION STAGING

Like many large-scale projects, the Loop 410 project used staged construction. It took almost 15 years (1995-2010) to complete construction from Culebra Road to just south of the I-35 interchange. Figure 25 shows the various completed segments and the yet-to-be-completed sections of Loop 410.

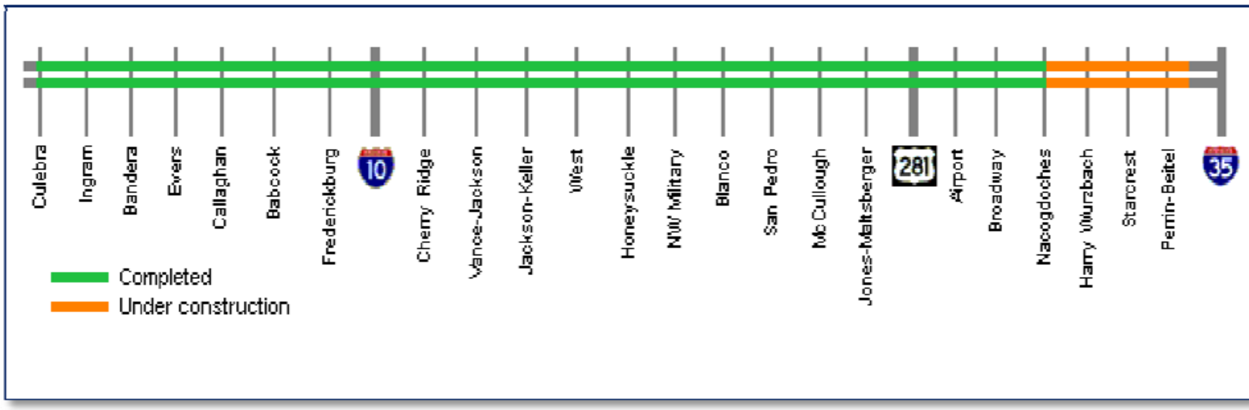


Figure 25. Loop 410 Construction Staging Schematic.

CONSTRUCTION COSTS

Loop 410 construction costs for the segments from Culebra through I-35 represent a cost of approximately $753 million (Table 1).[17]

[17] Texas Department of Transportation, San Antonio District.

Table 1. Segment Construction Costs for Loop 410 Reconstruction Project.

Main Segment	Start Year	Completion Year	Low Bid Construction Cost ($ million)	Right of Way Costs ($ million)
1. Cherry Ridge-Jackson	1995	1998	17.53	
2. Callahan-Fredricksburg	2000	2004	18.84	
3. Jackson Keller-Honeysuckle	2000	2005	29.59	
4. Honeysuckle-Blanco	2000	2005	18.85	
5. McCullough-US 281	2001	2006	13.115	
6. Callahan-North Crossroads	2002 1999	2009 2003	82.24 49.55	
7. Ingram-Callahan	2005	2010	75.09	5.38
8. Blanco-McCullough Ave	2004	2010	36.59	6.11
9. N. Cross Roads-Fulton Ave	2003	2008	60.59	
10. Culebra-Ingram	2003	2009	29.69	
Total for Completed Segments			431.68	
US 281 interchange Broadway-Beitel Creek Nacogdoches- Austin Hwy	Various for US 281 2006 2006		192.74 111.71 -	5.11
Total for Interchange Improvements and Yet-to-be-Completed Segments			304.45	5.11
Total Costs Total = $ 753 million			736.13	16.60

CONTEXT AND PROJECT GOALS

When it was originally constructed around San Antonio in 1966, Loop 410 was designed to handle 40,000 vehicles per day and was the first planned and constructed metropolitan loop in Texas. San Antonio's population in 1960 was 587,718. San Antonio's population has been growing, and the Census Bureau estimates the 2010 population to be approximately 1.35 million (Figure 26). Density as measured in persons per square mile has also been increasing since 1990 (Figure 27). By 1995, population approached approximately 1 million, and volumes on the roadway increased significantly. In the same year, TxDOT began what was then the largest freeway improvement project in South Texas history – expanding the loop's capacity to 400,000 vehicles per day while bringing the system up to modern design standards with a view to providing the much needed congestion relief. The Loop 410 project is located in the most densely populated region of San Antonio, as is seen from the 2000 population density map (Figure 28) surrounded by residential and commercial development even when construction started in 1995.

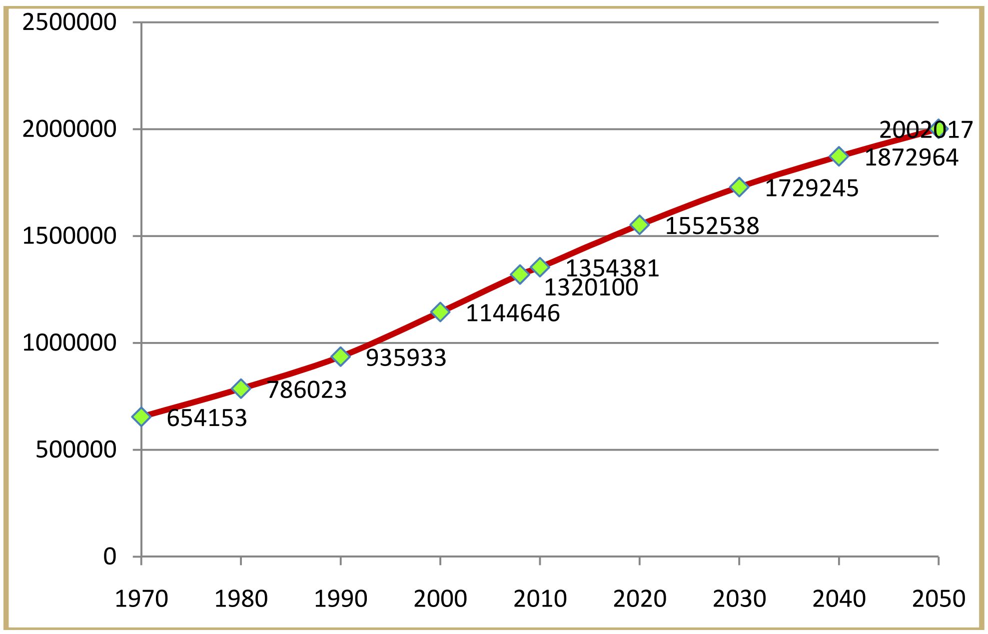


Figure 26. San Antonio Population Trends and Projections (*Source: Census Bureau*).

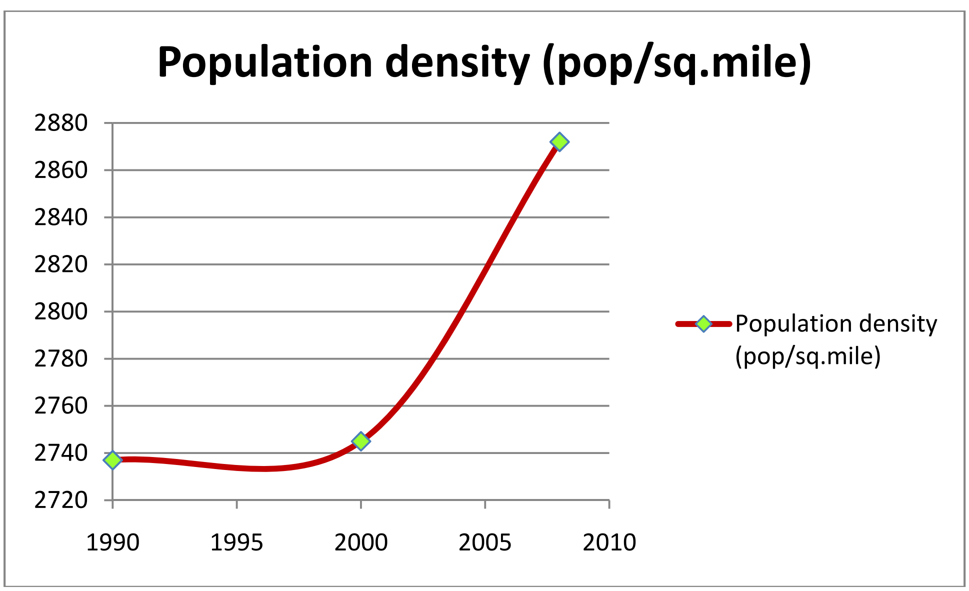


Figure 27. San Antonio Population Density Trends.

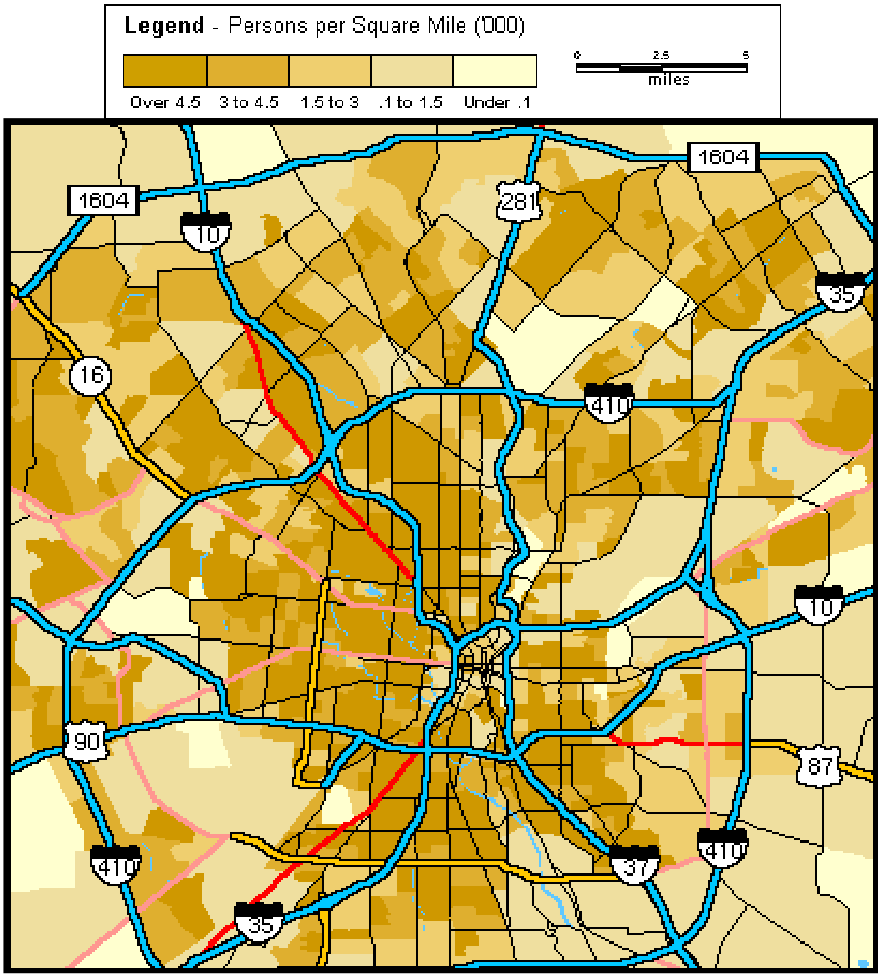


Figure 28. Population Density in San Antonio and around the Loop 410 Corridor (Year 2000).

HOW DOES ONE EVALUATE SUCH PROJECTS?

Planning Stage

Large-scale projects of this nature should undertake a full economic analysis in early stages and address economic consideration early on. This is possible by conducting a benefit-cost analysis and an impact analysis very early in the process. The benefit-cost analysis typically includes travel efficiencies, accident impacts, fuel cost impacts, and emission impacts (if applicable) and folds them into a life-cycle perspective. Impact analysis, on the other hand, conducts an analysis of the potential wider benefits and goes beyond looking at travel efficiencies into what the spending and efficiencies could mean to the region. Data needs for this kind of analysis typically involve demand model projections of build and no-build scenarios, which are fed into benefit-cost tools. TTI has developed several tools to help with this part of the analysis. Per the American Recovery and Reinvestment Act (ARRA) these criteria have become an important deciding element to help determine funding decisions.

Next, projects of this scale must conduct an economic impact analysis, which is different from a benefit-cost analysis. This economic analysis provides decision makers with a sense of how the project actually benefits the economy in ways wider than those considered in a benefit-cost analysis. It essentially provides a wider economic assessment. One reasonable way to conduct this analysis is to develop benchmark examples to see how items have impacted their economies.

Appropriate Metrics and Measures for Projects of This Type

The literature on economic impacts is replete with measures and metrics ranging from local measures to regional measures. Many kinds of measures might be selected for communicating the value of economic contributions. The prime concern is to avoid double counting when developing estimates of return on investment or cost-benefit analysis. Additionally, it is of value to propose metrics that are trackable.

Typical local trackable measures of economic impact for a project of this nature include:

- Land use impacts (changes in use, value, developments, private investments stimulated).
- Fiscal effects stimulated due to land use impacts.
- Impacts related to changes in sales.

Typical regional trackable measures of economic impact include:

- Contributions to regional output and value added.
- Job-related impacts (construction-induced contributions of operating and maintenance expenses and as a cumulative consequence of efficiencies and improvements made possible by the project).

Base values are often obtained in pre-completion stages or by using predictive methods and case comparisons.

Of the regional measures discussed when productivity impacts are likely due to potential impact on business activity, output is a representative measure of return on investments and represents the contributions to gross regional product. Together, these sources of economic impact accrue over the life of the project to government entities, other stakeholders, and to the general public. For instance, land use impacts accrue to the larger community in a variety of ways and often to individuals who directly benefit from a larger range of choices and private investments. Fiscal effects accrue to the larger community where these resources are used to provide services to a growing region.

Impacts accruing to users and/or commuters are another direct source of impact. These are not trackable and are often estimated using predictive methods and models. However, they are easily understood popular measures and accrue as a first-round impact from any project. Should these effects be small or negligible, the consequent economic impacts attributable to a project are also likely to be small and limited to just the construction spending stimulus.

- These include direct travel efficiencies incurred while driving. Travel efficiencies include both reductions in potential time traversing the improved road and improvements to reliability of the travel.
- In many situations, impacts on vehicle operating costs and fuel consumption are valid user benefits which, if quantifiable, should be considered.
- Contributions to safety.
- Contributions to air quality and emissions are also valid user impacts impacting overall quality of life and sustainability.
- Improvements in levels of service.
- Improvements in access.

Not all of these measures may be added up with user impacts to determine return on investment. For projects of this type, output contributions as a regional measure may be used as an appropriate metric. Other measures noted above accrue in different forms to different stakeholders.

Appropriate Time Span for Evaluation of Projects

In most predictive simulation studies and benefit-cost studies of large-scale projects, evaluation tends to occur over long time spans, most often over the typical service life of the project. In these studies, user benefits and induced economic impacts are assumed to continue to accrue through the project life span. A project of this nature, with its attendant capacity additions, in a predictive study would be evaluated with a service life of 25 years from the end of construction. For Loop 410, this suggests a potential terminal evaluation year of 2035.

In most evaluation studies of projects that are already in place, the typical frame of evaluation of economic impacts is typically 3–5 years before start to a minimum of 5 years after completion with the necessary precondition being the availability of good data and causal models for analyzing true contributions. For Loop 410 improvements, this would imply a minimum evaluation period from approximately 1992–2016 (approximately 25 years). Given that the year is 2010 at the time of this report, an economic impact evaluation is likely to showcase only partial benefit and perhaps be more reflective of construction effects than a long-run steady state.

ESTIMATED DELAY IMPACTS

In order to estimate the efficiency increases of Loop 410 improvements, researchers were tasked with preparing estimates of the mobility impacts of Loop 410 improvements developed over the past 18 years. In aggregate, the improvement projects constitute an upgrade of the freeway through lanes and frontage roads along a 15-mile stretch of Loop 410 in northwestern and northern San Antonio between Culebra Road and I-35. Not only were the number of directional through lanes increased from three to five in each direction, but also major interchange improvements were made at the Loop 410 junctions with Bandera Road, I-10, San Pedro, and US 281. This chapter documents the methods and procedures used to estimate the roadway network performance changes attributable to the physical improvements within the Loop 410 corridor.

In an effort to quantify the commuter impacts of Loop 410 improvements, the research team identified and fulfilled the following goals for the operations assessment:

- Develop an operations impact methodology to estimate motorist delay before and after programmed improvements were made within the Loop 410 corridor.
- Incorporate interchange and intersection delay benefits, as necessary, to account for the system-wide impacts of Loop 410 improvements.
- Estimate before and after corridor average speeds and aggregated delay times to enable additional corridor improvement benefits assessment procedures.
- Project the impact improvements into future years, given available data resources and known improvements project timeline and details.

OPERATIONS BENEFITS METHODOLOGY

The motorist delay benefits estimation procedure for the overall Loop 410 improvement project utilized a procedure involving the following five steps:

1. Estimate mobility improvements along Loop 410 and I-10 primary travel lanes.
2. Quantify before/after delays at intersections (freeway-to-arterial facilities).
3. Quantify delay savings at interchanges (freeway-to-freeway facilities).
4. Estimate relative mobility benefits within the Loop 410 corridor relative to efficiencies realized in the entire San Antonio roadway network.
5. Estimate future benefits.

Step 1: Estimate Mainlane Operations Impacts

Among the most widely known products of TTI is the *Urban Mobility Report*[18] (UMR), an annual review of congestion in urban areas around the country. Contained within the latest UMR is a methodology for estimating peak and off-peak freeway and arterial speeds based on daily traffic volume per lane (see Figure 29). Thus, given the number of lanes on a given portion of a roadway facility and daily traffic volume data, it is possible to quickly estimate roadway performance.

This method was applied to the Loop 410 corridor to produce year-by-year estimates of the speeds on major segments of Loop 410 and I-10, and such calculations were produced for both a build scenario (i.e., segments of Loop 410/I-10 improved as per construction completion schedule) and a no-build scenario (i.e., all segments of Loop 410/I-10 if they retained three lanes in each direction).

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[18] Lomax, T. J. and D. L. Schrank. "2009 Urban Mobility Report." *Texas Transportation Institute*, College Station, Texas, July 2009.[19] Texas Department of Transportation, Traffic Map portion of agency website, http://www.txdot.gov/travel/traffic_map.htm. Site and page accessed during August and September 2010.[20] Daniels, G., D. Ellis, and W. Stockton. *Techniques for Manually Estimating Road User Costs Associated with Construction Projects.* Texas Transportation Institute, 1999.[21] Synchro plus SimTraffic 7 Traffic Signal Coordination Software, Trafficware, Ltd., 2007.[22] *Road User Cost Manual*, New Jersey Department of Transportation, June 2001.[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

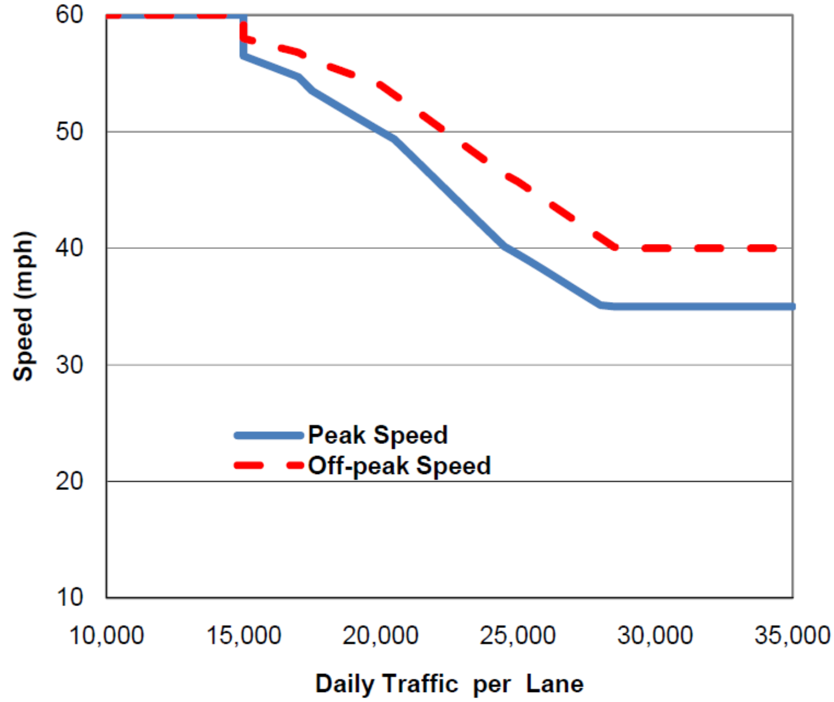

Figure 29. *Urban Mobility Report*, Freeway Speed Estimates.[1]

Input data for the UMR-based mainlane speed estimation process was extracted from annual average daily traffic (AADT) count maps produced by the Texas Department of Transportation's Transportation Planning and Programming Division. These data are online for the last three years,[19] data for years 1995–2005 were extracted from a TTI digital archive of TxDOT historic AADT count data from the same source. A sample of the 2008 AADT map for the San Antonio area is provided in Figure 30.

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[19] Texas Department of Transportation, Traffic Map portion of agency website, http://www.txdot.gov/travel/traffic_map.htm. Site and page accessed during August and September 2010.[20] Daniels, G., D. Ellis, and W. Stockton. *Techniques for Manually Estimating Road User Costs Associated with Construction Projects.* Texas Transportation Institute, 1999.[21] Synchro plus SimTraffic 7 Traffic Signal Coordination Software, Trafficware, Ltd., 2007.[22] *Road User Cost Manual*, New Jersey Department of Transportation, June 2001.[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

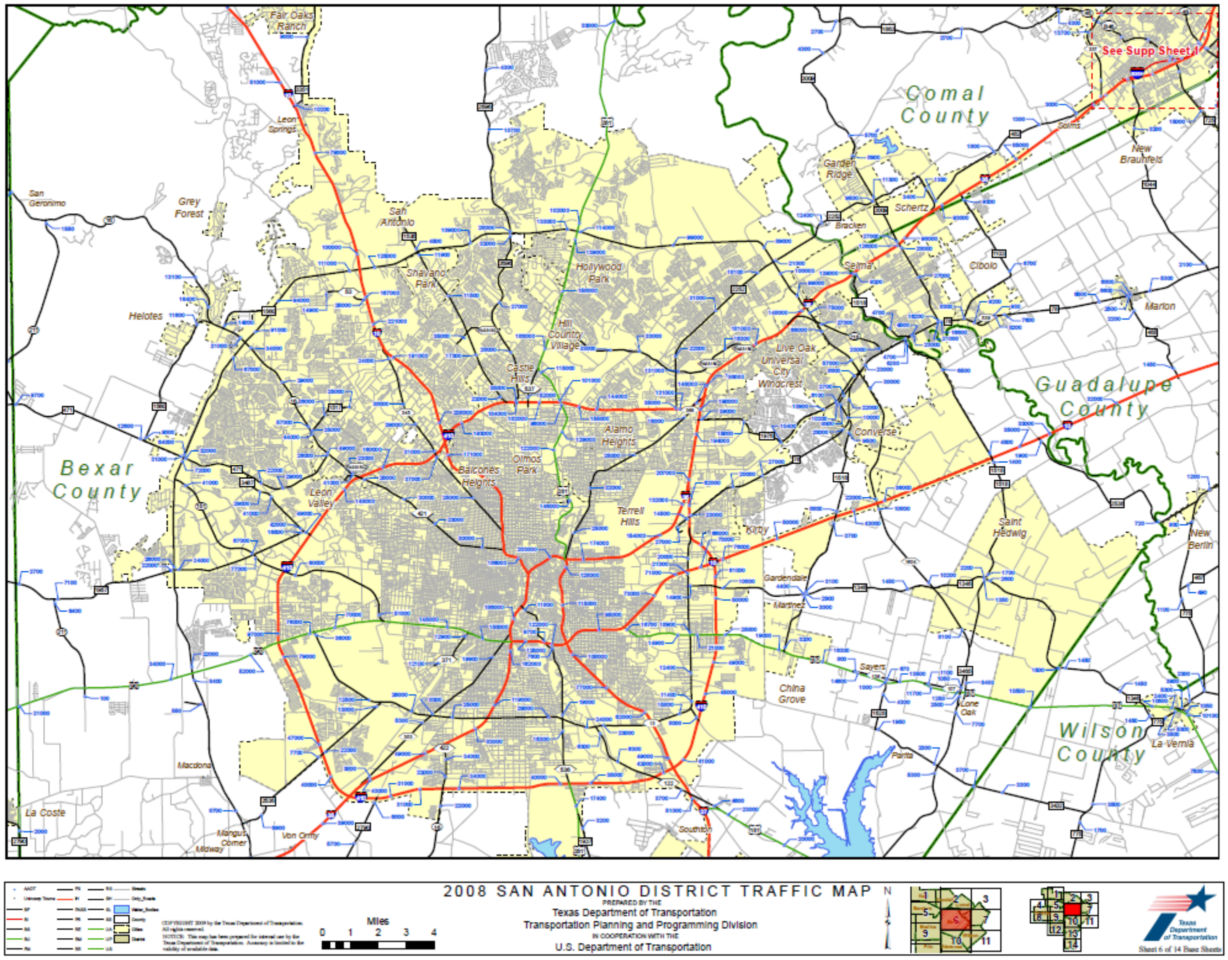

Figure 30. 2008 TxDOT San Antonio District AADT Map.[2]

To process the AADT data, segments along Loop 410 were established based on the locations of AADT reference data from the maps. Table 2 provides a list of the segment definitions used in the UMR analysis of mainlane segments of both Loop 410 and I-10. For each segment, basic assumptions were made that frontage road traffic consisted of 15 percent of the overall AADT volume, and that traffic was equally split on a directional basis over the course of the (average) day. A linear regression based on segment-by-segment traffic volumes from the previous five years was used to generate AADT data for 2009 and 2010.

Table 2. Loop 410 and I-10 Mainlane Analysis Segments.

Loop 410 Segment	Length (Feet)
I-35 to Austin Highway	1,100
Austin Highway to Perrin Beitel	3,600
Perrin Beitel to East of New Braunfels	15,600
East of New Braunfels to East of Wetmore	3,400
East of Wetmore to West of McCullough	8,750
West of McCullough to East of Blanco	3,250
East of Blanco to West of Vance Jackson	9,600
West of Vance Jackson to East of Evers	21,300
East of Evers to West of Bandera	6,000
West of Bandera to Culebra	12,800
I-10 Segment	**Length (Feet)**
Callaghan to Crossroads	7,000
Crossroads to Vance Jackson	5,400
Vance Jackson to Fulton	11,700

Researchers adjusted AADT for directional volume and frontage road traffic to produce a mainlane AADT estimate and then divided this value by the number of lanes present within each Loop 410 and I-10 segment for the build and no-build conditions based on construction completion information supplied by TxDOT (Table 3). As the outcome of this process was a daily volume by lane, analysts were then able to directly apply the UMR process to generate a peak-hour mainlane speed estimate. Segment-by-segment peak-period speeds were used to compute segment travel times, and differences were computed between the build and no-build scenarios.

To convert the average daily peak delay savings into an annual savings value, researchers assumed that there was an equivalent of three peak hours of delay per day, that the ratio of traffic served in the peak hour compared to the average daily volume (i.e., the "K" factor) was 0.09, and that there were 250 typical commuting days per year. These assumptions and practices are based on the processes defined for TxDOT in estimating road user costs.[20]

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[20] Daniels, G., D. Ellis, and W. Stockton. *Techniques for Manually Estimating Road User Costs Associated with Construction Projects.* Texas Transportation Institute, 1999.[21] Synchro plus SimTraffic 7 Traffic Signal Coordination Software, Trafficware, Ltd., 2007.[22] *Road User Cost Manual*, New Jersey Department of Transportation, June 2001.[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

Table 3. Loop 410 and I-10 Phased-Construction Completion Dates.

Year	Construction Phase Completed
1998	Loop 410 – Cherry Ridge to Jackson-Keller
2004	Loop 410 – Callaghan to Fredericksburg
2005	Loop 410 – Jackson Keller to Blanco
2008	I-10 – Fulton to Loop 410
2009	Loop 410 – Blanco to McCullough Loop 410 – Culebra to Ingram Loop 410/I-10 Directional Interchange
2010	Loop 410 – Ingram to Callaghan Loop 410 – McCullough to I-35 Loop 410/Bandera Direct Connector Ramps Loop 410/US 281 Directional Interchange

Step 2: Quantify Arterial Intersection Impacts

Several arterial roadways experienced direct impacts as a result of the improvements constructed along Loop 410 between Culebra (to the west) and I-35 (to the east). The direct-connector ramps between Bandera Road and Loop 410 east of Bandera Road essentially removed westbound-to-northbound and southbound-to-eastbound traffic between the two facilities from the Loop 410/Bandera interchange and from Bandera Road from south of Seneca to Loop 410. The reconstructed Loop 410/US 281 interchange removed traffic being exchanged between the two facilities from both San Pedro (for US 281 North) and Airport (for US 281 South).

To account for the road user congestion impacts of the Loop 410 improvements that affected arterial roadways, the research team used the Synchro/SimTraffic[21] arterial roadway intersection analysis and optimization software. This program readily optimizes arterial roadway signal settings for a range of volume and geometry scenarios and produces a range of output data applicable to the benefits estimates procedures being used for the Loop 410 impacts assessment. Further, versions of Synchro input files with recent traffic volume data were available for the Bandera, Airport, and San Pedro corridors from TxDOT and the City of San Antonio Public Works Department. Analysts adapted these files to model both no-build (before/without

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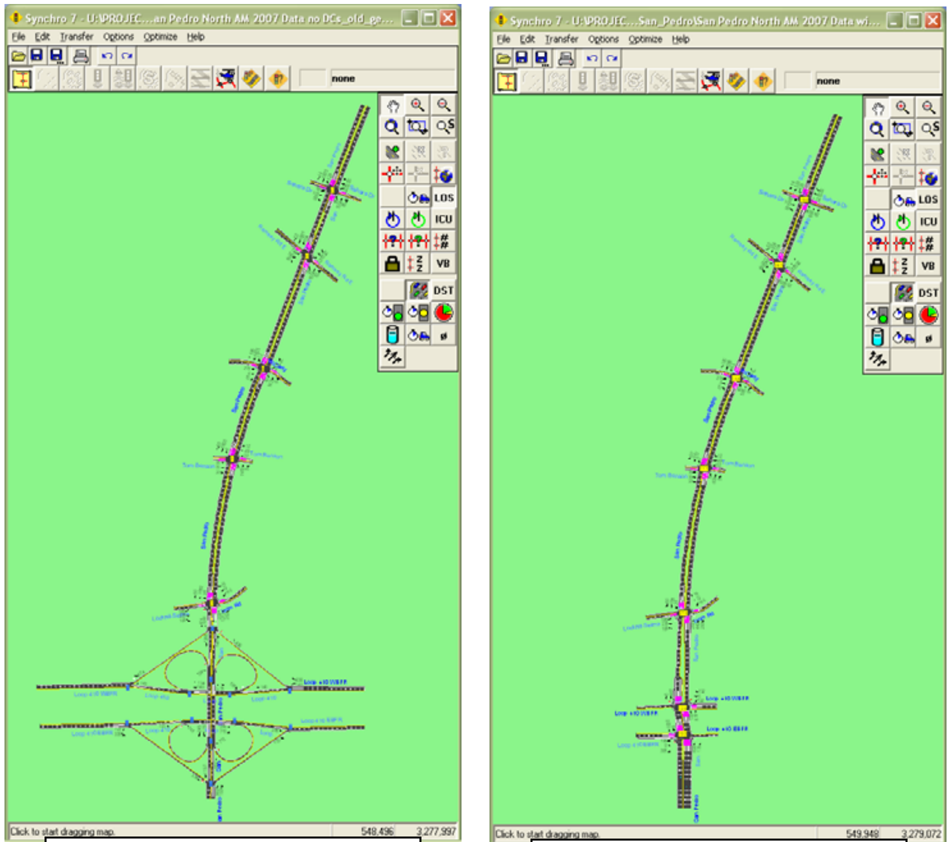
[21] Synchro plus SimTraffic 7 Traffic Signal Coordination Software, Trafficware, Ltd., 2007.[22] *Road User Cost Manual*, New Jersey Department of Transportation, June 2001.[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. “Assessing the Economic Impacts of Transportation Projects.” *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

improvements) and build (after improvements) conditions; an example of each network for San Pedro (US 281 to Loop 410) is shown in Figure 31.



No-Build Network (previous cloverleaf interchange)

Build Network (high-capacity diamond

Figure 31. San Pedro Synchro Models of No-Build and Build Conditions.

Synchro generated peak-hour delay estimates for both no-build and build networks for Bandera Road (between Loop 410 and Seneca), San Pedro (between Loop 410 and US 281), and Airport (from US 281 to Loop 410). Differences in the delay values between the build and no-build condition were calculated as peak-hour delay savings introduced by the Loop 410 corridor improvement project. Following road user cost estimation procedures, analysts translated peak-hour benefits to annual benefits by assuming the equivalent of three peak hours of delay per day and 250 commuting days per year.

Step 3: Quantify Freeway Interchange Impacts

Researchers were able to apply arterial analysis software to estimate the congestion relief impacts that would be brought about by the Loop 410/Bandera connector ramps and the new

Loop 410/US 281 interchange, but they could not use this type of software tool for the Loop 410/I-10 interchange. This interchange was essentially rebuilt from a hybrid direct/partial cloverleaf design to a higher-capacity, fully directional ramp design; no arterial roadways were directly affected or served as connector routes between the two facilities. While a number of methodologies exist for estimating interchange delay, from time-intensive field studies to detailed microsimulation models, analysts determined that the most reliable method of quickly estimating delay was an input-output method that estimated queued, or unserved, demand within congested hours of the day. Essentially, the method estimates how much demand exceeds interchange ramp capacity on an hour-by-hour basis and tallies delay for hours during which ramp demand outweighs capacity.

Source data for ramp volumes within the Loop 410/I-10 interchange were estimated using AADT volume maps for San Antonio freeway corridors developed by the TxDOT San Antonio District with input data from the TxDOT Transportation Planning and Programming Division. To convert the ramp AADT data to hour-by-hour volumes, volume profiles from the New Jersey Department of Transportation's *Road User Cost Manual*[22] were applied. Profiles chosen were those whose K factor (i.e., ratio of peak hour to daily traffic volume) were consistent with traffic volume projections for the Loop 410 improvement project. Assumed ramp capacities were 1300 vehicles per hour for partial cloverleaf ramps, 2300 vehicles per hour for single-lane direct connector ramps, and 4200 vehicles per hour for two-lane direct-connector ramps. Since the daily volume profiles analyzed traffic for a full 24 hours of the average day, conversion of daily delay savings to annual savings simply required multiplication by 250 commuting days per year.

Step 4: Estimate City-Wide Impacts

While Steps 1 through 3 of this methodology explain the process for estimating benefits associated with roadway improvements directly within the Loop 410 corridor, there also exist benefits to other roadways within the San Antonio roadway network. These less direct benefits are more difficult to quantify in some respects, but in aggregate represent the extent to which Loop 410 becomes a more viable—or at least in regard to travel time—route in comparison with

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[22] *Road User Cost Manual*, New Jersey Department of Transportation, June 2001.[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

other roadway segments, some of which parallel improved portions of Loop 410 or I-10. As other roadways lose vehicles to the improved mainlanes and interchanges of Loop 410 and I-10, they become less congested; lower overall network delays are the outcome.

In an effort to estimate the quantity of network-wide benefits found for San Antonio roadways outside the improved portions of the Loop 410 and I-10 corridors, analysts employed a model of the entire San Antonio urbanized area. The DynusT dynamic traffic assignment tool was chosen for this aspect of the analysis, both due to the fact that an existing San Antonio roadway and demand data model was available and because the nature of the analysis could make use of the traffic routing capabilities of the DynusT program. The source model for the DynusT network was a year 2020 travel demand model of the San Antonio urban area developed by the San Antonio-Bexar County Metropolitan Planning Organization (MPO) in TranPlan. The network was obtained from MPO staff and converted to Dynasmart/DynusT format in 2005. While MPO staff currently use TransCAD travel demand modeling software and have an updated travel demand model for the San Antonio region, the older model was used for this analysis due to time constraints on the current analysis.

Similar to the previous steps of the traffic analysis on Loop 410, both a build and no-build network were created in DynusT. Build and no-build models were created at each time horizon at which a major new improvement was completed for Loop 410 (Table 7). Geometric details for each new, phased improvement were coded into the build models while the no-build models retained the Loop 410 and I-10 geometric details of the roadway network from 1998. The origin-destination table was factored up to reflect increases in San Antonio city traffic over time; a volume increase of 2 percent per year was used to reflect long-range, city-wide growth. A screen shot of the San Antonio DynusT network is provided in Figure 32, showing roadway segments included in the Loop 410 improvements assessment as highlighted.

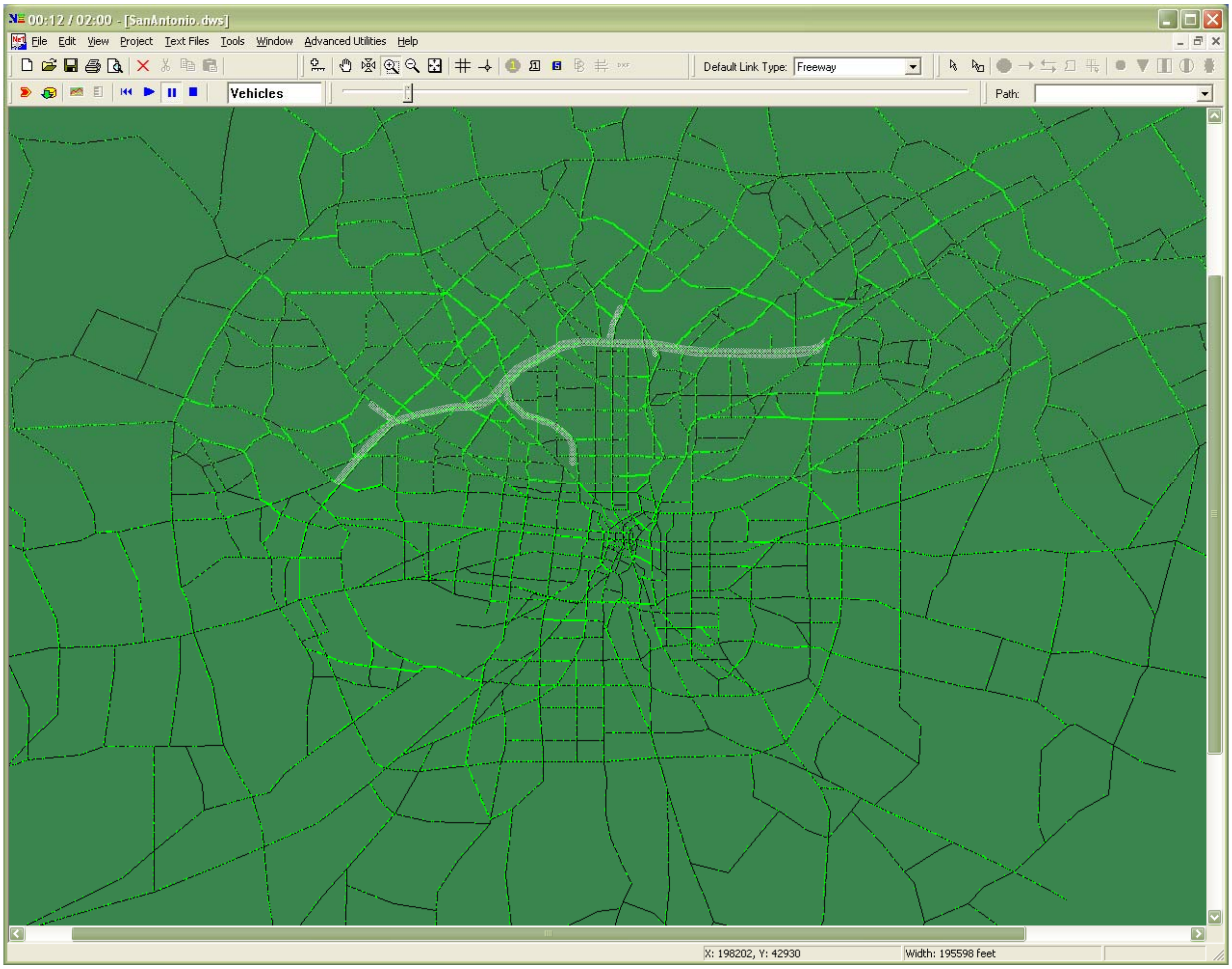

Figure 32. DynusT Network of San Antonio Urban Region (Study Segments Highlighted).

The "dynamic" aspects of the DynusT model mean that vehicles within the network attempt to identify a route that gets them from their origin to their destination in the least amount of time, realizing that route congestion has an impact on roadway travel time and that the level of congestion on a given roadway changes over time. In the build networks, vehicles could – and did – route from other roadways to take advantage of higher speeds on Loop 410 compared with alternative routes, especially as more and more of the Loop 410 improvements were completed.

Analysts produced separate tallies of the delay from DynusT along improved portions of the Loop 410 corridor (i.e., along Loop 410 between Culebra and I-35, I-10 between Fulton and Loop 410, Bandera Road between Seneca and Loop 410, Airport Boulevard between Loop 410 and US 281, and San Pedro between Loop 410 and US 281) and the overall network for both the build and no-build networks. After normalizing for Loop 410 project benefits for the build network, analysts then calculated the system-wide impacts of Loop 410 improvements as the difference in overall delay between the build and no-build networks. Since peak-hour conditions were modeled in DynusT, conversion to annual delay savings was performed assuming the equivalent of three peak hours of delay per day and 250 commuting days per year.

Note that analysts could not realistically use the DynusT model to provide accurate benefits estimates for Loop 410 and Interstate 10 mainlanes. Given the way that the San Antonio DynusT model was adapted from an earlier MPO TranPlan model, it represented all freeway corridors in the city with a single link. That is to say, both freeway mainlanes and frontage roads – and their volumes – between major crossing arterial roads and freeways were "coupled" together in a single network link. This rough level of roadway representation is adequate for travel demand models and trip estimation purposes, but was not judged adequate for producing realistic estimates of mainlane peak-hour speed. As other, operations-oriented methods were available to the analysis team for those aspects of the analysis, the DynusT model was simply used to estimate motorist benefits for all roadways in the San Antonio network, excluding the portions of the Loop 410 corridor where improvements were made.

Step 5: Estimate Future Benefits

Projections of traffic volume and delays for future years up to the year 2020 employed the same procedures and analysis models as the assessments of operating conditions and delay for years 1998 through 2010. For the Loop 410 and I-10 mainlane operations assessment, aggregated traffic volumes for all study locations along Loop 410 were projected forward to 2020 using linear regression of volumes form years 2006–2010. UMR procedures were then applied (see Step 1 discussion for details) to estimate build and no-build speeds for peak-hour conditions; these speeds were ultimately converted into travel times, delays, and annual delay savings (from comparisons of build to no-build operations). As several Loop 410 and I-10 mainlane links were observed to reach the congested speed threshold of 35 mph for the UMR procedures, analysts concluded that projections beyond the year 2020 using these techniques were impractical.

Projections for future arterial roadway (Step 2) and ramp (Step 3) impacts within the Loop 410 corridor were more broadly estimated. In 2008, the Loop 410/I-10 interchange was effectively completed. Loop 410/US 281 interchange impacts on San Pedro (between Loop 410 and US 281) and Airport (between US 281 and Loop 410) effectively began in 2009, when the

Loop 410/US 281 interchange was completed. Loop 410 direct connectors to Bandera Road were not completed until late 2009/early 2010. At the completion date for each project, the Step 2 or Step 3 procedures established the annual benefits expected for that year. Benefits for each subsequent year, up to the year 2020, were estimated to increase linearly with the overall traffic volume growth within the Loop 410 corridor, which was estimated by the TxDOT Transportation Planning and Programming Division at between 1.5 and 1.7 percent per year,[23] depending on location along Loop 410 within the study boundaries. A growth rate of 1.5 percent per year was conservatively selected for this aspect of the analysis.

For system-wide benefits estimation (Step 4), linear regression was applied to predict build versus no-build delay savings for both the entire San Antonio roadway network and the subset of roadways that are part of the Loop 410 corridor improvement project. Delay savings for Loop 410 corridor roadways were then subtracted from the overall San Antonio area network delay to provide an annual estimate of the amount of delay savings experienced by motorists on roadways outside of the improvement corridor. These benefits were ultimately added to the Loop 410 corridor benefits estimated using the more detailed procedures found in Steps 2 and 3 to produce final system-wide benefits estimates for each year between 2010 and 2020.

A final aspect of future year benefits estimation was to identify impacts of the Loop 410 corridor improvements beyond the year 2020. Though the methods described in Steps 1 through 4 have practical limits that preclude their applicability beyond the year 2020, the current MPO travel demand model for the San Antonio urban area has a year 2035 projection. Working in cooperation with MPO staff, analysts obtained year 2015 and year 2035 results for a build/no-build comparison for Loop 410 corridor improvements. Understanding that the planning model uses entirely different methods for computing project impacts, the primary utilization of the travel demand model's output was to establish a ratio of delay savings between San Antonio roadway network conditions in the year 2015 compared with the year 2035. This ratio was applied to estimated benefits from the year 2015 (as documented in this report) to roughly calculate expected benefits in the year 2035.

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[23] Loop 410 Corridor Analysis Traffic Projections 1995-2015, TxDOT Transportation Planning and Programming Division, May 1991.[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

OPERATIONS ASSESSMENT RESULTS

After applying the five analysis steps in the Loop 410 improvement impacts estimation methodology, measures of performance were available for both the Loop 410 corridor and for the San Antonio roadway network as a whole. Figures 39 through 41, along with Tables 8 and 9, present the results of the analysis. Delay statistics are presented as the primary measure of the corridor and system impacts of the physical improvements to Loop 410 (Culebra to I-35), I-10 (Fulton to Loop 410), Bandera Road (Loop 410 to Seneca), San Pedro (US 281 to Loop 410), and Airport (Loop 410 to US 281).

Within the Loop 410 Corridor

Table 4 and Figure 33 present the delay benefits information produced by the stepwise analysis procedure described in detail above. Both the tabular and graphical results illustrate that substantial benefits are not realized in the Loop 410 corridor until the 2008–2009 time frame, when the majority of the corridor's planned/phased improvements were completed. Additional insight into Loop 410 performance is available through Figure 34, which details an average peak-period mainlane speed for Loop 410 on the north side of San Antonio from Culebra to I-35. Speeds are observed to increase as improvements are constructed up to the completion year of 2010. After 2010, both the build and no-build networks show speed reductions as volumes increase over time, but the build network has an average speed that is over 15 mph high than that of the no-build network.

Table 4. Direct Delay Savings (Build vs. No-Build) for Loop 410 Improvements.

Improved Facility	Loop 410 Corridor Delay Savings (vehicle-hours/year)				
	2000	2005	2010	2015	2020
Loop 410 – Culebra to I-35	215,200	490,400	881,400	1,207,700	1,346,200
I-10 – Fulton to Loop 410	n/a	n/a	304,700	426,700	396,900
Loop 410/I-10 Interchange	n/a	n/a	757,800	816,300	879,400
Loop 410/US 281 Interchange	n/a	n/a	214,700	231,300	249,100
Bandera Road – Loop 410 to Seneca	n/a	n/a	212,300	228,700	246,300
TOTAL	215,200	490,400	2,370,900	2,910,700	3,117,900

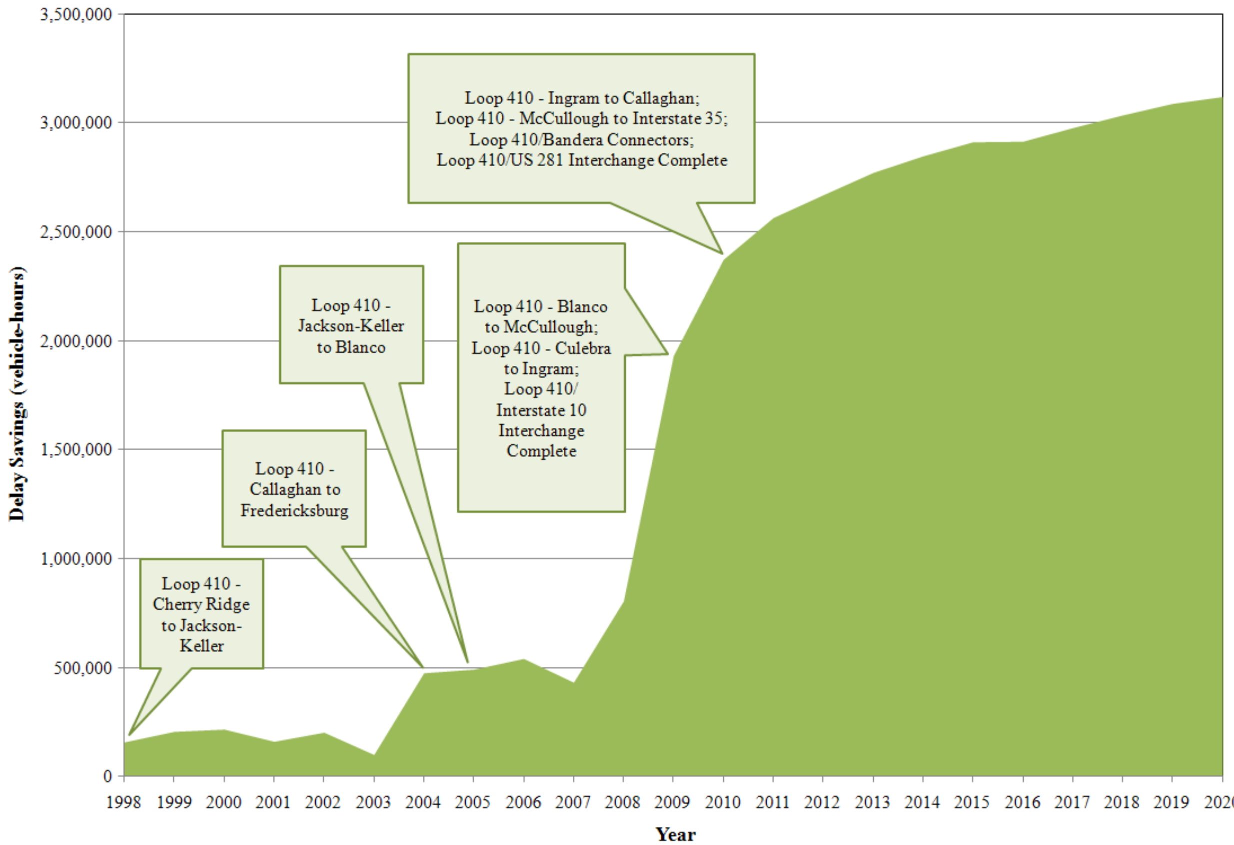

Figure 33. Annual Delay Savings (Build vs. No-Build) for Loop 410 Corridor Improvements.

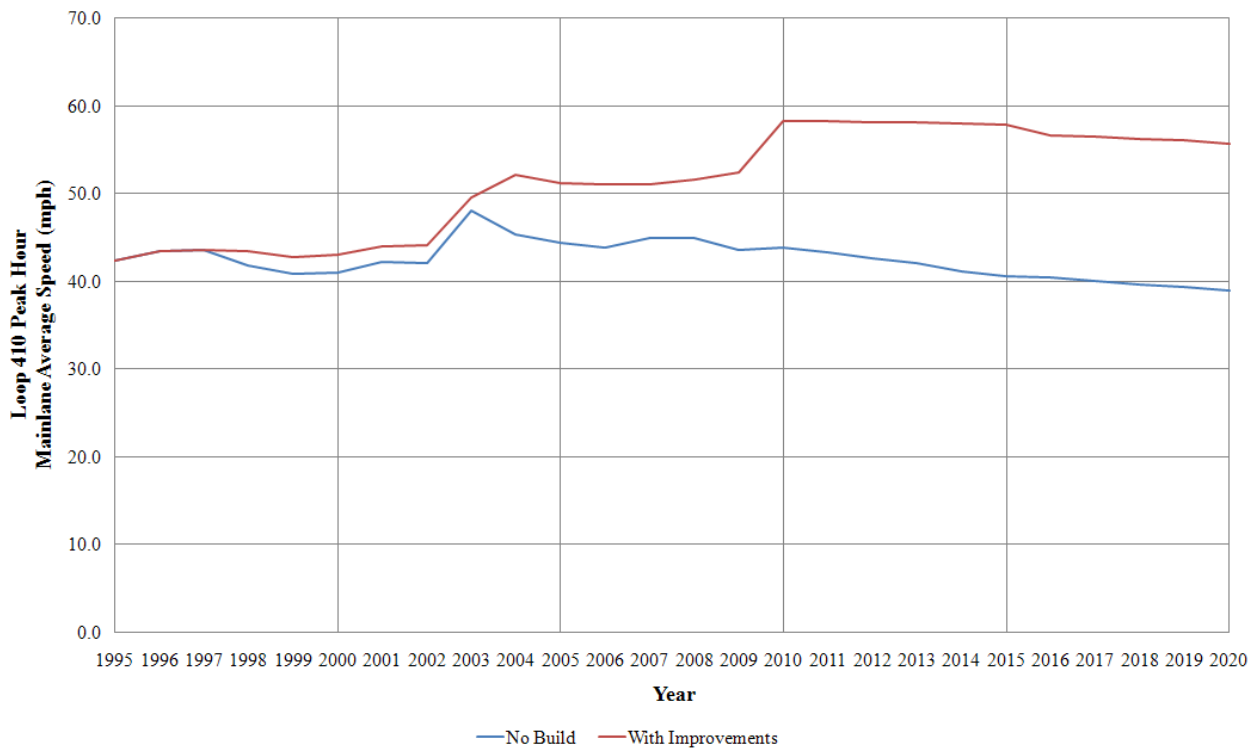

Figure 34. Loop 410 Average Peak-Period Speed – Culebra to I-35.

In the San Antonio Metropolitan Area

Results for the Loop 410 corridor clearly demonstrate the delay-saving impacts of the physical improvements made to Loop 410, portions of I-10 south of Loop 410, the direct-connect interchanges provided at Loop 410/I-10 and Loop 410/US 281 and the Bandera Road arterial to freeway connector ramps. When these benefit assessments are expanded to include the indirect delay-saving benefits found within the rest of the San Antonio area's roadway network, long-term delay reductions are noted not only for Loop 410 motorists, but for all urban area roadway users.

Table 5 and Figure 35 present the delay savings realized as a result of congestion in the no-build network being higher than congestion in the build network. Delay results are separated into that component occurring within the Loop 410 corridor where improvements were made, and more indirect delay savings occurring throughout the remainder of the network where volumes have decreased as a result of increased traffic utilizing improved portions of Loop 410 or I-10. Note that in early years of construction, there is little benefit or even some disbenefit caused by the discontinuity in Loop 410 cross-section brought about by construction phasing. However, the delay reduction benefits to both the corridor and the urban network are apparent as more of the Loop 410-related improvements are completed. In future years approaching 2020, the benefits outside of the corridor take on increasing importance as other roadways are more readily able to absorb trips in a roadway environment where a higher-capacity Loop 410 can absorb trips better served by the freeway trunk system.

Table 5. San Antonio Area Delay Savings (Build vs. No-Build) for Loop 410 Improvements.

Facility Component	Network Delay Savings (vehicle-hours/year)				
	2000	2005	2010	2015	2020
Loop 410 Corridor	215,200	490,400	2,370,900	2,910,700	3,117,900
San Antonio Area-Wide (less Loop 410)	-110,200	111,800	845,200	1,046,500	1,458,300
TOTAL	105,000	602,200	3,216,100	3,957,200	4,576,200

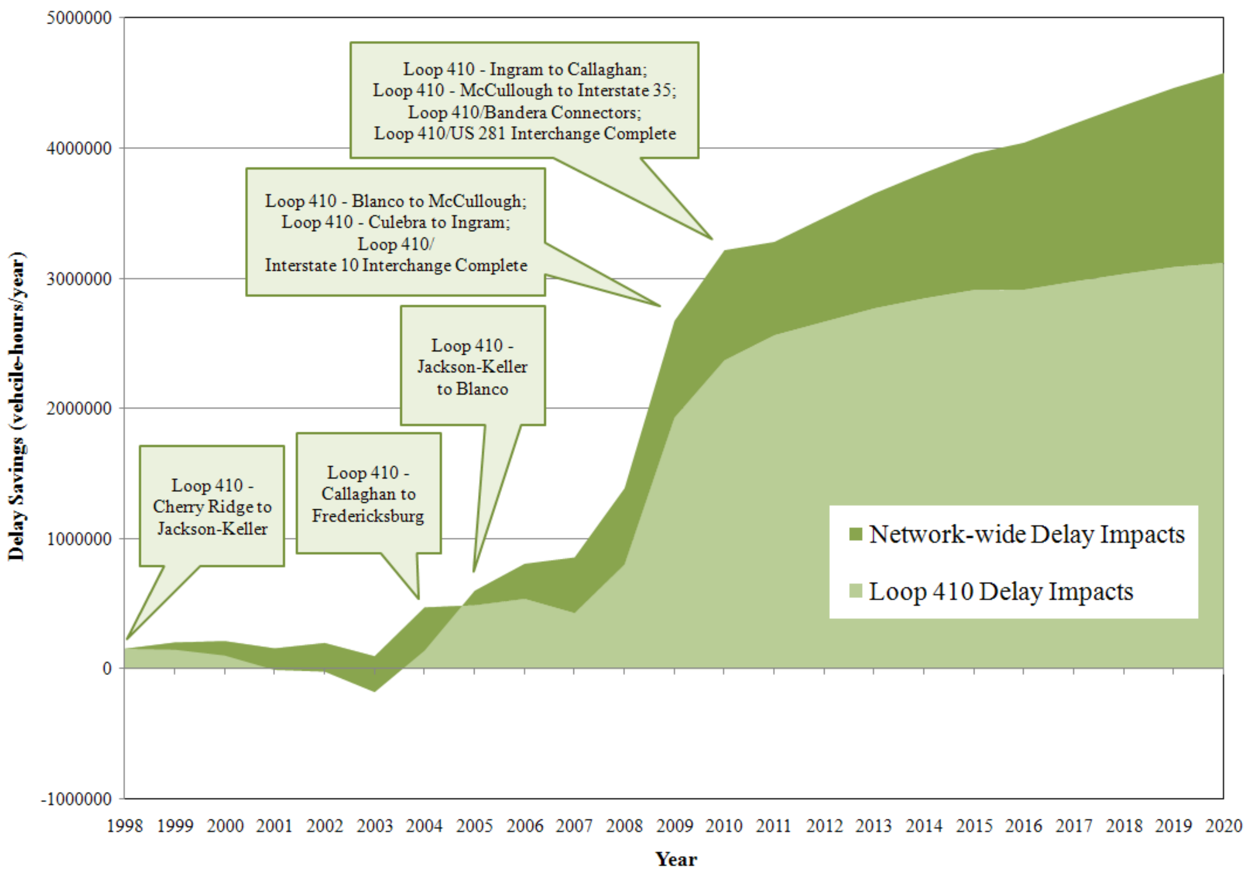

Figure 35. San Antonio-Wide Delay Impacts of Loop 410 Corridor Improvements.

The final aspect of network-wide benefits estimation was to apply methods for determining what impact the Loop 410 corridor improvements will have beyond the year 2020. To provide a basis for this estimation, city-wide model build and no-build network delay results were obtained in cooperation with the San Antonio-Bexar County MPO from the MPO's TransCAD travel demand model for the years 2015 and 2035. Since the model produced network-wide travel data for both average and loaded network conditions, both are reported in Table 6. In order to perform a straightforward comparison between 2015 and 2035 conditions, it was necessary to aggregate average and loaded network delay estimates into a single delay value. This was accomplished by a rough calculation of a weighted average daily delay difference assuming 6 hours (roughly speaking, peak-hour equivalents per day) of loaded network conditions per day and 18 hours of "average" traffic conditions per day. The resultant weighted average is presented in the rightmost column of the table.

The objective for this delay comparison was not the determination of network-wide delay estimates, but rather an approximation of the relative increase in network-wide delay between 2015 and 2035. This increase was calculated as the average ratio of 2035 to 2015 differences in delay between the build and no-build networks. Ratios were based on a weighted average of average and loaded calculations to produce a final 2035:2015 delay ratio of 2.95:1. Applying this ratio to the previously calculated 2015 delay savings of 3,957,200 annual vehicle-hours (see Table 11), analysts estimated that Loop 410 corridor improvements would produce an estimated 11,693,200 vehicle hours of annual delay savings in the year 2035.

Table 6. MPO Travel Demand Model Results – Build and No-Build Networks in 2015 and 2035.

Network	Daily Total Travel – Average Conditions (vehicle-hours)	Daily Total Travel – Loaded Network (vehicle-hours)	Daily Delay Difference Weighted Average (vehicle-hours)*
2015 No-Build	1,318,521	1,518,739	
2015 Build	1,314,165	1,491,743	
2015 Daily Delay Savings	4,356	26,996	10,016
2035 No-Build	1,876,874	2,394,939	
2035 Build	1,861,949	2,321,324	
2035 Daily Delay Savings	14,925	73,615	29,597
Ratio 2035 to 2015 Daily Delay Savings			2.95:1

* Assumes 6 "loaded" hours per day and 18 "average" hours per day

ECONOMIC IMPACTS

On behalf of TxDOT, researchers at the Texas Transportation Institute (TTI) conducted an economic impact study of Loop 410 reconstruction in the San Antonio area. The economic impact study involved a series of steps – these guiding steps have been established in various past studies.[24]

ARE THERE OTHER PROJECTS LIKE LOOP 410 THAT HAVE BEEN EVALUATED?

Congestion relief projects that have been studied and evaluated were extracted from the Strategic Highway Research Program (SHRP2) database of completed projects. Often, experiences from past similar projects provide the first best and simplest indication of the likely range of impacts for a planned future project. Much of that information might form the precursor to a more analytical study. Such information can then make its way into traditional environmental documentation combined with more detailed case analysis depending on specific circumstances surrounding the project.

Table 7 shows what measures were evaluated and tracked in two SHRP2 comparable cases. In the case of the I-15 expansion project, the direct effects account for 58 percent of total

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[24] Weisbrod, G. and B. Weisbrod. "Assessing the Economic Impacts of Transportation Projects." *Transportation Research Circular 477*, 1997. http://gulliver.trb.org/publicatins/circulars/circular477.pdf.

effects reported. In the case of a Dallas reconstruction project, the direct effects account for 63 percent of total effects reported 8 years after construction. The two representative cases indicate that effects could differ widely depending on specific circumstances and locations, since the effects evaluated represent the cumulative effects of spending and all feedback from every source of efficiency. In the I-15 scenario, the actual multipliers for indirect and induced effects are 0.23 to well over 100 for the US75 scenario. These indirect and induced effects could be attributable to induced efficiencies, agglomeration, and many other local factors like supportive policies.

Table 7. Comparable Stage-Constructed Case Examples: I-15 Expansion in Salt Lake, Utah, and North Central Expressway in Dallas.

Case Example 1. I-15 Project I-15 is the main transportation artery for in-state commercial, commuter, and personal travel			
Case Discussion		**Net Impacts Evaluated**	
State	Utah	**Increased speeds *(From reports)***	Increased by 20%. Details NA.
City	Salt Lake City (SLC)	**Delay *(From Reports)***	Decreased by 36%. Details NA.
AADT	N/A	**Cumulative Jobs (Tracked)**	12,750 (7500 direct)
Type	Widening	**Cumulative Wages (million) (Tracked)**	$5.8 ($3.4 direct)
Planned cost	$1.3 billion	**Cumulative Output (billion) (Tracked)**	$1.73 ($1.01 direct)
Actual cost	$1.52 billion	**Evaluation period**	Pre construction -2008 (approximately 19 years)
Actual cost (2008$)	$2.67 billion		
Construction Start	1996		
Construction End	2001		
Length	17 miles		
Impact Area	SLC		
Goal	Congestion relief, improve deteriorating condition in face of rising population growth		
Case Example 2. US 75 North Central Expressway combined with transit improvements in the same right-of-way. US 75 is the spinal cord of Dallas essentially radiating out from the Central Business District.			
Case Discussion		**Net Impact Evaluated**	
State	Texas	**Increased speeds**	N/A
City	Dallas	**Delay**	N/A
AADT	242,200	**Cumulative Jobs**	15,484 (9800 direct)
Type	Widening (Combined with transit)	**Cumulative Wages (million)**	$9.89 ($6.3 direct)
Planned cost	N/A	**Cumulative Output (billion)**	$2.9 billion ($1.9 direct)
Actual cost	$3.1 million	**Evaluation period**	Pre construction –2008 (approximately 19 years)
Actual cost (2008$)	$5.7 million	**Other measures evaluated**	Rising property values and tax base as early as end of construction year (up 2% in the improvement area due to synergistic effects) (*TTI Study, 2008*) (Evaluation period: 22 years since data were available)
Construction Start	1992		
Construction End	1999-2000		
Length	8.5 miles		
Impact Area	Dallas		
Goal	Congestion relief, in the face of explosive growth.		
Source: From SHRP2 T-PICS database and http://www.kiewit.com/projects/transportation/i15-corridor-reconstruction.aspx.			

LAND DEVELOPMENT CONDITIONS PRIOR TO AND POST CONSTRUCTION

Even in 1986, the Loop 410 corridor was characterized by dense urban development in the study area. Most of these urban developments were predominantly residential and commercial (Figure 36). Unfortunately, the available files from TxDOT did not cover regions outside the study area for 1986. Hence, they provided limited opportunity to explore other regions in the vicinity of the study area. Nonetheless the digital imagery files are still suggestive of pockets of undeveloped land along several parts of the corridor, particularly along its southern fringe near Culebra Road and nearby interchanges. The availability of some undeveloped parcels in a region that is growing is a necessary precondition for subsequent development and positive impact, given the right conditions and stimuli. (See Appendices A, B, and C for distributions of parcel growth.)

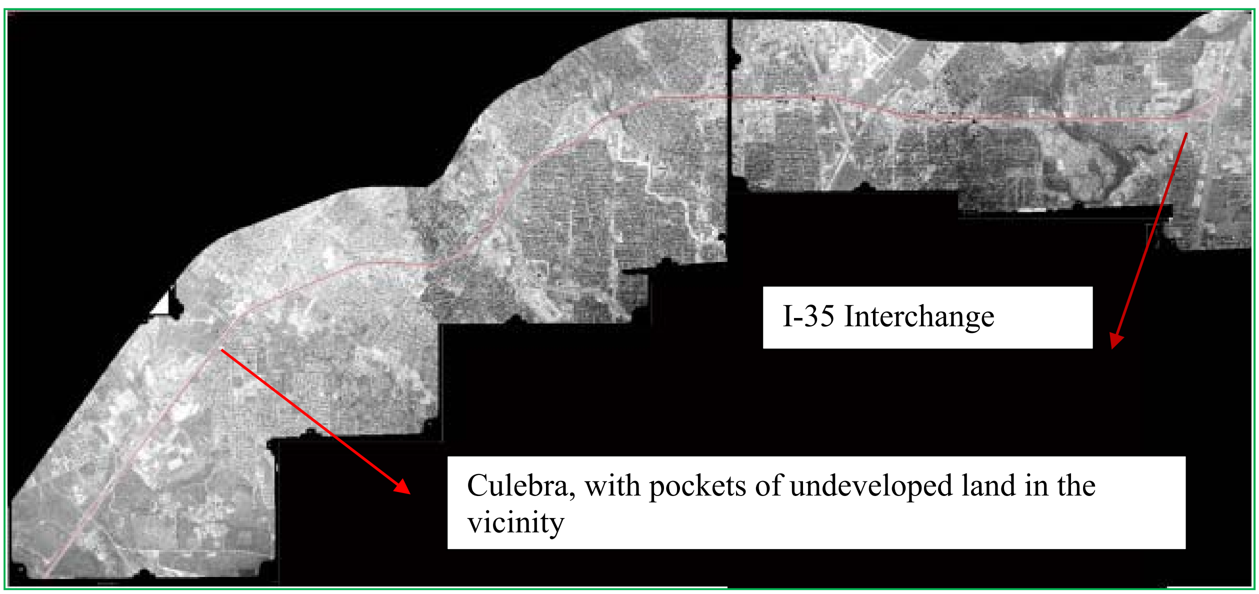

Figure 36. Land Development around the Loop 410 Corridor before the Loop 410 Project (1985).[25]

Several later years were explored for subsequent developments, and Figure 37 shows a snapshot of the same region in 2009, the most recent year for which aerial images were available for exploration (Figure 37). By 2009, a significant portion of Loop 410 had been reconstructed, and there was an even denser urban environment with increased development around the corridor. There was increased density and more development south of Culebra and, in general,

[25] Source: Made available by the Texas Department of Transportation.

all along the loop. There was also an indication of increased land development that might include the development of existing vacant areas, as well as redevelopment in some areas. Some of this is a natural result of population growth in the region. Yet patterns of altered land development both in and around the corridor in linked areas are clearly evident, with increasing population and population densities around the corridor.

Exploration of historical digital parcel data sets obtained from the Bexar County Appraisal District affirmed that the predominant forms of land use developments existing and spurred in and around the corridor were residential (low-density single family and high-density residential) and commercial developments.

Figure 37. Land Development around the Loop 410 Corridor (2009).[26]

Investigation of Contributions to Land Development in the City and Tax Base

Tables 8a-8b indicate interesting patterns as to where the growth has occurred and potential contributions to the city and consequently city tax base and county tax base and potential contributions to private investments in the region. The first part of the analysis focuses on growth patterns and the latter part on tax base effects.

[26] Source: Texas Natural Resource Information System (TNRIS).

Growth in terms of new development is observed all around San Antonio, but just prior to the reconstruction of Loop 410 the immediate vicinity of the study section recorded a higher growth in new developments and additions to tax base than the rest of the Loop. More specifically, a Loop 410 study in the immediate vicinity added an additional 2,736 parcels (with an average 2010 value of $254,000) just before construction relative to rest of the Loop. However, as construction progressed the new growth appears to have occurred in other portions of Loop 410 and elsewhere in the city. This seems to suggest that construction may have spurred growth and development in linked areas since the increasing population in the region would have to be absorbed in regions with greater land available for development. Furthermore, in the most recent years of construction, 2006–2010, which also correlated with economic downturns, there is decline in growth reflected in all regions. Tables 8a-8b, Figure 38, and Appendices A through C provide striking evidence of this dynamic.

Table 8a also indicates that during the construction years 2001–2005 there were significant contributions from the additions of high-valued property (756 parcels) within the immediate vicinity of the Loop 410 study area. In terms of new tax base and commercial private investment stimulated in the study area, the immediate vicinity of Loop 410 added approximately $1.2 billion ($2010) in new commercial and industrial investment value between 1996–2010, constituting almost 15 percent of the overall city value during the same period in that category.

Table 8a. Land Development, Value Change in Loop 410 Corridor Properties (Study Area).

<table>
<tr><th>Year Group</th><th>Parcels</th><th>Parcel Growth (Relative to Previous Period)</th><th>Net Percent Change in Taxable Value Relative to 1999[27]</th><th>Average Value 2010</th><th>Change in Taxable Value (2010-1999)</th></tr>
<tr><td>Unknown</td><td>2620</td><td></td><td>-</td><td>$254,645</td><td rowspan="3">$5.9 billion for properties 1995 and earlier</td></tr>
<tr><td>1990 and before</td><td>24956</td><td>Base 1</td><td>521.36%</td><td>$941,380</td></tr>
<tr><td>1991–1995</td><td>488</td><td>Base 2- Pre construction</td><td>402.05%</td><td>$829,822</td></tr>
<tr><td>1996–2000</td><td>605</td><td>23.98%</td><td>426.84%</td><td>$555,449</td><td rowspan="3">$1.7 billion for properties developed 1996 and later</td></tr>
<tr><td>2001–2005</td><td>756</td><td>24.96%</td><td>-</td><td>$1,366,479</td></tr>
<tr><td>2006–2010</td><td>300</td><td>−60.32%</td><td>-</td><td>$302,741</td></tr>
<tr><td>Total</td><td>29725</td><td></td><td>571.7%</td><td>$254,645</td><td>-</td></tr>
</table>

[27] Data quality was very poor for years 1999 and earlier with several missing values, with 1998 being the earliest for which the appraisal district could provide data.

Table 8b. Land Development, Value Change: City of San Antonio Excluding Study Area.

Year Group	Parcels	Parcel Growth (Relative to Previous Period)	Percent Change in Taxable Value Relative to 1999	Average Value 2010
Unknown	47396		-	$129,990
1990 and before	234547	Base 1	−20.11%	$249,091
1991–1995	19898	Base 2- Pre construction	714.81%	$279,515
1996–2000	28738	44.43%	674.92%	$273,482
2001–2005	33039	14.97%	-	$449,615
2006–2010	16169	−51.06%	-	$190,175
Total	379787		113.03%	$129,990

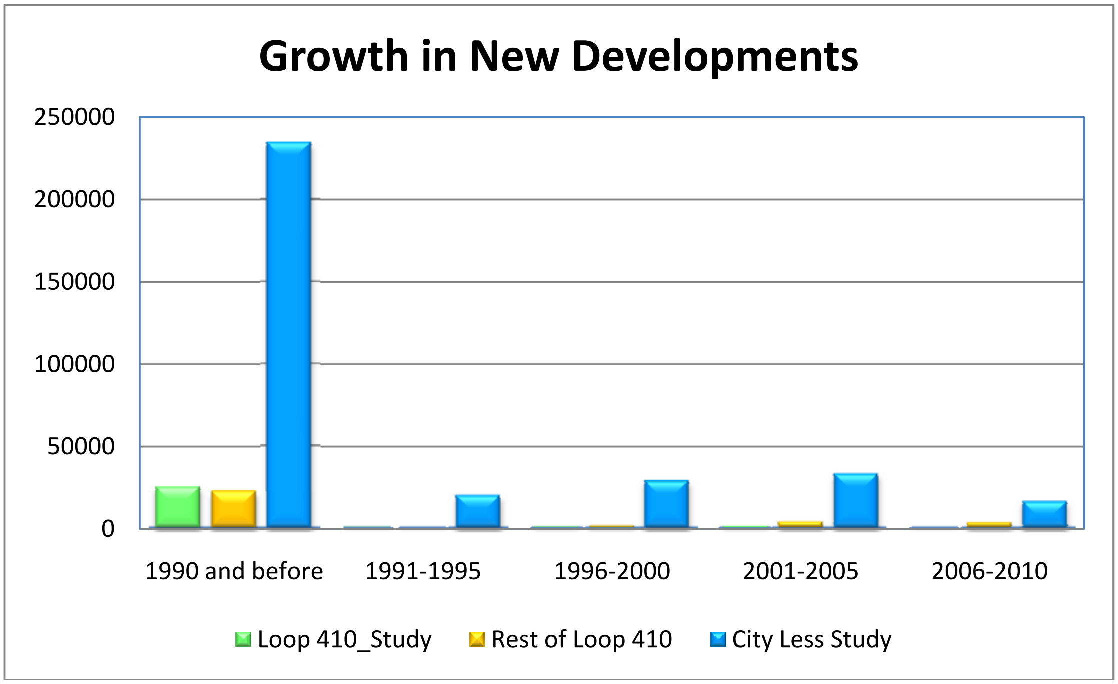

Figure 38. Development Trends-Loop 410 Study Section Relative to Other Areas in San Antonio.

Tax Base Effects-Fiscal Effects to Local Entities

Tax base effects accrue to city governments and school districts as a fiscal unintended effect of transportation improvements from three sources a) from additions to tax base, b) from appreciating properties, and c) from removals of tax base due to right of way acquisitions. Since very limited parcels were subjected to right-of-way[28] the last category was not considered specifically, however, they would be included as losses in parcel numbers and values in the year groups selected as long as they were complete acquisitions. Based on analysis in Table 8a and property tax rates for the city and independent school districts, a preliminary assessment was made to contributions to local entities. Property tax rates were obtained from the appraisal district reports.[29] Figures 39 and 40 show the average annual contributions made by Loop 410 study section properties during 1999–2010 to the city and to school districts in the region. Through the duration 2010, these accumulated benefits to the city and school districts amount to $43.3 million and $16.2 million ($2010). Over the 2020 duration, these same contributions to the city and ISD could amount to $79.39 million and $29.36 million, respectively ($2010).

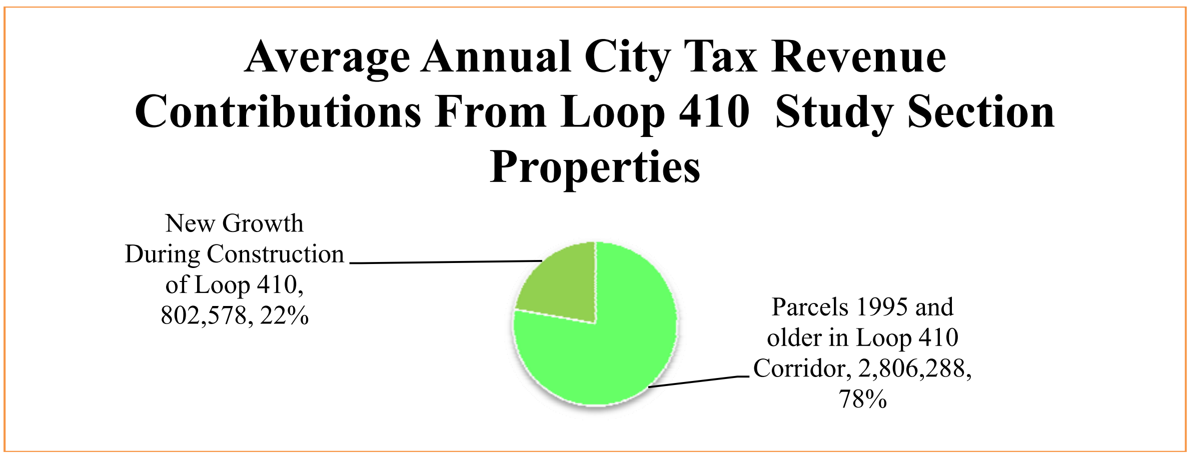

Figure 39. Average Annual City Tax Revenue Contributions (Loop 410 Study Section Properties).

[28] TxDOT cost tables suggested only 26 parcels affected by right of way acquisition.

[29] Property tax rates for the city and independent school district (ISD) did not vary significantly over the duration 1985–2010. Hence, the city and ISD tax rates for 2009 were used for the analysis: city tax rate = 0.56569 per $100 valuation, ISD rate = 0.211500 per $100 valuation.

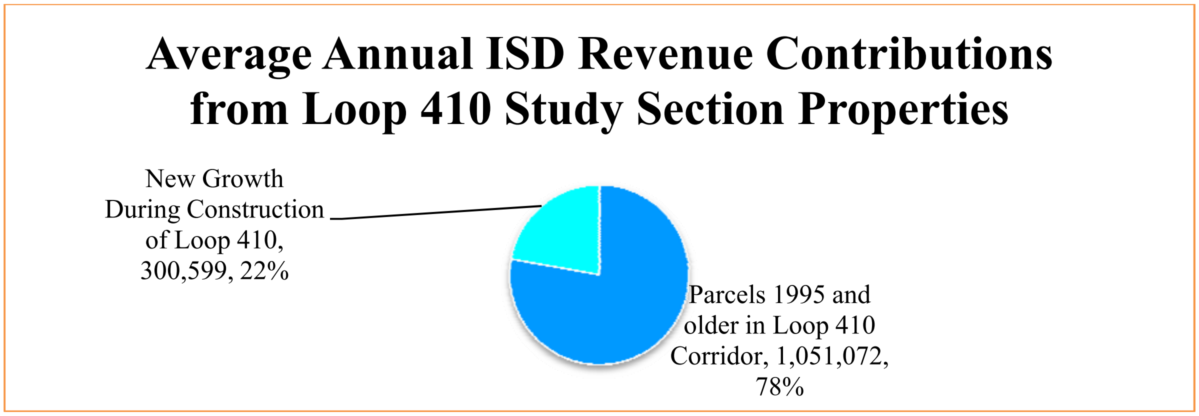

Figure 40. Average Annual ISD Tax Revenue Contributions (Loop 410 Study Section Properties).

COMMUTER BENEFITS AND TRAVEL EFFICIENCIES

Under typical settings, travel efficiencies are rarely ever tracked. They are often predicted using a variety of methods and from outputs of demand models. Few studies have attempted to develop delay measures that are temporarily sensitive to construction phasing. Figure 41 shows the commuter benefits that are evaluated through 2010 and 2020 in $2010. These are later discounted for use in benefit-cost analysis to the base year of 1992 the first year in which Loop 410 reconstruction expenditures were made.

Commuter Benefits – Speed Impacts

Approximately 31 percent higher speeds to date are estimated with the project in place (Figure 41).

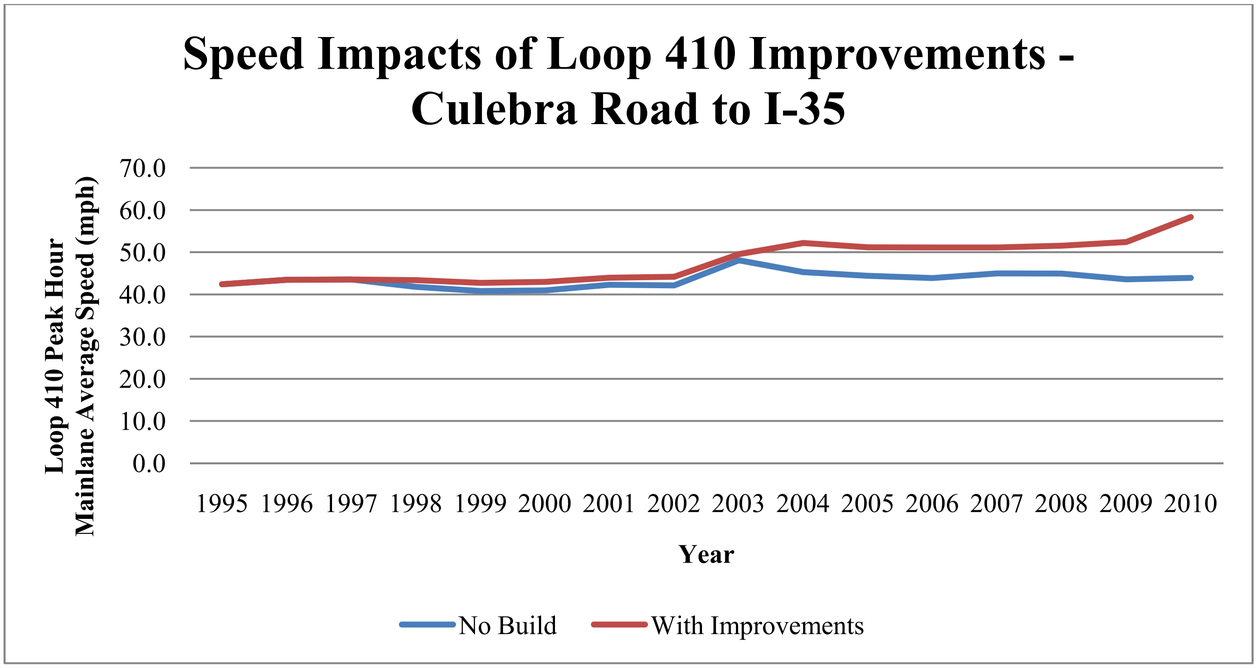

Figure 41. Speed Efficiencies Generated by Loop 410 Improvements.

Discounted Travel Efficiencies

Estimates of value of delay hours saved are often key elements in cost-benefit analysis. However, they need to be discounted for these purposes to a base year. In this case, the base year of 1992 was selected for the cost-benefit analysis since it was also the first year in which Loop 410 reconstruction expenditures were made. Table 9 shows the assumptions used to reassess delay savings and obtain the discounted value of delay savings used in cost-benefit analysis.

Table 9. Assumptions Used in Delay Savings and Discounted Value of Delay Savings.

Time Frame	Assumptions	Delay Hours Saved	$2010 Value 7%	1992 Discounted Value (7%)	1992 Discounted Value (3%)
1998-Through 2010	Combined value of time $26.5 (zero growth)	8 million	$ 114 million	$73.6 million	$168.1 million
Through 2020	Value of time- Same as above	36.9 million	$637 million	$228.3 million	$505.7 million
Through 2035	Value of Time- Same as above Other - 2035 annual delay hours of 11,693,200 estimated from MPO models used for the analysis. Values were linearly interpolated for 2021–2034 using the 2020 delay hours of 3,117,939 and 2035 estimates.	112 million	$1.2 billion	$393.09 million	$1.16 billion

Commuter Benefits – Fuel Savings

Fuel consumption savings is another significant effect of congestion relief projects. This section details the estimated savings in fuel consumption derived from delay hours estimated in the Companion Operations Report (Table 10). The fuel consumption savings are obtained using the following relation following Redbook procedures:[30]

$$fuel\ savings = change\ in\ delay \times fuel\ price \times fuel\ consumption\ in\ gallons\ per\ minute$$

[30] American Association of State Highway and Transportation Officials (AASHTO*). User Benefit Analysis for Highways Manual,* 2003.

Table 10. Fuel Consumption Savings from Delay Reduction.

Time Frame	Assumptions	1992 and 2010 Discounted Value of Fuel Savings 7%	1992 Discounted Value of Fuel Savings 3%
1998-Through 2010	Fuel price assumed at a conservative $2 throughout Combined fuel consumption gallons per minute of delay of 11 cents (3 cents for autos and 17 cents for trucks and using the 5% truck allocation) (*Source: AASHTO Redbook, 2003*) (Converted to gallons per hour) ($6.8 per hour) Free flow speed of 42 mph	1992: $40.3 million 2010: $62 million	$70.47 million 2010: 109 million
Through 2020	Fuel price assumed at a conservative $2 throughout Combined fuel consumption gallons per minute of delay of 11 cents (3 cents for autos and 17 cents for trucks and using the 5% truck allocation) (*AASHTO Redbook, 2003*) Free flow speed of 45 mph	1992: $121.12 million 2010: $335 million	1992: $266.6 million 2010: $443 million
Through 2035	-Fuel price assumed at a conservative $2 throughout -Combined fuel consumption gallons per minute of delay of 11 cents (3 cents for autos and 17 cents for trucks and using the 5% truck allocation) (*AASHTO Redbook, 2003*) -Free flow speed of 45 mph -Other - 2035 annual delay hours of 11,693,200 estimated from MPO models used for the analysis. Values were linearly interpolated for 2021 - 2034 using the 2020 delays hours of 3,117,939 and 2035 estimates.	$207.18 million 2010: $626 million	$609.7 million 2010: $1 billion

ECONOMIC IMPACTS OF CONSTRUCTION SPENDING

The construction cost expenses were evaluated for their potential economic impact on the economy using a Bexar County IMPLAN model. This analysis represents an analysis of the construction phase of the impact analysis (see Table 11).

Table 11. Construction Related Estimated Economic Impacts ($2010) (Short and Long Term).

Metric	Value	Comments	Accrues to Whom?
Cumulative Jobs	11,442	Construction including ripple and feedback.	Community
Cumulative wages and/or labor income earned	$387.9 million	Construction including ripple and feedback.	Community
Cumulative value added	$742.2 million	Construction including ripple and feedback.	Community/General economy
Cumulative output	$1.3 billion	Construction including ripple and feedback.	Community/General economy

The jobs are full-time equivalent jobs and are distributed in several sectors beyond the construction industry. These include but are not limited to: the manufacturing, mining, retail, and service sectors.

LIFE-CYCLE ECONOMIC IMPACTS OF RECURRING EXPENSES

Recurring expenses like operations and maintenance expenses also lead to economic impacts because of their infusion into the economy (see Table 12). Despite being small relative to construction expenses, these are expended through the life of the project and therefore bring a life-cycle perspective to economic impacts. Operations and maintenance expenses were obtained for both the East Loop 410 (non-study area) and for West Loop 410 (study area) from TxDOT. The composition of operations expenditures for both sections is shown in Figures 30 and 31. The 3-year average expenses for the West section are $770,518 and for the longer East section are $1.47 million. The East section data are shown as a benchmark, although they represent a much longer section. The expenses shown in Figures 42 and 43 are expenses for maintaining Loop 410 in its current status and would continue through the life of Loop 410.

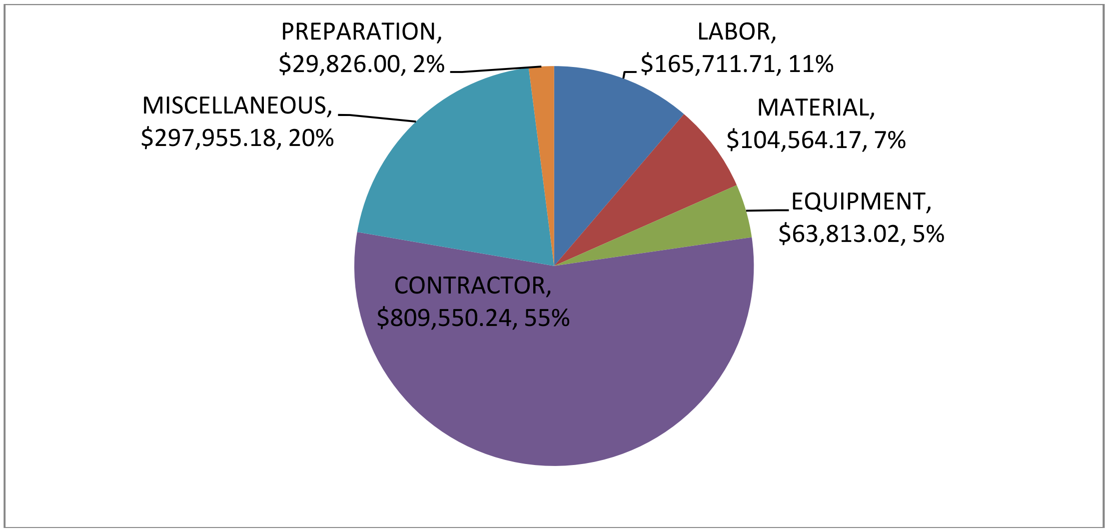

Figure 42. Operations and Maintenance Expenses on Loop 410 East Section.

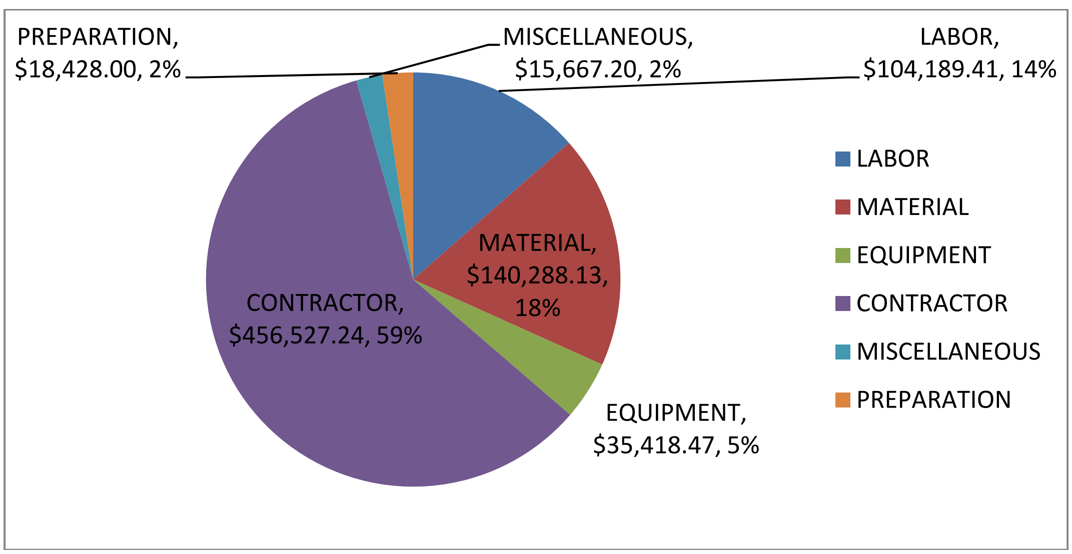

Figure 43. Operations and Maintenance Expenses on Loop 410 West Section.

Table 12. Life-Cycle Impact from Operations and Maintenance Expenses ($2010).

Metric	Value	Comments	Accrues to Whom?
Operations Spending Through 2020			
Cumulative Jobs	117 (76 direct)	Construction including ripple and feedback.	Community
Cumulative wages and/or labor income earned	$5.7 million ($4 million direct)	Construction including ripple and feedback.	Community
Cumulative value added	$7.3 million ($4 million direct)	Construction including ripple and feedback.	Community/General economy
Cumulative output	$19 million ($25 million direct)	Construction including ripple and feedback.	Community/General economy
Operations Spending Through 2035			
Cumulative Jobs	184 (120 direct)	Construction including ripple and feedback.	Community
Cumulative wages and/or labor income earned	$6 million ($9 million)	Construction including ripple and feedback.	Community
Cumulative value added	$11.5 million ($6 million direct)	Construction including ripple and feedback.	Community/General economy
Cumulative output	$39 million ($30 million direct)	Construction including ripple and feedback.	Community/General economy

BUSINESS EFFICIENCIES

Time savings are direct productivity benefits; however, construction spending also creates opportunities for induced efficiencies during reductions in the cost of doing business. In the long run, these induced efficiencies may lead to company input reorganizations with further repercussions to business productivity through contributions to output. One way to approximate these business effects has been to adopt a rate of return measure. While the jury is still out on appropriate rates of return, the rates of return estimated by Nadiri and Mamunaes (1996)[31] have been the rates most widely adopted (10 percent for highway capital stock). More recently, these rates have been questioned by researchers such as Clifford Winston and Chad Shirley who suggest more modes returns of 5–6 percent in production costs including logistics.[32]

Adopting a conservative 6 percent rate and the discounted costs in Appendix D, these business efficiencies of the construction spending in present value terms are shown in Table 13.

[31] Nadiri, I. and T. Mamunaes. "Contributions of Highway Capital to Industry and National Productivity Growth." *New York University and National Bureau of Economic Research*, 1996.
[32] Shirley, C. and C. Winston. "Firm Behavior and Returns from Highway Infrastructure Investments," *Journal of Urban Economics*, 2004.

In turn these business effects do have additional economic impact consequences by way of output and productivity effects in the long run. These feedbacks have not been figured in the calculations since these must be simulated. Assuming that businesses in San Antonio do not face tight labor and capital markets and are able to internalize efficiencies then a portion of the delay savings and fuel savings may be translated to productivity gains. If that were the case, approximately another $13 million in productivity gains to businesses could be gained from induced efficiencies associated with delay and fuel. The section below presents benefit cost ratios without considering these induced efficiencies.

Table 13. Estimates of Spending Induced Business Efficiencies.

Duration	Present Value of Business Efficiencies at 3% ($2010)	Present Value of Business Efficiencies Estimates at 7% ($2010)
Through 2035	$34 million	$45 million

BENEFIT-COST RATIOS

Benefit-cost ratios (Table 14 and Appendix D) are provided for three time frames and two scenarios: considering delay savings and fuel savings only, and delay and fuel savings and all related wider benefits associated with the spending itself. Loop 410 shows positive benefit-cost ratios for the appropriate reference time for a predictive study 2035 is over 1 in every case even with the conservative approach adopted in this study.

Table 14. Benefit-Cost Ratios for Loop 410 (Benefits and Costs Discounted to $1992[33]) at 7% and 3% Discount Rates.

Benefit-Cost Ratio Scenario #	Scenario	3%	7%
1. 2010	Time. Fuel	**0.42**	**0.30**
2. 2020	Time, Fuel	**1.36**	**0.90**
3. 2035	Time, Fuel	**3.09**	**1.54**
4. 2010	Time, Fuel, Spending (Construction and Operations) and Efficiencies	**1.85**	**1.35**
5. 2020	Time, Fuel, Spending (Construction and Operations) and Efficiencies	**2.90**	**2.04**
6. 2035	Time, Fuel, Spending(Construction and Operations) and Efficiencies	**4.82**	**2.75**

SUMMARY AND LIMITATIONS

The objective of this study has been to demonstrate the potential economic impacts of a large-scale congestion relief project like Loop 410. This study should be considered preliminary because projects like these should have a full evaluation study after completion for actual impacts. The time frame covered in this study represents a corridor that is still subject to construction and construction related effects.

This report had analyzed several sources of impact. In particular, the following sources of impact have been investigated and analyzed through three time frames: through 2010, through 2020 and through 2035.

- Delay reduction savings.
- Fuel consumption savings.
- Economic impacts from construction spending and operations spending including jobs supported, labor income, value added, and output.
- Induced business effects from spending.
- Visible effects of Loop 410 improvements on land and related fiscal effects.

[33] The year 1992 is merely used as the base to reflect the first injection of construction expenditures into the Loop 410 improvement. The construction costs were distributed on Loop 410 from 1992 onwards. Benefit Cost rations are based on output as wider economic benefit and evaluated as though the assessment was being conducted in 1992. Double counting is not an issue since alternative representations are not considered. Seven percent discount rates are recommended by Office of Management and Budget for recent projects.

The land development trends analyzed in this study provide an exciting first time evidence of linked outcomes and contributions of the Loop 410 project. The Loop 410 project may have stimulated growth in linked regions-East Loop 410 and just beyond the study area in addition to growth within the corridor. However, that said, note the following:

- The patterns and trends are merely suggestive of Loop 410 project's likely contributions. They are certainly not causal. Clearly, attributing these effects directly to the project certainly requires more investigation.
- The effects are also suggestive of construction trends. It will be of value to revisit this investigation a few years from now. However, in order to facilitate this study, it will be of value to maintain yearly records from the Bexar County Appraisal District as well as aerial photography of the entire city.
- Actual contributions to tax base can only be completely assessed 5+ years after completion. This analysis presents the likely contributions through the current time frame. Based on this analysis, the fiscal effect or benefit transfer to local governments by 2010 is estimated at $60 million in $2010 (city and school districts). Over the 2020 duration, these same contributions to the city and ISD could amount to $109 million ($2010).
- Evidence of $1.2 billion dollars ($2010) in new commercial and industrial investment tax base in the immediate vicinity of the Loop 410 value between 1996–2010 constituting almost 15 percent of the overall city value for the same category during that period.

The tax base effects are linked to land development effects. These effects are a unique unintended consequence-a fiscal effect that benefits local entities like school districts and city governments as these impacts may have been spurred by the improvement. These impacts are also subject to the same limitations and are not causal at this point. At best, they should be considered preliminary. However, they are a unique spillover fiscal effect. These effects should not be considered in any benefit-cost analysis since they are benefit transfers. However, they must be reported since they happen due to a first order response of land. These responses and impacts must be analyzed in greater detail for causal effects at an appropriate time frame, i.e., 5+ years post construction.

The Loop 410 project analysis suggests that the project may support a total of 12,000 jobs (sources combined direct, indirect, and induced) in various sectors of the San Antonio economy. These are estimates. This project's contributions to gross product of the San Antonio economy can be sized at approximately 1.2 percent of 2009 gross product of the San Antonio Metropolitan Statistical Area.

The economic effects examined do not consider in detail the joint interactions of time savings as a productivity benefit and induced productivity benefits to the construction stimulus. The effects must be simulated and studied in detail. The effects presented here are a first approximation. The degree of specific benefits, access, and induced efficiencies generated by an improvement in the specific context and region are critical to determining what the actual impact is likely to be. If these additional feedbacks from induced efficiencies are considered, they could lead to well higher positive impacts to businesses in the region as an improvement in the cost of doing business in the San Antonio region. The business survey should reflect some of these effects.

The benefit-cost analysis conducted for this study shows a ratio of 2.75 through 2035 at the Office of Management and Budget specified rate of 7 percent and 4.8 at 3 percent. The benefit-cost ratios are conservative estimates. Hence, Loop 410 may be said to generate a return of $3 for every dollar of investment. By 2020, the delay and fuel efficiencies would just about offset the cost of investment.

RESEARCH RECOMMENDATIONS

Near-Term Research

- There might be some value in conducting a more detailed study of regional economic impacts of this project. Clearly, the evidence of benchmark projects indicates that the range is very wide. This may provide a new look into the benefit-cost analysis presented in this report.
- Compile and track data for business sales, outputs, and employment in the region and corridor through current period.

Mid-Term Research

- Reevaluate the Loop 410 project approximately 6 years from now. This will allow a more comprehensive analysis of impacts from a project that will already have been in place and completed for 6 years by then.
- Develop a research agenda to evaluate similar congestion relief projects in the State of Texas and analyze them for their implications. In the larger scheme of issues, this agenda must be expanded to encompass projects of the widest variety and not just of the congestion relief type. Texas has limited recent evaluation studies as of now.

PROCESS-ORIENTED SUGGESTIONS

Large scale projects of this type must follow a process to enhance accountability and to ensure that expenditures incurred are also followed on by trackable economic consequences. Some of the key process recommendations revolve around the treatment of economics at the start of a project. These steps may be laid out in three stages: planning, construction, and post-construction. Large scale projects like this should also have tracking protocols to monitor first order jobs, i.e., the direct component of expenditures. This is now a federal requirement for all projects with ARRA funding, and it sets forth the framework to facilitate evaluation of all transport improvement expenditures. That would help provide better estimates of direct job numbers.

Planning Stage

- Explore the project, area, and circumstances of the project.
- Understand the demographics and regional conditions at the time of the project including land developments in the region. These latter analyses also facilitate the NEPA process and various categories associated with the NEPA regulation.
- What are economic projections for the region? Transportation projects typically have a positive impact when the economic conditions are strong and only tend to have a mitigating effect when the economy is not as strong.
- Will the project impact intermodal connections? Access? Access to what?
- Are there multimodal aspects?

- Is there likely to be a network effect? (From large-scale investments, pricing, or other source of traffic and operations impact)
- Determine the key sources of impact for the project. For most projects of this type, commuter impacts and economic impacts are typically considered. Evaluate these impacts through procedures discussed in this and companion reports and/or other methods.
- Draw from the experience of benchmark examples like the proposed project and document their effects. What transpired in those example cases? This provides cost-effective bounds on economic expectations.
- Conduct a detailed benefit-cost analysis for the project and operations analysis. There are many tools available for this purpose including simulation tools to sketch plans based on the project and its features. At the most basic level, TTI can make available a sketch plan tool called the Project Economic Evaluation Tool (PEET) (consistent with Federal Highway Administration criteria and Office of Management and Budget) calibrated for Texas that can facilitate a simple analysis of most impacts discussed in this report at the early stages. In most cases, for large-scale projects, PEET will have to be complemented with more detailed analysis until it is developed further.
- Establish a tracking protocol for job outcomes (direct) from spending.
- It is equally important to track accidents and safety implications.

Construction Stage

- Evaluate and monitor construction-related economic effects. These relate to business effects close by and containing road user costs due to lane closures and access limitations. This should have an important effect on overall economic impact of a project.

Post Construction Stage

- Conduct an evaluation study after completion to document effects (5+ years after completion).

BUSINESS IMPACTS

The research team contacted local companies and businesses in the greater San Antonio area to assess their perceptions of Loop 410 improvements. While these assessments are understood to be qualitative rather than quantitative in nature, they can provide a frame of reference for the impacts that major corridor improvements have had on the local and regional business community (see Appendix E). Researchers were in charge of designing a comprehensive survey to be strategically sent to San Antonio businesses that were directly impacted from Loop 410 improvements. To accomplish this task, researchers designed uniform criteria used to select businesses and compiled survey questions that accurately measure perceived impacts associated with Loop 410 improvements. See Appendix F for a copy of the survey questionnaire and Appendix G for some of the open-ended survey responses.

RESEARCH GOALS

In order to determine the business impacts of Loop 410 improvements, the research team set forth the following goals:

- Develop a research methodology to measure perceived impacts of Loop 410 corridor improvements.
- Assess perceived business attitudes toward immediate factors regarding travel time and mobility.
- Assess overall viability of business operations in the San Antonio region.
- Develop a survey using both ordinal and open-ended questions for various business leaders near relevant sections of Loop 410.
- Conduct and distribute an email survey to businesses that are directly affected by Loop 410 improvements.
- Summarize, analyze, and present survey results in one succinct report.

BACKGROUND AND OVERVIEW

Over the past 15 years, TxDOT has spent over $700 million on over 50 infrastructure improvement projects along Loop 410 in north and west San Antonio. Projects such as the reconstruction of a three-lane directional, access-controlled facility to a modern five-lane directional facility, two fully directional interchanges, and the addition of several direct connector ramps were among some of the most notable improvements made. As TxDOT strives toward facilitating the development and exchange of comprehensive multimodal funding strategies with project partners,[34] it is crucial for TxDOT planners to assess how these improvements have impacted the San Antonio business community.

Despite the nation-wide recession of the past few years, the San Antonio economy has shown itself to be remarkably resilient. According to a recent economic report that incorporated factors such as job counts and new home prices, the San Antonio region surpassed the other four major Texas metro areas in terms of economic performance. The San Antonio region is also one of the few regions in the country that has an economy that is performing slightly better now than in 2002.[35]

In addition, many trade unions and economists predict good economic times ahead for the region. One manufacturing trade union published an article suggesting a "very positive view" of San Antonio, claiming that the city "is widely perceived in the industry as a low-cost place to do business and that the cost of living is 10 percent below the U.S. average."[36]

The San Antonio economy is highly diverse, which means that the local population depends heavily on a flexible and vibrant transportation network. Top employment sectors include finance, government, biomedical and biotechnology, food service, manufacturing, and tourism. The service sector is the largest and fastest growing sector of the economy, largely due to increased demand for health care and business services. Medical and biomedical industries contributed approximately $11.9 billion to the area in 2003. San Antonio's highly regarded medical industry includes the 900-acre South Texas Medical Center, which employs approximately 25,000 people. The manufacturing sector, which employs over 50,000 and pays out over $2.2 billion in salaries, has grown from a $10 billion industry in 1996 to over $14 billion today; a 44 percent overall increase in just 14 years.[37] San Antonio's largest employers comprise a diverse industry sampling: USAA, H-E-B Grocery, Wells Fargo, Citibank, Valero Energy, Clear Channel Communications, and the Alamo Colleges System.[38]

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[34] Texas Department. of Transportation, Goal #6.
[35] Quarterly Economic Forecast, San Antonio Chamber of Commerce, July 2010.
[36] Costin, J. "San Antonio- Ahead of the Curve." Associated Equipment Distributors, January 1, 2010. http://www.cedmag.com/article-detail.cfm?id=10925592.
[37] San Antonio Chamber of Commerce, *San Antonio Manufacturing Industry*: 2006 Economic Impact.
[38] San Antonio Economic Development Corporation, *Major Employers and Support Organizations*, http://www.sanantonioedf.com/index.php?module=xarpages&func=display&pid=7, accessed September 2010.

The purpose of this analysis is to assess how infrastructure improvements along Loop 410 have influenced business development. One major goal of this analysis is to provide useful information so that TxDOT can critically evaluate how its improvements have impacted the local San Antonio business community.

SURVEY METHOD PROCEDURE

The survey method procedure involved the following three steps:

1. Map areas of improvements along Loop 410.
2. Collect business data and strategically select businesses for interviews.
3. Develop and distribute comprehensive email questionnaire.

Appendix H lists business survey comments.

Step 1: Map Construction Improvements

The first step involved assessing where the majority of the Loop 410 improvements occurred over the past 15 years. This step directed survey distribution toward businesses in areas where the majority of the Loop 410 construction occurred. Using available data obtained from TxDOT,[39] TTI researchers entered all construction project locations into BatchGeo web software in order to analyze where improvement construction occurred.[40] From the results, the study team found that a majority of the improvements occurred in or near nine major San Antonio zip codes: 78216, 78213, 78230, 78229, 78238, 78251, 78228, 78209, and 78217.

Step 2: Collect Business Data and Select Businesses to Interview

After zip codes near improvement sections of Loop 410 were identified, a request was sent to the San Antonio Chamber of Commerce for a list of all businesses located within those zip codes. The nine San Antonio zip codes that contained the segment of Loop 410 relevant for this analysis were identified and used to narrow the search results further. After business data were obtained, each business was then categorized based on industry type. Using the well-respected North American Industrial Classification System, all businesses collected were classified into 10 major industry categories. Business categorization was conducted to ensure

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[39] Data obtained from Projects-IH 410.xls; sent from Jonathan Bean of TxDOT to Steven Venglar of TTI, 8/5/2010.
[40] Location plotting software obtained online from http://www.batchgeo.com/

that a healthy sample of businesses from all industry types was collected for this study. Business categories used for this analysis include:[41]

- Construction.
- Retail Trade.
- Banking, Finance and Insurance.
- Real Estate Sales, Rental, and Leasing.
- Professional, Scientific, and Technical Services.
- Educational Services.
- Heath Care and Social Assistance.
- Government.
- Restaurants and Food Services.
- Accommodation.

Step 3: Develop and Distribute Comprehensive Survey

Once the relevant businesses were categorized, researchers began developing a survey that queried businesses located near the Loop 410 improvement section regarding immediate factors relating to travel time and mobility as well as impacts on the overall viability of business operations. Questions such as "Has your morning commute time increased or decreased since completion of the Loop 410 construction?" and "Has employee turnover increased or decreased since completion of the Loop 410 construction?" were asked. Overall, the research team sought to develop a survey that encouraged both open-ended and closed responses. Open-ended questions that allowed respondents to provide their own answers were included because they are preferred by most social scientists for collecting qualitative, in-depth information.[42] Both types of survey questions were chosen for this analysis because both open-ended and closed responses aid in providing a comprehensive view of the overall viability of business operations in the San Antonio region resulting from the improvements to Loop 410.

Survey questions were modified according to the industry and nature of the business. For example, businesses were asked different questions based on which industry category their

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[41] "Using Empirical Information to Measure the Economic Impact of Highway Investments," *Economic Development Research Group Inc.*, Federal Highway Administration, April 2001,
[42] The Practice of Social Research, 12th Edition.

business fell under. Businesses categorized as "Health Care & Assistance" were asked questions such as, "Before improvements were made to Loop 410, how often did you hear patients complaining about access to 410?" In contrast, businesses categorized as "Retail Trade" were asked more customer-related questions, such as "Have overall sales increased or decreased since completion of Loop 410 construction?" These questions were then analyzed and verified by researchers at TTI to ensure that survey questions were appropriately worded to reduce response bias.

Once all survey questions were verified, a link to the Survey Monkey™ questionnaire was forwarded to the San Antonio Chamber of Commerce. San Antonio Chamber of Commerce officials then distributed the survey to the businesses within the zip codes identified by TTI researchers.

SURVEY RESULTS AND ANALYSIS

TTI received a total of 44 survey responses from respondents located in the targeted zip codes, or about 10 percent of all surveys distributed. Some important findings regarding utilization of Loop 410 resulted from the analysis of these responses (see Appendix I). TTI researchers found that respondents generally concluded that they:

- Use Loop 410 more now than before improvements were made.
- Choose not to stay after hours to avoid heavy traffic more now than before Loop 410 improvements were completed.
- Spent less time waiting for traffic conditions to improve after work.
- Saw their morning and evening commute times decrease.
- Saw no change in employee turnover and employee tardiness.
- Were unlikely to relocate a business due to traffic congestion.
- Stressed the importance of access to Loop 410 for the viability of their business.
- Felt the improvements did not negatively impact their businesses.
- Were generally satisfied with Loop 410 after improvements were completed.

Profile of Businesses Surveyed

There was a wide variance in the number and type of business responses. The majority of the companies who responded were "Professional, Scientific, and Technical Services" companies making up 36 percent of the total businesses surveyed. “Banking, Finance, and Insurance” companies comprised 13 percent of the respondents; “Real Estate Sales, Rental, and Leasing Services” made up 11 percent of the total. Finally, 20 percent of respondents classified the nature of their business as “Other.” See Appendix J for a graphical breakdown of survey responses by industry.

Business Impacts Analysis

Business Longevity

There were important findings that resulted from survey input by over 40 respondents to the survey. Of all the companies surveyed, 55 percent of the respondents had been at their present location 10 or more years. Moreover, 73 percent had been at that location for at least five years. Only 7 percent of businesses surveyed had been at that location for less than two years. Thirty-nine percent of employees who answered the survey had worked at that location for at least 10 years.

When asked whether business leaders chose Loop 410 over alternative routes, respondents claimed to take Loop 410 much more often since completion of improvements. When asked how often they took Loop 410 before improvements were made, 32 percent of respondents responded “Never” or “Almost Never” compared to 11 percent who responded similarly after Loop 410 improvements were completed. In addition, 34 percent of respondents said they “Always or Almost Always” took Loop 410 before improvements occurred, and 59 percent had corresponding replies in connection with the time frame since completion. See Appendix K for more information.

Traffic Conditions

Respondents mentioned that they spent less time waiting for traffic conditions to improve after work. When respondents were asked how often they stayed after work to avoid heavy traffic, 32 percent mentioned “Always” or “Almost Always” before Loop 410 improvements were made whereas 7 percent said they stayed late since completion of improvements. Additionally, 39 percent of respondents mentioned that they “Never” or “Almost Never” stayed after work to avoid heavy traffic before improvements were made, versus 52 percent who had identical answers for the time since Loop 410 improvements.

Morning Commute Time

Generally, respondents said that morning commute time had decreased since improvements to Loop 410 were finished. Of all the businesses who responded, 60 percent claimed that their morning commute time has "Decreased" or "Slightly Decreased," 5 percent claimed that their commute "Increased" or "Slightly Increased," and 35 percent mentioned that there was "no change."

For businesses within the "Banking, Finance, and Insurance" sector, 80 percent responded that their morning commute had either "Deceased" or "Slightly Decreased" since completion of improvements. Additionally, 63 percent of businesses within the "Other" economic category claimed that their morning commute had either "Decreased" or "Slightly Decreased." Of the two respondents who were accommodation-related businesses, both said that their morning commute time has "Decreased" since the Loop 410 improvements were made. (See Appendix L for both morning and evening commute times.)

Evening Commute Time

For evening commute time, many businesses mentioned that their commute time decreased since completion of the Loop 410 improvements. Overall, 54 percent of respondents claimed that their evening commute time had "Decreased" or "Slightly Decreased," 38 percent said there was "No Change," and only 8 percent mentioned their commute had increased.

Eighty percent of "Banking, Finance, and Insurance" businesses responded that their evening commute time had decreased, but only 50 percent of "Other" businesses claimed that their commute time had "Decreased" or "Slightly decreased." Only 58 percent of "Professional, Scientific, and Technical" businesses claimed that their evening commute had decreased.

Employee Turnover Rate

The survey asked company leaders to assess their employee turnover rates. The general response was that there was little change in employee turnover. Of all the businesses surveyed, 92 percent responded that there was "No Change" in employee turnover, and 8 percent mentioned that employee turnover has "Slightly Decreased" or "Decreased" since improvements were made.

Employee Tardiness

The responses to the question regarding employee tardiness illustrated little change in employee tardiness after Loop 410 improvements were completed. Overall, 76 percent of employers noticed no change in employee tardiness, 21 percent claimed that employee tardiness decreased, while only 3 percent said they noticed employee tardiness increase during this time frame. Among the "Banking, Finance, and Insurance" industry, 20 percent mentioned that employee tardiness had either "Decreased" or "Slightly Decreased" during that time period.

Relocation Concerns

Overall, only 3 percent of all respondents mentioned that they were "Very" or "Extremely" likely to relocate their businesses due to traffic concerns since completion of Loop 410 improvements, and 92 percent mentioned that they were "Not at All" or "Slightly" likely to relocate since Loop 410 improvements were made due to traffic concerns.

Eighty-eight percent of businesses in the "Other" category mentioned that they would be "Not at All" or "Slightly" likely to relocate their businesses due to traffic concerns. Finally, all of the respondents in the "Banking, Finance and Insurance" industry said that they are "Not at All" concerned about needing to relocate their businesses due to traffic concerns.

Customer, Client, and Employee Access

In general, access to Loop 410 is very important to businesses interviewed in this survey. Forty-one percent of all businesses interviewed mentioned that access to Loop 410 is "Very" or "Extremely" important to the organization's decision to remain at its current location. All restaurant businesses interviewed said that access to Loop 410 is "Very" important for the company to remain at its current location.

Overall, 12 percent of respondents mentioned that they hear employees and customers complain about traffic on Loop 410 "Almost Never," or "Never" since improvements, as opposed to 36 percent before. Before improvements were made, 80 percent of the "Banking, Insurance, and Finance" companies said that their employees complained about access to Loop 410 "Sometimes." Since improvements were made, 80 percent of those same respondents said that they "Almost Never," or "Never" hear employees complaining about access to

Loop 410. Seventy-five percent of real estate businesses say that since improvements, tenants "Never" or "Almost Never" complain about access to Loop 410 from their properties.

Overall Loop 410 Business Impacts

Of those surveyed, 94 percent felt that the improvements had not negatively impacted their business, with 50 percent reporting a positive or slightly positive impact. Forty-four percent of respondents answered that they have experienced no impact from Loop 410 improvements and 6 percent responded that improvements have had a negative or slightly negative impact.

Open Comments

In the open comment section, there were many comments that seemed to praise the construction efforts undertaken by TxDOT. Some people mentioned that improvements have led to an easier commute to the San Antonio Airport from I-37 and Loop 410. Others mentioned that the Loop 410/I-10 interchange was "one of the few projects that [they] were happy to have their tax dollars go toward." Some individuals commented on how they were "amazed" by how well TxDOT kept traffic flowing during construction periods. Finally, one business mentioned that because they were service-oriented, improvements "have improved attitudes" about travel along Loop 410.

There were also some criticisms with Loop 410 improvement construction. Generally, the criticisms came in the form of ramp relocations and the length of the improvement project. One respondent expressed dissatisfaction with the Nacogdoches exit's removal/combination with the Fort Sam Houston exit and mentioned that the change in exit location made it more difficult for students to find their location. Another comment mentioned that on- and off-ramps and the turnarounds were areas that were not addressed by construction. Another commenter mentioned that the intersection of I-10 and Loop 410 still needed work. Finally, one respondent mentioned that these improvements had "detrimentally" damaged their business.

Others offered constructive suggestions for improvement. For example, one respondent mentioned that better police enforcement is needed to ensure that everyone is traveling the minimum speed limit. Others made specific recommendations to construction decisions. For example, one respondent mentioned that something needed to be done to increase visibility on the ramp from Loop 410 to I-10 and from I-10 to Loop 410. Finally, one respondent suggested that TxDOT consider what the road conditions will be in 20 years, and not just build for present needs.

CONCLUDING THOUGHTS, LIMITATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Businesses were generally mixed on how much improvements had benefitted their businesses. Survey respondents said that generally traffic conditions improved, morning commute and evening commute times had decreased, and employee turnover rate and employee tardiness had decreased. TTI researchers did their best to ensure that response bias was mitigated and that questions were clearly asked.

While this task sought to provide a well-developed snapshot of the feelings and concerns by the business community, TTI researchers suggest using a more comprehensive analysis with additional samples to get a more accurate picture of the feelings of the business community in the future. In addition, more data could be collected through the use of focus groups to collect business sentiment on the improvement impacts from Loop 410.

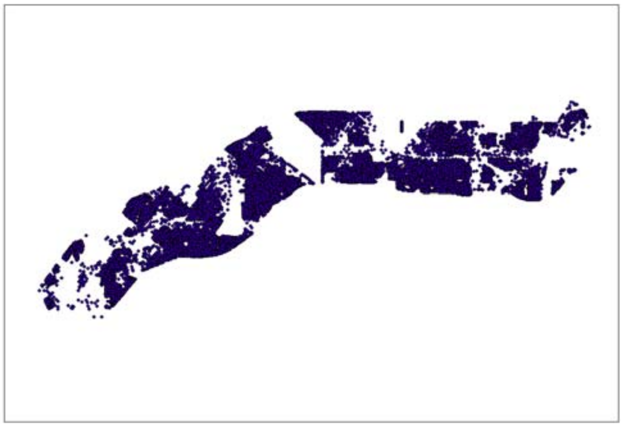
While considerable effort was taken to ensure that all research methods were carefully laid out, there were limitations to the research methods used for this task due to the inherent time and financial constraints associated with this project. These limitations include:

1. Due to the lack of data available, Loop 410 improvement sections were approximated to the nearest roadway intersection. Individual projects occurred throughout the Loop 410 corridor. However, it is likely that the distance between research projects and approximated locations varied by at most 1 or 2 miles.
2. This analysis did not take into consideration the nature of the transportation project. While improvement projects ranged from $100,000 in small utility adjustments to $1 million-plus lane freeway upgrades, each improvement was mapped along the highway. Due to time and funding constraints, further study focusing on improvement projects that could have the most impact on local businesses were not studied in this economic impact analysis.

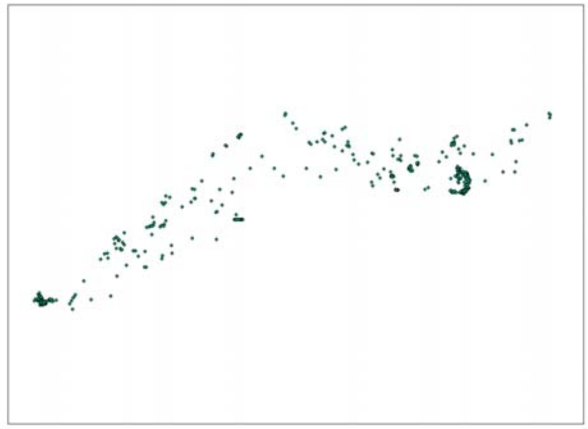
This is not a random sample of the San Antonio business population. Surveys were sent to businesses that were registered with the San Antonio Chamber of Commerce. This was because the Chamber of Commerce was the organization with the best available data providing business e-mail addresses. While TTI researchers concede that this is not a perfect approach, given the financial and time constraints for this analysis, it was the most practical. While the San Antonio Chamber of Commerce does not provide a list of all businesses in San Antonio (approximately 1800 businesses are registered with the San Antonio Chamber), TTI researchers are confident that this research procedure will still provide reliable results that are practical and useful for analysis by TxDOT.

APPENDIX A: DISTRIBUTION OF PARCEL GROWTH IN THE STUDY AREA

San Antonio Study Area Before 1990 Year Built

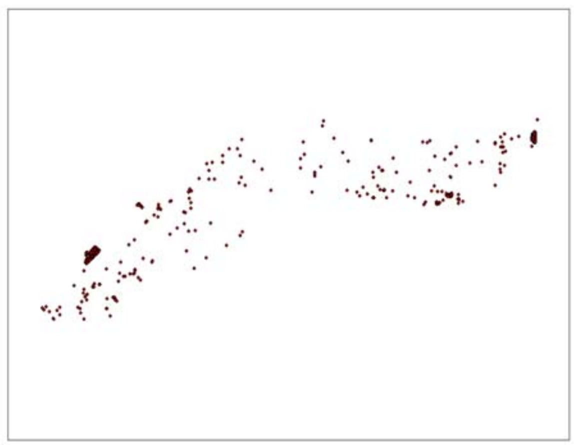


San Antonio Study Area 1991 - 1995 Year Built



San Antonio Study Area 1996 - 2000 Year Built

San Antonio Study Area 2001 - 2005 Year Built

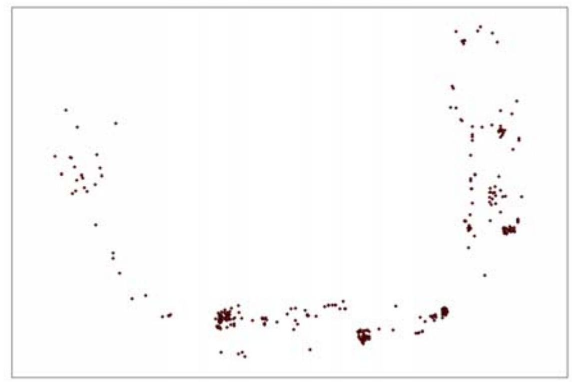


San Antonio Study Area 2006 - 2010 Year Built

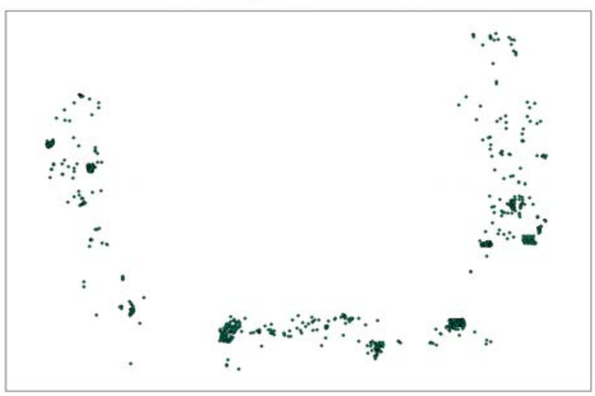
APPENDIX B: DISTRIBUTION OF PARCEL GROWTH IN THE REST OF LOOP 410

San Antonio Non Study Area 1990 and Before Year Built

San Antonio Non Study Area 1991 - 1995 Year Built

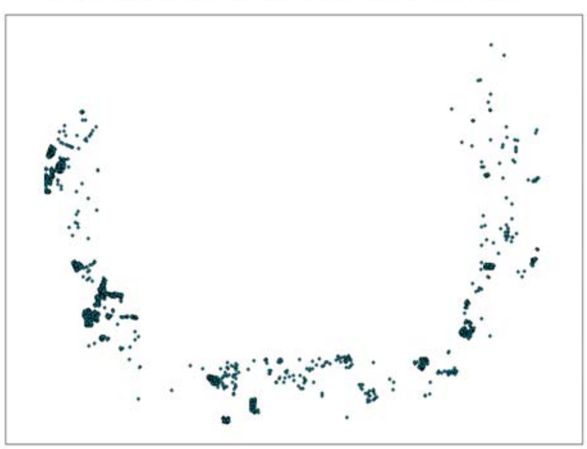


San Antonio Non Study Area 1996 - 2000 Year Built



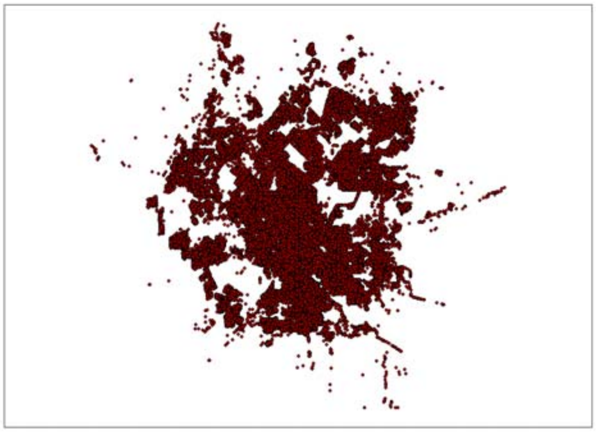
San Antonio Non Study Area 2001 - 2005 Year Built

San Antonio Non Study Area 2006 - 2010 Year Built

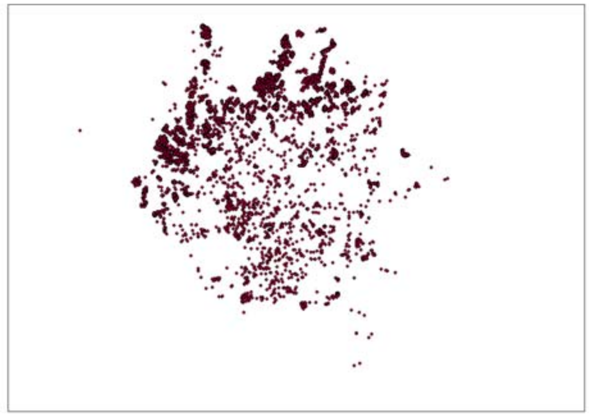


APPENDIX C: DISTRIBUTION OF PARCEL GROWTH IN THE CITY

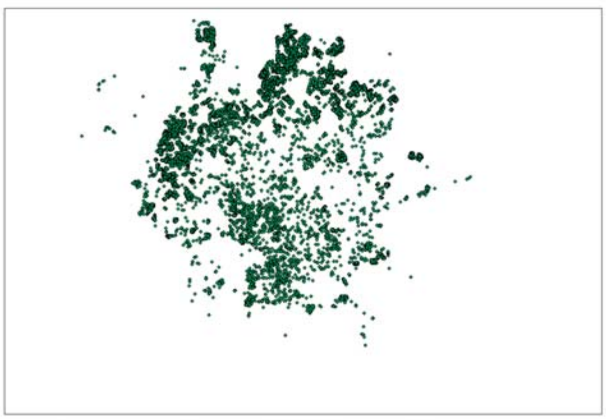
San Antonio 1990 and Before Year Built



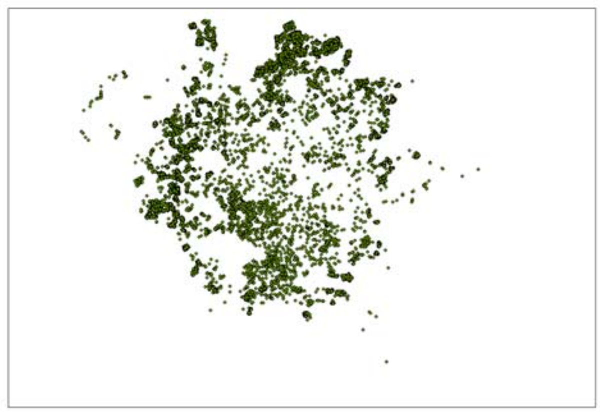
San Antonio 1991 - 1995 Year Built



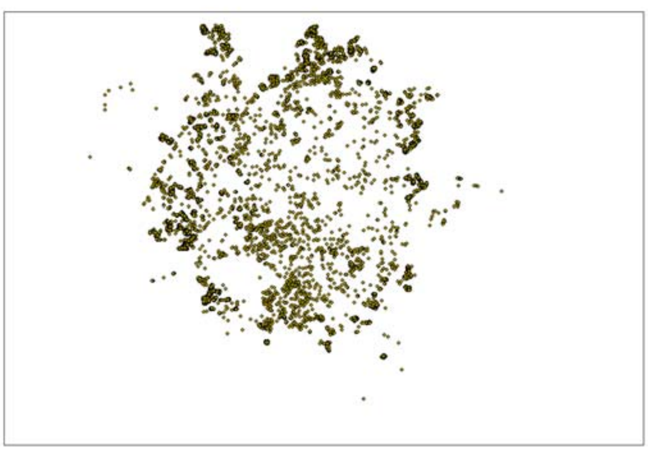
San Antonio 1996 - 2000 Year Built



San Antonio 2001 - 2005 Year Built



San Antonio 2006 - 2010 Year Built

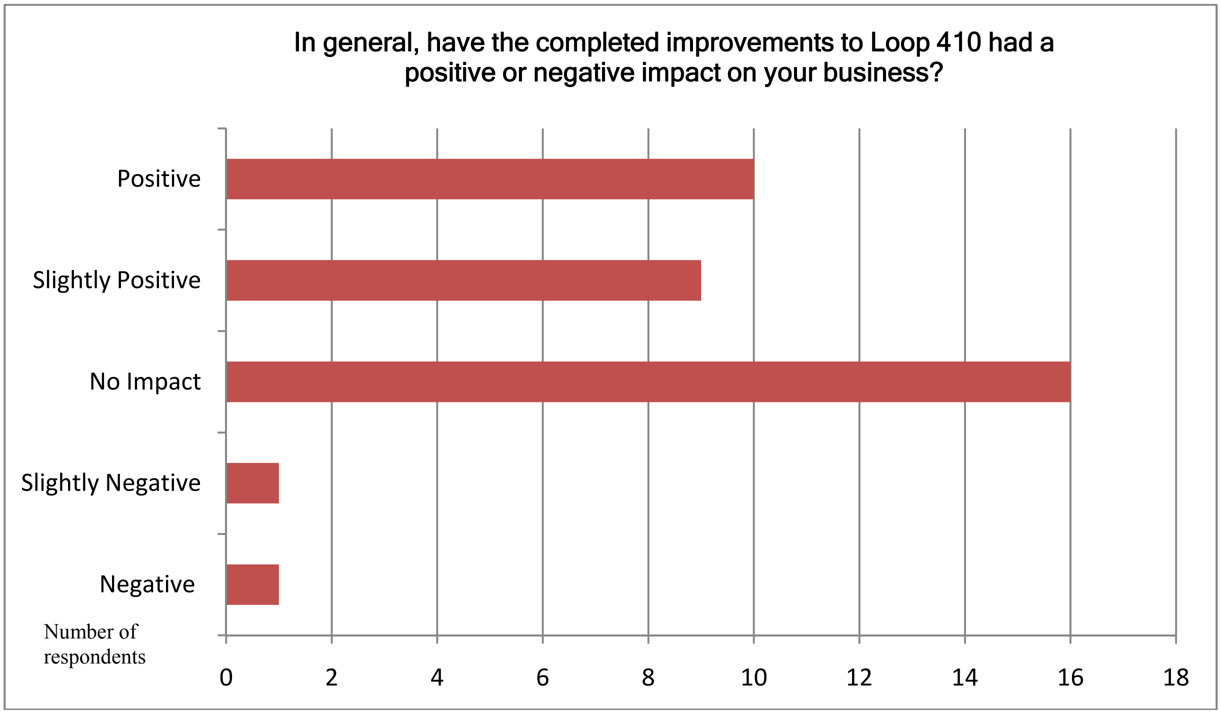


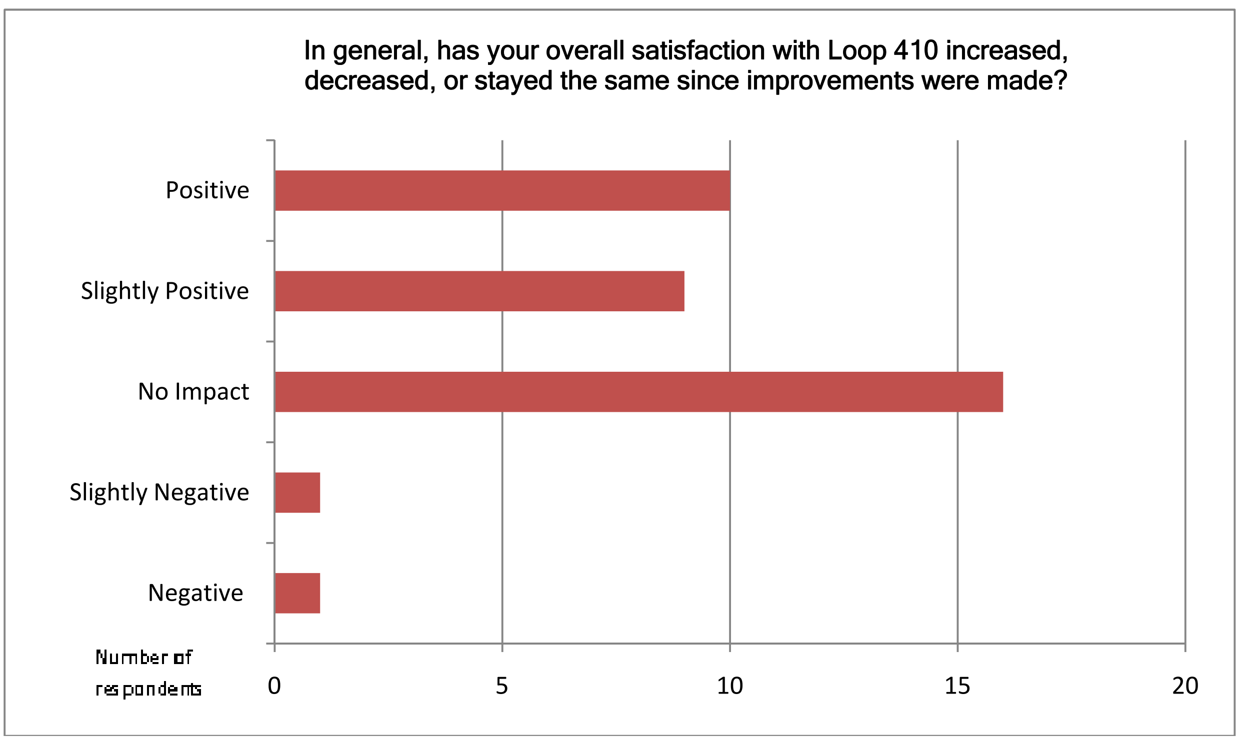
APPENDIX D: DISCOUNTED COSTS AND BENEFITS IN $1992 (MILLION)

Category	**2010**	**2020**	**2035**
Construction Costs @ 3%	386.89	386.89	386.89
Construction Costs @ 7%	564.8	564.8	564.8
Delay savings @ 3%	$168	$505	$1160
Delay savings @ 7%	$74	$228	$393
Fuel savings @ 3%	$70	$266	$609
Fuel savings @ 7%	$40	$121	$207

Source: From SHRP2 T-PICS database and http://www.kiewit.com/projects/transportation/i15-corridor-reconstruction.aspx.

APPENDIX E: OVERALL EFFECT OF LOOP 410 IMPROVEMENTS





APPENDIX F: SURVEY QUESTIONNAIRE

Loop 410 Improvements Assessment

General

1. Please choose the time frame that best fits the following:

	0-2 years	2-5 years	5-10 years	10-20 years	20+ years
How long has the business been located at the current address?	○	○	○	○	○
How long have you been employed at this location?	○	○	○	○	○

2. Please rate how often the following occurred due to traffic conditions BEFORE completion of the Loop 410 improvements.

	Never	Almost Never	Sometimes	Almost Always	Always
You chose to travel Loop 410 over alternative routes	○	○	○	○	○
You stayed after hours to avoid heavy traffic	○	○	○	○	○

3. Please rate how often the following occur due to traffic conditions SINCE completion of the Loop 410 improvements.

	Never	Almost Never	Sometimes	Almost Always	Always
You choose to travel Loop 410 over alternative routes	○	○	○	○	○
You stay after hours to avoid heavy traffic	○	○	○	○	○

4. Your company can be categorized as which of the following:

- ☐ Accommodation
- ☐ Banking, Finance, and Insurance
- ☐ Educational Services
- ☐ Government
- ☐ Health Care & Social Assistance
- ☐ Other
- ☐ Professional, Scientific and Technical Services
- ☐ Real Estate Sales, Rental and Leasing
- ☐ Restaurants and Food Services
- ☐ Retail Trade

Loop 410 Improvements Assessment

Banking, Finance, and Insurance

5. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

6. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

7. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

8. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

9. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

10. How often do you hear customers complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

11. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

12. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

13. Since completion of the Loop 410 improvements the number of customers who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	○	○	○	○	○
During off-peak travel times has ______	○	○	○	○	○

14. Please enter your business zip code.

ZIP Code:

Loop 410 Improvements Assessment

Other

15. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

16. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

17. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

18. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

19. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

20. How often do you hear customers complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

21. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

22. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	◯	◯	◯	◯	◯

23. Since completion of the Loop 410 improvements the number of customers who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	◯	◯	◯	◯	◯
During off-peak travel times has ______	◯	◯	◯	◯	◯

24. Please enter your business zip code.

ZIP code: [ ]

Loop 410 Improvements Assessment

Professional, Scientific and Technical Services

25. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

26. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

27. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

28. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

29. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

30. How often do you hear customers complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

31. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

32. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

33. Since completion of the Loop 410 improvements the number of customers who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	○	○	○	○	○
During off-peak travel times has ______	○	○	○	○	○

34. Please enter your business zip code.

ZIP code:

Loop 410 Improvements Assessment

Real Estate Sales, Rental and Leasing

35. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

36. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

37. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

38. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

39. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

40. How often do you hear tenants complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

41. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

42. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

43. Since completion of the Loop 410 improvements the number of clients who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	○	○	○	○	○
During off-peak travel times has ______	○	○	○	○	○

44. Please enter your business zip code.

ZIP code: [ ]

Loop 410 Improvements Assessment

Accommodation

45. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

46. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

47. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

48. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

49. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

50. How often do you hear guests complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

51. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

52. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	◯	◯	◯	◯	◯

53. Please enter your business zip code.

ZIP code: ______

Loop 410 Improvements Assessment

Restaurants and Food Services

54. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

55. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

56. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

57. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

58. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

59. How often do you hear patrons complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

60. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

61. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

62. Please enter your business zip code.

ZIP code: [ ]

Loop 410 Improvements Assessment

Educational Services

63. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

64. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

65. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	○	○	○	○	○
Yourself	○	○	○	○	○

66. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

67. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

68. How often do you hear students/participants complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

69. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

70. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	◯	◯	◯	◯	◯

71. Since completion of the Loop 410 improvements the number of students/participants who schedule classes or appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	◯	◯	◯	◯	◯
During off-peak travel times has ______	◯	◯	◯	◯	◯

72. Please enter your business zip code.

ZIP code: ________

Loop 410 Improvements Assessment

Government

73. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	◯	◯	◯	◯	◯
Your evening commute time	◯	◯	◯	◯	◯
Employee turnover rate	◯	◯	◯	◯	◯
Employee tardiness	◯	◯	◯	◯	◯
Overall satisfaction with Loop 410	◯	◯	◯	◯	◯

74. How likely were you or your office to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Office	◯	◯	◯	◯	◯
Yourself	◯	◯	◯	◯	◯

75. How likely are you or your office to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Office	◯	◯	◯	◯	◯
Yourself	◯	◯	◯	◯	◯

76. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

77. How important is access to Loop 410 in your office's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

78. How often do you hear the public complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

Loop 410 Improvements Assessment

79. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

80. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business/office?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	◯	◯	◯	◯	◯

81. Since completion of the Loop 410 improvements the number of persons who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	◯	◯	◯	◯	◯
During off-peak travel times has ______	◯	◯	◯	◯	◯

82. Please enter your business zip code.

ZIP code:

Loop 410 Improvements Assessment

Health Care & Social Assistance

83. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	○	○	○	○	○
Your evening commute time	○	○	○	○	○
Employee turnover rate	○	○	○	○	○
Employee tardiness	○	○	○	○	○
Overall satisfaction with Loop 410	○	○	○	○	○

84. How likely were you or your office/facility to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Office/Facility	○	○	○	○	○
Yourself	○	○	○	○	○

85. How likely are you or your office/facility to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Office/Facility	○	○	○	○	○
Yourself	○	○	○	○	○

86. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

87. How important is access to Loop 410 in your office/facility's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

88. How often do you hear patients complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

Loop 410 Improvements Assessment

89. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

90. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

91. Since completion of the Loop 410 improvements the number of patients who walk-in or have appointments:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	○	○	○	○	○
During off-peak travel times has ______	○	○	○	○	○

92. Since completion of the Loop 410 improvements:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
Emergency response time has ________	○	○	○	○	○
Patient access has ________	○	○	○	○	○

93. Please enter your business zip code.

ZIP code: ______

Loop 410 Improvements Assessment

Retail Trade

94. Please rate the following as they apply since completion of the Loop 410 improvements.

	Decreased	Slightly Decreased	No Change	Slightly Increased	Increased
Your morning commute time	◯	◯	◯	◯	◯
Your evening commute time	◯	◯	◯	◯	◯
Employee turnover rate	◯	◯	◯	◯	◯
Employee tardiness	◯	◯	◯	◯	◯
Overall satisfaction with Loop 410	◯	◯	◯	◯	◯

95. How likely were you or your business to relocate due to traffic concerns BEFORE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	◯	◯	◯	◯	◯
Yourself	◯	◯	◯	◯	◯

96. How likely are you or your business to relocate due to traffic concerns SINCE completion of the Loop 410 improvements?

	Not at All	Slightly	Somewhat	Very	Extremely
Business	◯	◯	◯	◯	◯
Yourself	◯	◯	◯	◯	◯

97. How often do you hear other employees discuss relocating closer to work because of traffic concerns?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

98. How important is access to Loop 410 in your company's decision to remain in its current location?

	Not at All	Slightly	Somewhat	Very	Extremely
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

99. How often do you hear customers complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	◯	◯	◯	◯	◯
Since completion of Loop 410 improvements	◯	◯	◯	◯	◯

Loop 410 Improvements Assessment

100. How often do you hear employees complaining about access or traffic on Loop 410?

	Never	Almost Never	Sometimes	Almost Always	Always
Before completion of Loop 410 improvements	○	○	○	○	○
Since completion of Loop 410 improvements	○	○	○	○	○

101. In general, have the completed improvements to Loop 410 had a positive or negative impact on your business?

	Negative	Slightly Negative	No Impact	Slightly Positive	Positive
Business impact:	○	○	○	○	○

102. Since completion of the Loop 410 improvements the number of customers who walk-in:

	Decreased	Slightly Decreased	Not Changed	Slightly Increased	Increased
During peak travel times has ______	○	○	○	○	○
During off-peak travel times has ______	○	○	○	○	○

103. Please enter your business zip code.

ZIP code: [ ]

Loop 410 Improvements Assessment

Conclusion

104. Please add any additional comments regarding the impact improvements to Loop 410 have had on your business.

APPENDIX G: OPEN-ENDED SURVEY RESPONSES

I am always amazed how TXDOT keeps traffic moving pretty well even during construction periods.
We are a service business and overall, improvements have improved attitudes about travel on Loop 410
Traffic on Culebra Is horrible takes 45 minutes to travel 4.5 miles
Traffic at I-10 and 410 needs work
My commute is typically along US 281 versus 410.
The biggest issues are the on and off ramps and the turnarounds and their completion.
I am NOT happy that the Nacogdoches exit was removed and combined with the Ft. Sam Houston/Harry Wurzbach exit. Our business is just off 410 at the Nacogdoches exit and the change in exit location has made it more difficult for potential students to find our location.
Overall, since completion, it has been so much easier to move in this area. TxDOT should, however, consider building for what the road will likely need to be in 20 years, not just for present needs. Also, you should have N/A as a choice as some of these questions are not applicable to our organization.
Love it, love this city.
The improvements, while welcome, have taken an extremely long time and has detrimentally affected our business over this time frame. We welcome the final completion of the improvements in the near future.
I love the Loop 410 interchange. It has made my life much easier. My daily commute is stress free - this is one of the few projects that I am happy to have had my tax dollars go toward. Please do the same thing at loop 1604 and Hwy 281 and put in overpasses NOT TOLL ROADS! Thanks!
Lots easier to commute to Airport from IH37 and 410; that was a lifesaver!
It is wonderful now that the construction is complete on Loop 410!
The access onto I 10 from Callaghan hides the businesses the nearer you get to 410. something should be done to increase visibility both from 410 onto I10 and from 410 onto I10
Hopefully, this survey is helpful - it is worded in a way that is confusing.
I feel that better monitoring of traffic flow by the police would be a real help.
Those drivers or vehicles that do not travel at the flow of traffic should be addressed by the police.
We can have shorter, safer, and less stressful commutes if these individuals are made aware of the laws and held responsible. We would not have to build and pay for additional roads to accommodate these drivers. I know California monitors these types of drivers with success and has improved commute times overall on the same roads

APPENDIX H: BUSINESS SURVEY RESULTS

Survey Summary

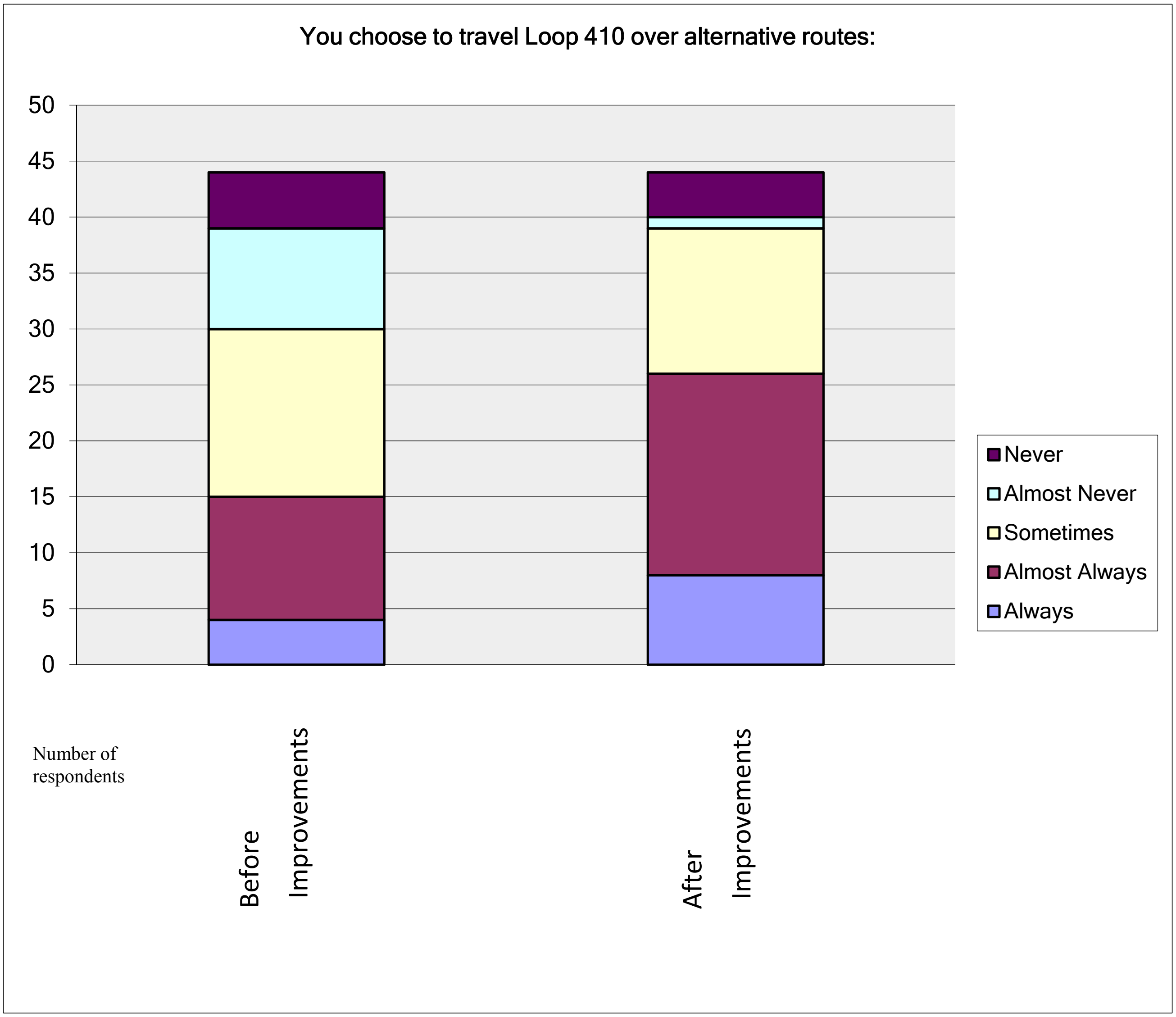
Transportation improvement projects like those completed on Loop 410 allow an area to be more attractive to businesses. One such example is that of the Toyota Tundra plant located in the San Antonio area. An incentive package was offered, which included the requirement that the state fund the construction of a second rail spur to the site. Having dual-rail service was a critical factor in site selection as it allows for competition among rail carriers and helps keep Toyota's costs down. The Tundra plant itself employs approximately 2,000 workers and with the recent addition of the Tacoma line an additional 1,000 workers have been added. Improved roadways allow an area to be more attractive to businesses which in turn leads to a more productive and positive economy.

TTI researchers surveyed businesses located in close proximity to the improved segments of Loop 410 to determine what impact these projects had on the local business community.

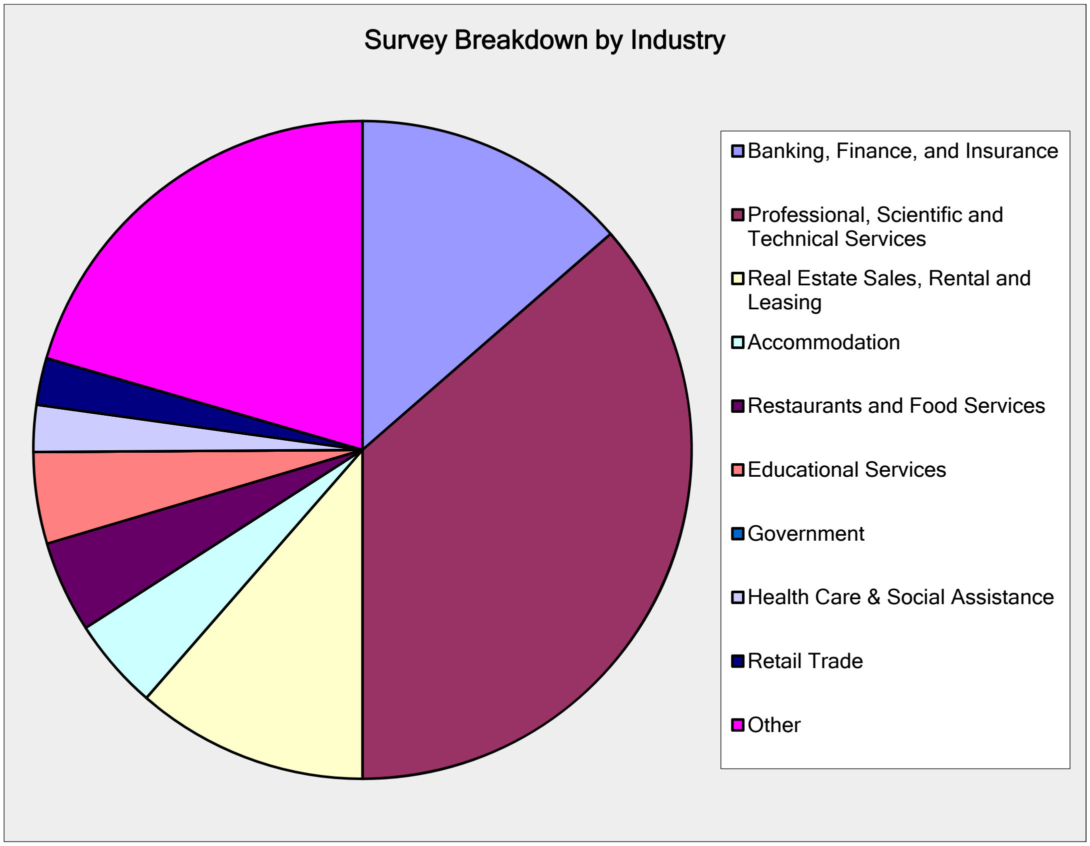
- Fifty-five (55) percent of the businesses surveyed had been in their current location for 10 years or more.
    - 7% 0 to 2 years
    - 20% 2 to 5 years
    - 18% 5 to 10 years
    - 30% 10 to 20 years
    - 25% 20 or more years
- When asked how often businesses chose to travel Loop 410 over alternative routes before and after improvements were made:
    - An increase of 25% was seen in those always or almost always choosing to travel Loop 410 over alternative routes.
    - A decrease of 21% was seen in those who never or almost never choose to travel Loop 410 over alternative routes.
    - <u>Before Improvements:</u>
        - 32% never or almost never chose to travel Loop 410 over alternative routes
        - 34% sometimes chose Loop 410
        - 34% always or almost always chose Loop 410
    - <u>Since Improvements:</u>
        - 11% never or almost never choose to travel Loop 410 over alternative routes
        - 30% sometimes choose Loop 410
        - 59% always or almost always choose Loop 410

- Eighty-nine (89) percent of businesses reported that their overall satisfaction with Loop 410 has increased or slightly increased since completion of improvements.
- Ninety-four (94) percent of those surveyed felt that the improvements had not negatively impacted their business with 50 percent reporting a positive or slightly positive impact.
    - 50% positive or slightly positive
    - 44% no impact
    - 6% negative or slightly negative
- Sixty (60) percent of those surveyed feel their morning commute has decreased or slightly decreased, and 54 percent feel the same about their evening commute.
    - 60% decrease or slight decrease in morning commute
    - 35% no change in morning commute
    - 5% increase or slight increase in morning commute
    - 54% decrease or slight decrease in evening commute
    - 38% no change in evening commute
    - 8% increase or slight increase in evening commute
- Businesses were also asked how often they heard customers or employees complain about access or traffic on Loop 410:
    - ***Before*** improvements were made 36% heard complaints always or almost always, and
    - 50% heard complaints sometimes
    - ***Since*** completion of improvements 50% never or almost never heard complaints, and
    - 38% heard complaints only sometimes
- Businesses were asked how likely they were to relocate before and after improvements to Loop 410 were made:
    - When comparing those businesses who reported any likelihood of relocation a 33% decline was seen since completion of Loop 410 as compared to before improvements.
    - When comparing those individuals who reported any likelihood of relocation a 55 % decline was seen since completion of Loop 410 as compared to before improvements.

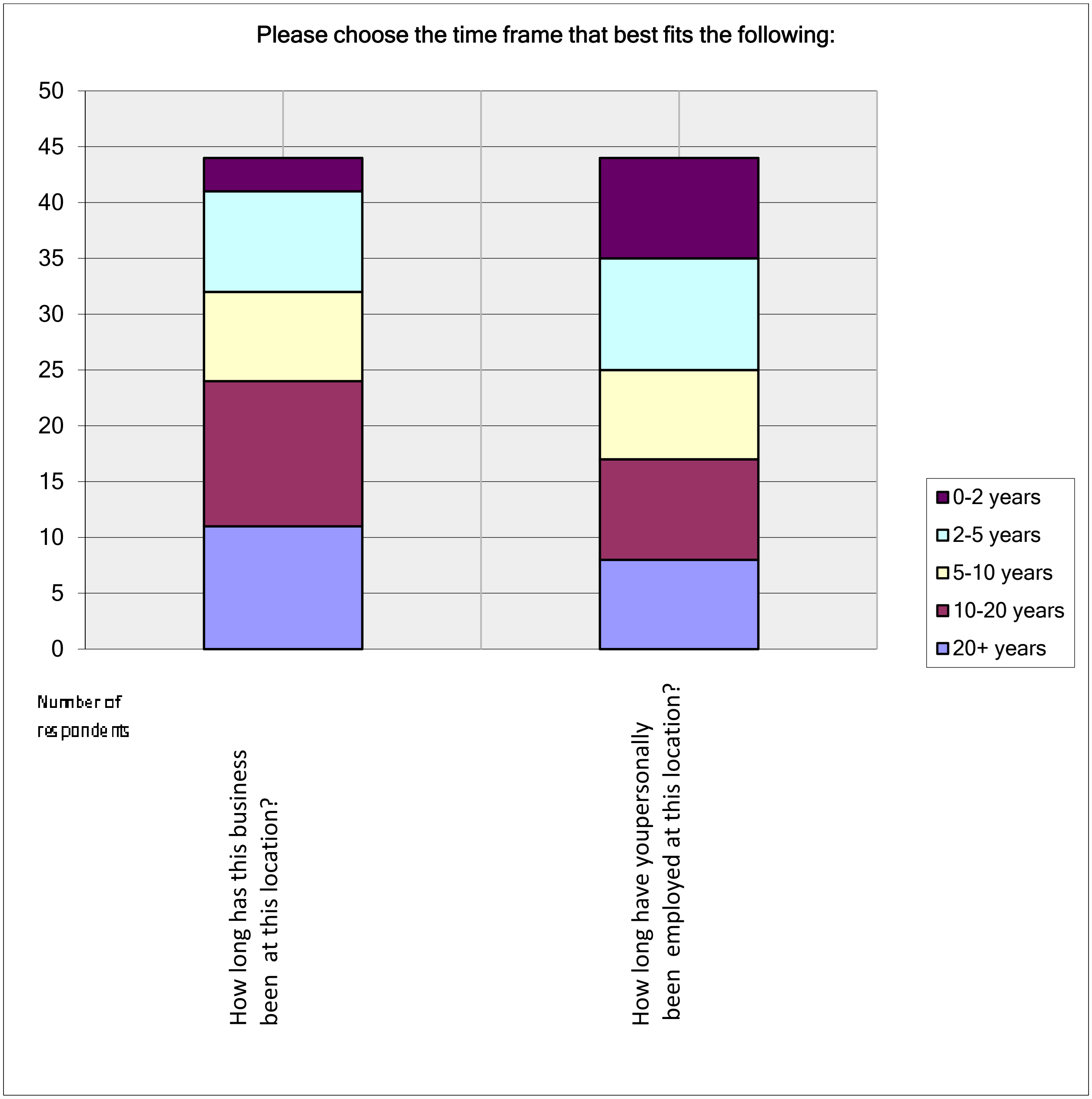
APPENDIX I: LOOP 410 UTILIZATION



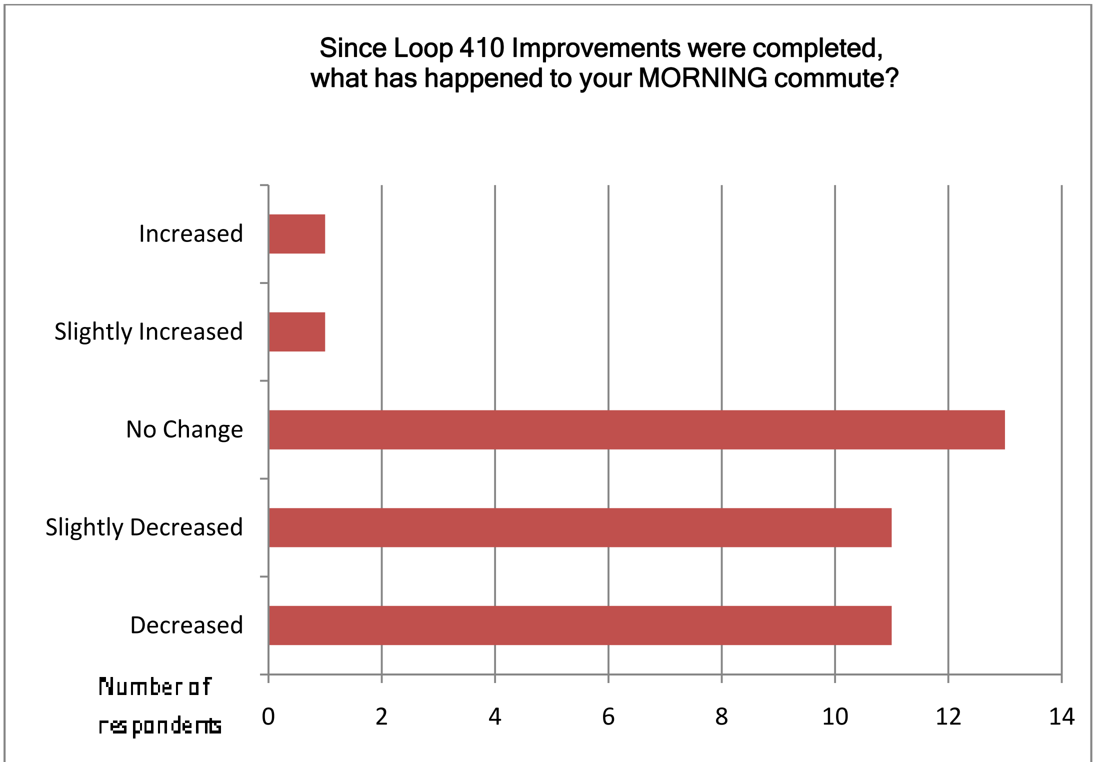
APPENDIX J: SURVEY BREAKDOWN BY INDUSTRY

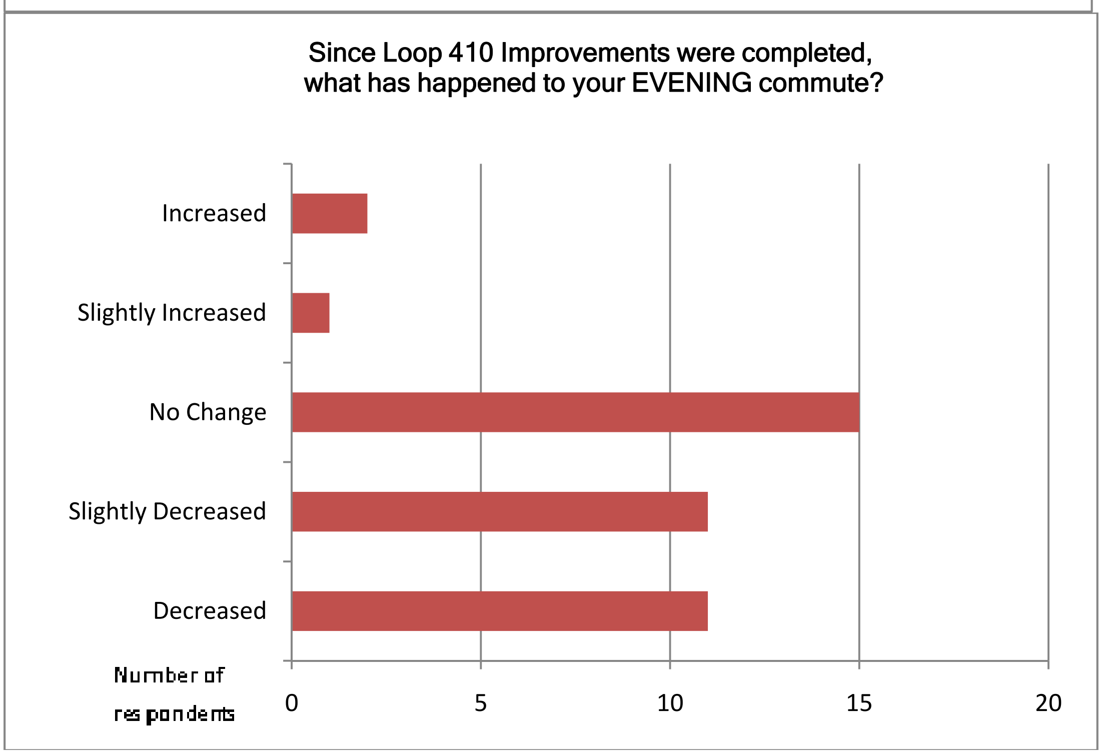


APPENDIX K: BUSINESS LONGEVITY



APPENDIX L: MORNING AND EVENING COMMUTE TIMES





WORK ORDER 19: EVALUATION OF INLAND ENVIRONMENTAL MODIFIED DRILLING FLUID AS A BASE COURSE MATERIAL

EXECUTIVE SUMMARY

The attached report contains a laboratory and field investigation of the modified drilling fluid (MDF) produced by Inland Environmental Company. This cement-treated drilling fluid has been used on a limited basis for full-depth base repair on two TxDOT low volume roads. It has been used as a base course on numerous county roads in the Yoakum District. As it was used for base repair, the material was tested according to Item 247 Base requirements, which include compressive strength testing at optimum moisture content. The results from the lab study were disappointing as the materials failed to meet TxDOT minimum strength requirements for any grade. This may be attributed to the fact that testing methods as used for conventional materials may not be appropriate for this material.

However, field testing of the TxDOT projects found reasonable in situ strengths as measured by the FWD. The MDF section had stiffness values similar to those typically observed for newly constructed flexible bases. The old, in-service flex base adjacent to the MDF section exhibited values half that of the MDF. Cores removed from the field also had significantly higher strength values than the lab-molded samples. From this observation, it is concluded that when evaluating it according to either Item 247 or Item 275 this material clearly has some unique engineering properties. Based on laboratory tests, it is our conclusion that the material, though weak initially, has the ability to gain strength with time. This hybrid material cannot be specified with current TxDOT specs. Further work is needed to develop a specification, which includes criteria for strength gain with time.

A visual inspection was made of full-scale county roads (see below) that were constructed with the material. These low-volume roads appear to be holding up very well. To proceed with wider scale implementation of the MDF, we recommend the following:

a. More FWD testing on the new county road sections.
b. Expanded laboratory test program to develop a practical specification, which includes both laboratory test requirements and construction recommendations.

c. The material will need to be certified by the TCEQ program and will need to pass the equivalent of the DMS 11000 specification to ensure no environmental concerns are raised by the product.

INTRODUCTION

This report describes a comprehensive laboratory and field performance evaluation of MDF produced by Inland Environmental and Remediation. This facility is permitted by the Railroad Commission of Texas (Permit No. STF-010, amended) to process oil based drilling wastes into a road base material. Laboratory tests were conducted to determine the potential uses for the "as-received" MDF in highway construction and maintenance applications.

According to Webster's dictionary, drilling fluid is a preparation of water, clays, and chemicals circulated in oil-well drilling for lubricating and cooling the bit, flushing the rock cuttings to the surface, and plastering the side of the well to prevent cave-ins. Drilling fluids are typically classified into water-based mud, oil-based mud, and gaseous drilling fluid. These drilling activities produce large amounts of drilling waste materials (DWMs) such as drilling mud and cuttings consisting of both liquid and solid phases. The management of these waste materials depends on the types of drilling fluids utilized. While water-based drilling wastes are simply disposed to open pit (mud pit), oil-contaminated wastes are typically disposed after subjecting them to a thermal treatment process. This treatment brings the oil content under "Special Waste" classification threshold and produces a more easily handled dry product (Page et al. 2003).

Other techniques are used to solidify and stabilize the drilling waste materials. Cementitious materials such as cement, lime, and fly ash are typically used in the stabilization and solidification process of DWMs. Cement-treated stabilization and solidification improve the physical, chemical, and mechanical properties of DWMs by binding their contaminants such as oil and metals in a structure formed by the cementitious materials (Martin et al. 1989; Pamukcu et al. 1989b; Sharma and Dukes 1990). As a result, either thermally treated or cement-treated DWMs can be transformed to a soil-like, compactable mixture and may potentially be used as a construction material in roadway construction.

In recent years, several researchers have investigated the utilization of oil-based drilling wastes as construction materials. Page et al. (2003) suggested three potential options for reuse of drilling waste in construction applications on the basis of a summary of previous research: (i) use in cement manufacture; (ii) use in roadway construction; and (iii) use in brick and block manufacture. Bernardo et al. (2007) investigated the feasibility of oil well-derived drilling wastes as components of the kiln feed during the process of the portland cement manufacture. It was found that the drilling wastes were partially able to replace limestone and clay in the cement clinker manufacture by up to 45 percent without degradation in performance of the hydraulic binders.

Offshore drilling waste was also used in hot mix asphalt (HMA) concretes as aggregate replacement (Wasiuddin et al. 2002). It has been found that as much as 20 percent drilling waste could be used as aggregate replacement in HMA concrete without sacrificing any of its properties such as Marshall stability, flow, permeability, and resilient modulus. Tuncan et al. (2000) stabilized petroleum-contaminated drilling waste (PDW) with 20 percent lime, 10 percent fly ash, and 5 percent cement and evaluated them as road subbase materials. They found that significant increases in the unconfined compressive strength, California bearing ratio, freeze-thaw resistance, and pH, depending on waste material's grain size, stabilizer type, and inherent composition property of PDW.

Chen et al. (2007) used thermally treated oil-base mud cuttings from drilling operations to manufacture permeable clay bricks. Furthermore, they have used these materials as a partial cement substitute in concrete. They reported that both brick and concrete made of drilling wastes successfully met Taiwan National Standard specification requirements in terms of permeability and strength. El-Mahllawy and Osman (2010) have successfully used thermally treated oil based mud waste to cast clay masonry units for load and non-load bearing walls construction, which met the acceptable limits of an Egyptian Standard.

It is estimated that approximately 29,097,984 cubic yards of solid drilling waste are generated annually in the United States (American Petroleum Institute 2009). The drilling waste management to minimize the environmental impact of drilling operations is one of the most important challenges in the petroleum industry. As previously stated, some research to further exploit the utilization of oil-based drilling wastes as construction materials has been conducted. However, little data are available on the application of these materials in roadway construction. Furthermore, because of an increasing scarcity of some sources of conventional aggregate and the high cost of transporting aggregate to the construction site, the interest in alternative reliable cost-effective materials that are more available locally or in situ for both flexible and rigid road-bases is significantly increasing in Texas.

EXPERIMENTAL DETAILS

Designing an experimental program using established material science and engineering principles is a basic means toward understanding key properties of the materials and determining the acceptability of modified drilling fluid (MDF) material in road base course applications. This chapter presents the research objective and experimental scope of this project. Also presented is a description of the processing method for oil-based drilling waste (MDF material).

Research Objective and Experimental Scope

The objective of this research was to evaluate the engineering properties of MDF. This goal was accomplished by both laboratory and field test section evaluations of MDF material, as illustrated in Figure 44. Laboratory tests are further categorized into two experimental series:

- Series I: Determination of the basic material characterization of the MDF material
- Series II: Evaluation of the MDF according to Item 247.

Series I focuses on the method for designing a road base material using treated petroleum-based drilling waste, sampling of MDF material, and characterization of chemical, physical, mineralogical, and geotechnical aspects of MDF material.

To assess the performance characteristics of this MDF material as a construction material, the testing protocol in Series II includes the determination of optimum moisture content, unconfined compressive and indirect tensile strengths of the fabricated specimens, evaluation of the moisture susceptibility using the capillary suction test and triaxial compression test, and seismic properties as per Texas Department of Transportation (TxDOT) guideline for base-course sample evaluation.

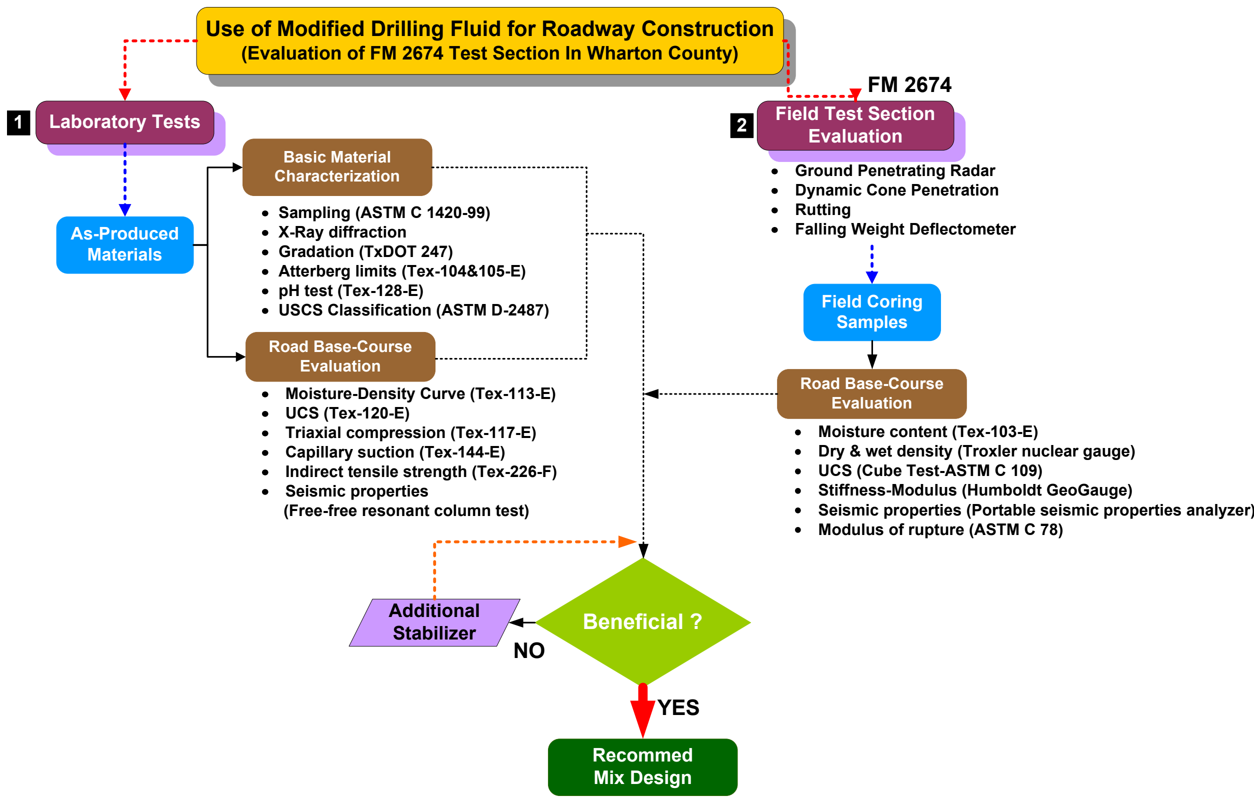


Figure 44. Diagram of Research Scope and Experimental Program.

The conduction and evaluation of a field test section were also carried out to determine the potential effectiveness of the MDF material as a road base material. The field test evaluation focuses on two areas of interest:

- Assessment of field cored samples.
- Post-construction evaluation.

Field cored sample analyses addressed whether mix design can have a potential for utilization in flexible base construction application. Core samples collected from the field test section were evaluated in terms of moisture content, dry and wet density, stiffness and seismic modulus, unconfined compressive strength, and modulus of rupture. The evaluation of the in-service performance of each test section was conducted using non-destructive testing techniques: ground penetrating radar (GPR), falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP). Rut-depth measurements in the wheel paths were also obtained. Finally, a connection between laboratory generated data and the field cored sample evaluation was established to predict performance in the field.

Production of Modified Drilling Fluid Material

As previously stated, a common method for processing drilling wastes is through solidification and/or stabilization by treating the waste with cementitious materials and inert materials (aggregates).

Figures 45 through 47 illustrate an overview of the steps to produce MDF. The first step is to separate water from drilling fluid waste received from the oilfield site in the form of either tank liquids or truck solids. Because the water-removed solids are still coated with contaminants, the solids must be further treated with centrifuges for further removal of more of the contaminant.

The second step is a stabilization and solidification process, wherein, treated drilling waste is combined with aggregate and a binder. The effort to stabilize the waste with cement is to reduce free moisture and minimize the solubility and mobility of the pollutant inside the waste. The solidification is aimed at increasing the bearing strength, decreasing the surface area of the waste, and converting the suspension or detached component inside wastes into a monolithic solid product of high structural integrity (Martin et al. 1990; Tuncan et al. 2000). To produce the MDF material, an approximate ratio of treated drilling fluid waste to aggregate (sand) of 3 to 1 was used. In addition, 12 percent cement of the total dry solid materials was added to the mixture.

The final step is to cure the MDF material to obtain additional strength for use as a road base-course material in the form of stockpiles. The coarser particles present in the excavated MDF materials are meant to satisfy the aggregate capacity in the base course. The unhydrated cement particles would potentially stabilize and bind the mix together by means of the residual pozzolanic activity intrinsic to the stockpiled material when water is applied during base-course construction.

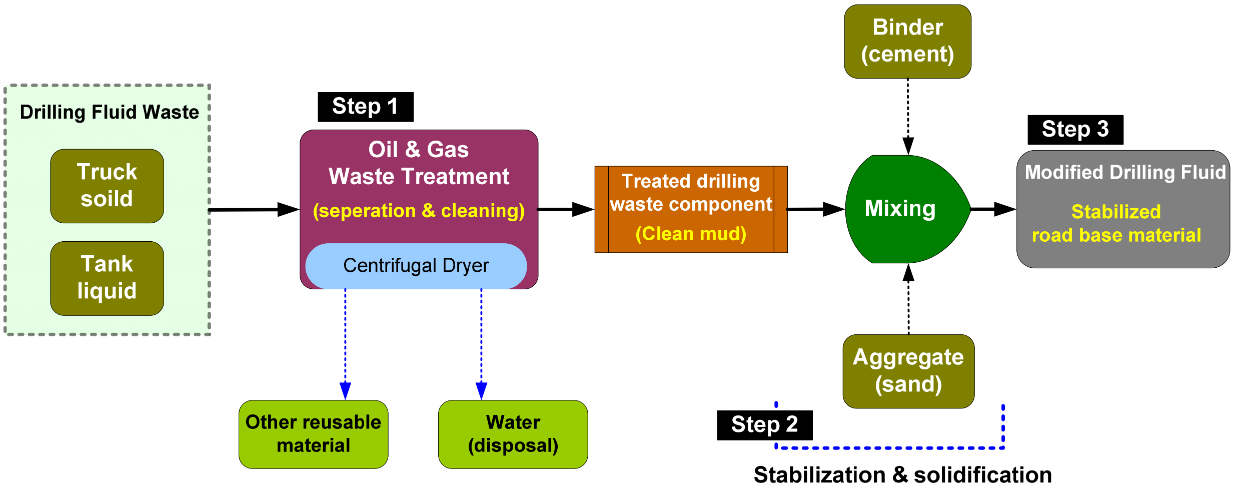


Figure 45. Schematic Procedure to Produce MDF Material.

Figure 46. Oil and Gas Waste Treatment Equipment.

Figure 47. Stabilization and Solidification Processes to Produce MDF Material.

MATERIAL CHARACTERIZATION OF MDF

This section presents the basic material characterization of MDF. Laboratory analysis of MDF material focused on characterization of chemical, physical, mineralogical, and geotechnical aspects of MDF material. Also presented are the details of test procedures related to the experimental program. Prior to the actual laboratory analysis, sampling of MDF material was also investigated.

Sampling Procedure

As previously noted, the aim of this project is to determine the acceptability of modified drilling fluid material for use in road base-course application. In order to obtain accurate test results for this experimental program, MDF materials were obtained from the plant stockpile. During the sampling procedure, a bucket excavator was first employed to extract the hardened MDF material from the stockpile and produce a miniature pile. The pile was thoroughly mixed and flattened for shoveling. MDF materials were manually shoveled from the MDF material pit as shown in Figure 48. Ten 5-gallon buckets were filled with the freshly excavated MDF material, loaded onto a pick-up truck, and transported to the McNew lab at the Texas Transportation Institute.

Materials

Two MDF materials designated as MDF A material and MDF B material were evaluated. MDF-A was obtained during the research team's plant visit, September 2010, and MDF-B was delivered from David Polston of Inland Environmental, November 2010. While a full scale characterization of the relevant chemical, physical, and mineralogical properties of the MDF-A material is described in Figure 44, a few additional selected tests such as X-ray diffraction, gradation, and pH tests were conducted.

Figure 48. Sampling of the MDF Materials from Stockpile.

Experimental Procedure

X-Ray Diffraction Analysis

Mineralogical properties of both powdered bulk MDF A and B samples were identified under X-ray powder diffraction (XRD) analysis using a Miniflex automated powder diffractometer, Rigaku/USA, Woodlands, TX, with CuKa radiation. The scan range was set at 5-60º and continuous scans for the θ-2θ range were run at a scan speed of 3º/min with a sampling interval of 0.03º. XRD data were obtained at room temperature.

In Situ Moisture Content

The TxDOT test method Tex-103-E, "Determining Moisture Content in Soil Materials," prescribes drying the loose soil sample at 110°C (230°F) for a minimum of 16 hours or until a constant mass is reached. Moisture content of the MDF material was determined according to Tex-103-E test procedure, although the MDF material, which is a blend of treated drilling fluid waste, cement, and sand is not a conventional soil material.

Particle Size Analysis

During stockpile sampling of MDF materials, the excavator bucket broke through the hardened material and generated both fine and coarse ash particles. The sieve analysis of the excavated MDF material was performed in accordance with the TxDOT test method Tex-110-E "Particle Size Analysis of Soils." Before sieving, MDF agglomerates larger than 44.5 mm (1-3/4 in.) were reduced in size, as permitted by the Tex-101-E test method "Preparing Soil and Flexible Base Materials for Testing" in order to achieve a 100 percent utilization of the material. A suitable size of the MDF material was obtained by quartering and splitting as illustrated in Figure 49. The sieve analysis was performed on the fully dried MDF material.

Figure 49. Particle Size Analysis Procedure.

Atterberg's Limit Values and Classification for MDF Material

The Atterberg limits determine the moisture content values, at which behavior of a soil or soil-like material changes. The Plastic Limit (PL) defines the lower moisture content limit, at which the material changes from a solid state to a plastic state. The Liquid Limit (LL) defines the lower moisture content limit, at which the material begins to exhibit characteristics of a viscous flow. The Plasticity Index (PI) is the difference between the Liquid Limit and the Plastic Limit and represents the range of water content where the material is plastic. Although the Atterberg limits are water content values, they are reported without the percent sign.

The Atterberg limits were determined for the dried MDF material passing the 425 μm (No. 40) sieve, defined by the test method Tex-101-E "Preparing Soil and Flexible Base Materials for Testing" as a "soil binder." The Atterberg limits were obtained according to the following test methods: (a) Tex-104-E Determining Liquid Limits of Soils; (b) Tex-105-E Determining Plastic Limits of Soils; and (c) Tex-106-E Calculating the Plasticity Index of Soils.

After determining Atterberg limit values for the MDF material, the classification of this material was conducted according to ASTM D 2487-10 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

pH Test

The pH of the MDF specimens was measured by a pH meter (Fisher Scientific XL 25 meter). Thirty (30) grams of air-dried (20 ± 3°C) samples, minus 425 μm (No. 40) were mixed and stirred with 150 ml distilled water and then left for 1 hour to determine the pH of specimen according to Tex-128-E Determining Soil pH.

Test Results and Discussion

X-ray Diffraction (XRD) Analysis of DMF Materials

Figures 50 and 51 show XRD analyses of MDF-A and-B material, respectively. There is not much mineralogical difference between the two materials. The main mineral constituents of the MDF material were quartz (SiO_2) and Barite ($BaSO_4$). Calcite ($CaCO_3$) and kaolinite ($Al_2Si_2O_5(OH)_4$) were identified as minor minerals. It was not surprising that the MDF material contains the high level of barite because barite comprises approximately 60 percent of the minerals and chemicals used in the manufacturing of drilling fluid in United States (Carignan et al. 2007). The sand used in the MDF material manufacturing process and stockpiled curing method in the field correspond to quartz and calcite minerals.

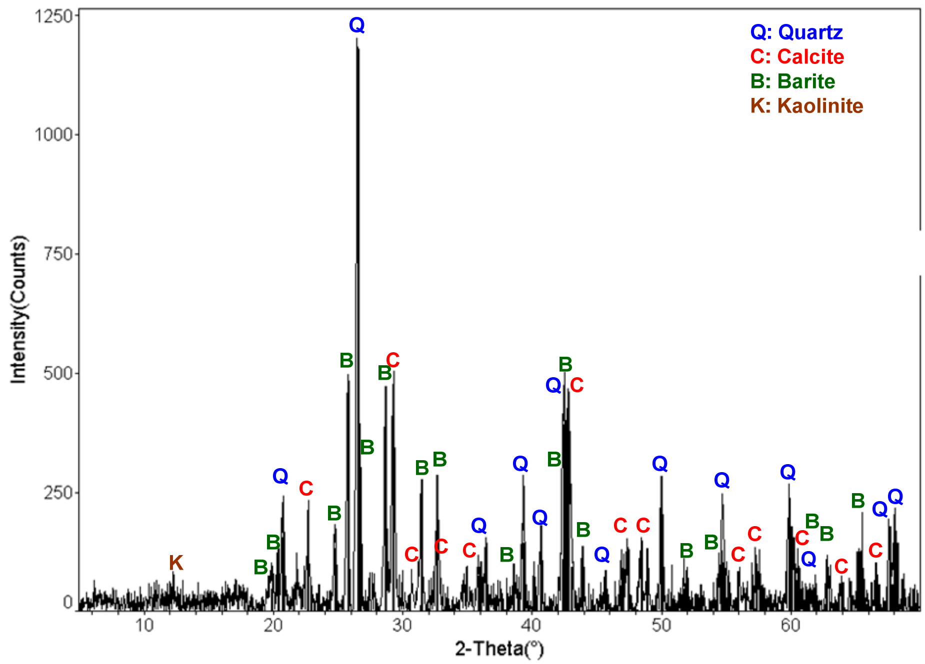


Figure 50. X-Ray Diffraction Analysis Result of MDF-A Material.

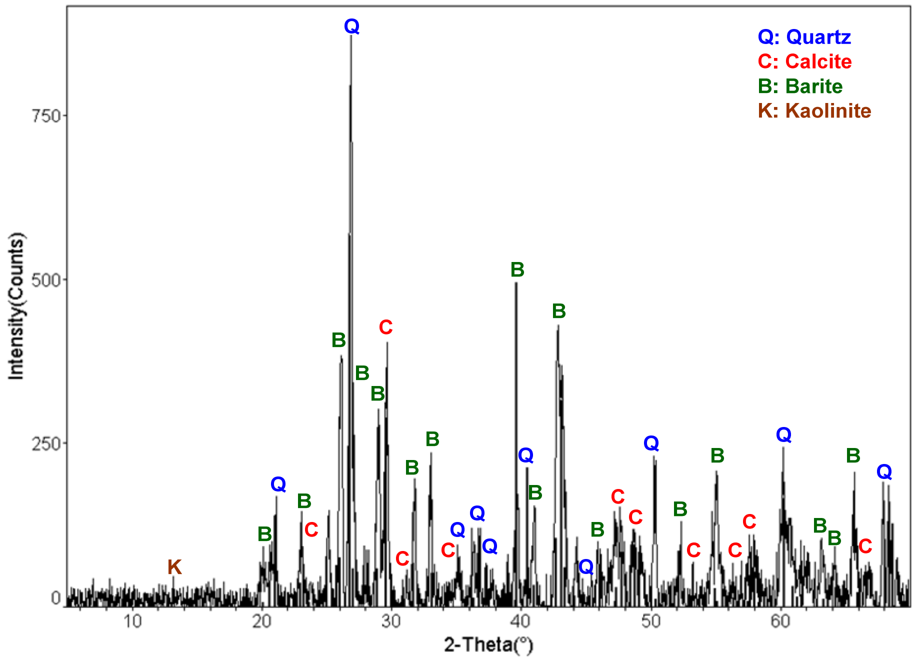


Figure 51. X-Ray Diffraction Analysis Result of MDF-B Material.

In Situ Moisture Content

The obtained MDF materials were not totally dried out because they were stockpiled in the field and subjected to periodic rain fall. Furthermore, the solidification process involving encapsulation of fine waste particle and a certain amount of moisture also causes the MDF material to be relatively wet. The percentage of water weight loss for MDF-A and MDF-B materials is given in Figure 52. The moisture content of the MDF-A material was 9.1 percent whereas the MDF-B material contained 14.6 percent of moisture. It should be noted that the difference of moisture content between these materials must be controlled because the residual moisture content is accounted for in the base-course mix design, and the water addition must be adjusted accordingly.

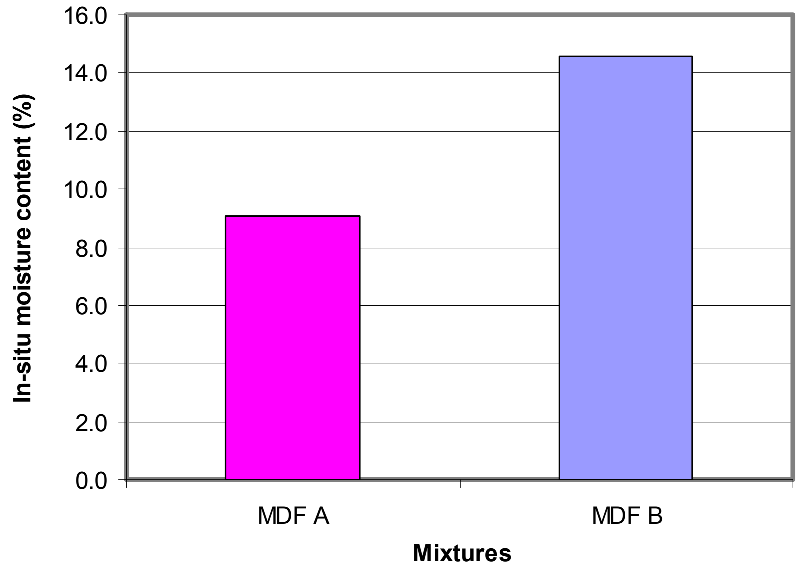


Figure 52. Particle Size Analysis Procedure.

Particle Size Analysis

TxDOT Item 247 guideline (Texas Department of Transportation 2004) specifies four different grades of aggregates that can be used in flexible base construction. Particle size distribution (PSD) analyses of MDF materials are given in Figure 53. While the MDF-B material conforms to Grade 1, the MDF-A material does not meet the gradation requirements for Grade 1 through 3 specified by TxDOT Item 247 regardless of using wet or dry sieving. The MDF-A material contains more fines than permitted for Grades 1 through 3 as specified by TxDOT Item 247. In particular, the most commonly referred to sieve No. 4 (4.75 mm) of the specification retained only 23 percent, which is 22 percent less than the required minimum of 45 percent. Use of this material by TxDOT will require enough process control to maintain the same grade of the MDF materials whenever they are excavated from the stockpile. Because the gradation is not restricted in Item 247, Grade 4, this designation may be more appropriate to the gradation of the material as sampled. Since the MDF material will be used under a special specification, the acceptable gradation can be specified separate from the requirements in Item 247.

Figure 53 also shows dry and wet sieving results for MDF-A material. In general, wet sieving is used when the material contains a very fine powder, which tends to agglomerate (e.g., mostly less than 45 μm). The amount of passing No. 200 sieve (minus 45 μm) was calculated to 20.9 percent.

Atterberg's Limit Values and Classification for MDF Material

Atterberg's limit results and Unified Soil Classification System (USCS) class symbols of MDF-A material according to ASTM D 2487-10 are tabulated in Table 15. Although the MDF material has no or little clay, it exhibits characteristics of a clayey sand with a low liquid limit (LL < 50), so its USCS classification is a CS soil. During the Atterberg limits tests, the MDF material appeared as a very sandy material, exhibiting virtually less cohesive properties. Upon water spraying, the dried MDF material, first, eagerly absorbed the water, barely reached the semi-plastic state, and then, after a few additional sprays, entered the semi-liquid state. With this, the Plastic Limit value was expected to be very close to the Liquid Limit value entailing a very narrow range of the water content, where MDF material is plastic with a low Plasticity Index (PI) value.

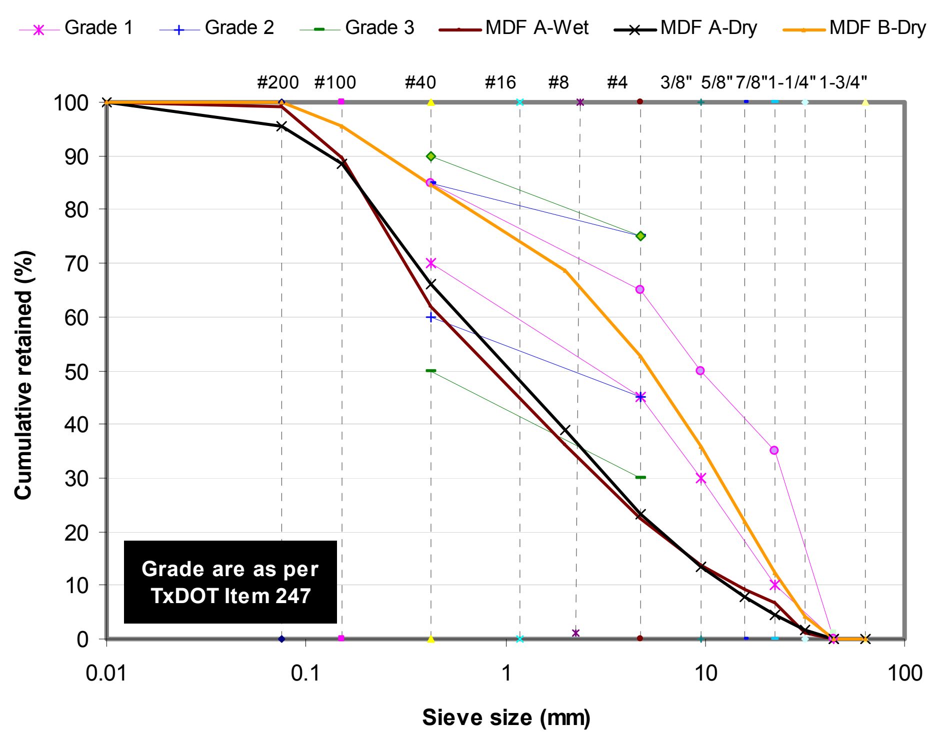


Figure 53. Particle Size Analysis.

Table 15. Atterberg's Limits and USCS Class Symbol of MDF Material.

Property	Value
Liquid Limit (LL)	31
Plastic Limit (PL)	23
Plasticity Index (PI)	8
USCS Class symbol	CS

pH Test

Figure 54 presents pH test results of MDF-A and MDF-B materials. For MDF-A materials, pH values before and after washing with water was measured. Both unwashed MDF-A and MDF-B materials have similar pH values, 11.3 and 11.1, respectively, whereas washed MDF-A materials shows a relatively lower pH value, 9.4. It can be seen that the addition of cement during material production process significantly increases the pH of the MDA material.

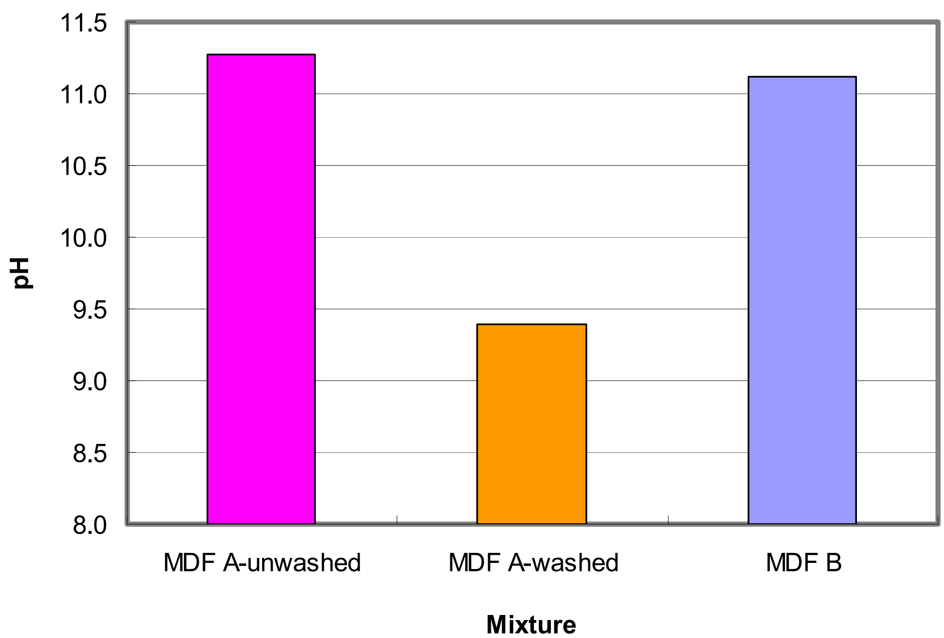


Figure 54. pH Test Results of MDF Materials.

Summary

Material characterization results of MDF materials indicate that the MDF material is a relatively high pH, low plastic, and clay sand material, mainly consisting of quartz and barite and belonging to Grade 4 category in TxDOT Item 247 Flexible Base Aggregate. It may be necessary that the quality control of this material be monitored in order to achieve consistent moisture content and gradation.

EVALUATION OF MODIFIED DRILLING FLUID MATERIAL AS A ROAD BASE-COURSE MATERIAL

This section presents the potential for the utilization of MDF material in road base-course construction. Laboratory assessment of MDF material includes unconfined compressive strength, indirect tensile strength, triaxial compressive strength, and capillary suction tests performed on cylindrical specimens compacted at their optimum moisture content. Also presented are the details of test procedures related to mixture proportion and sample preparation techniques used in this research.

Materials

As previously mentioned in Chapter 2, the modified drilling fluid (MDF) material is a cement-treated material combined with petroleum-based drilling fluid waste and sand. It is stockpiled at the processing facility with the intent that the material will cure in the stockpile and gain strength. The excavated MDF materials contain not only agglomerated coarse and fine particles due to a prolonged weathering process in the field, but also unhydrated cement particles due to insufficiently supplied hydration water during the material production process. If these MDF materials are used in the road base application, it is supposed that the coarser particles of these materials would fulfill the aggregate function in the base course mix, whereas the fines and unhydrated cement particles would stabilize and “glue” the mix together by means of the residual pozzolanic activity intrinsic to the stockpiled MDF material.

The same MDF-A and MDF-B materials used in Chapter 3, “Material Characterization,” were tested. Both materials were initially tested untreated and then with the addition of 3 percent by dry solids weight of Type I Portland cement if sufficient strength was not developed.

Experimental Procedure

For all tests, both untreated and cement-treated test specimens were prepared at optimum moisture content. The moisture-density relationship was used to determine the optimum moisture content (OMC), at which the untreated base material demonstrates the maximum dry density. In order to derive the moisture-density relationship, the MDF material was oven dried, re-wetted, and compacted as per Tex-113-E test method "Laboratory Compaction Characteristics and Moisture-Density Relationship of Base Materials" into 6 in. diameter by 8 in. height specimens at four different moisture contents using 10 lb hammer drops at 18 in. in height at 50 blows/layer. Each specimen consisted of 4 layers.

As per Tex-120-E "Soil-Cement Testing," the following formula was used to adjust the obtained OMC of the MDF material when adding cement:

$$W_c \text{ (with cement)} = W_{opt} + [0.25 \text{ x cement } \%] \tag{1}$$

Where, W_c = moisture content treated after treatment with cement and W_{opt} = optimum moisture content.

Unconfined Compressive Strength and Indirect Tensile Strength

Figure 55 shows the unconfined compressive strength and indirect tensile strength test setup. A set of both untreated and cement-treated test specimens with a diameter of 6 in. and a height of 8 in. were cast at optimum moisture content. Immediately after casting, the test specimens were wrapped with a plastic sheet and cured in a 100 percent moist-curing room at 73°F for 7 days. The unconfined compressive strength test was conducted on the Instron™-5583 testing machine. The average of the strength values of the three samples was recorded. The test was carried out at a constant rate of 0.135 in/min.

The indirect tensile strength (ITS) test was conducted in accordance with Tex-226-F. A 4 in. in diameter × 2 in. thick specimens were prepared, cured, and tested at a constant rate of 2 in/min. The indirect tensile strength S_T was calculated as following:

$$S_T = \frac{2F}{3.14 \times (h \times d)} \tag{2}$$

Where, S_T = Indirect tensile strength, psi; F = Total applied vertical load at failure, lb; h = Height of specimen, in.; and d = Diameter of specimen, in.

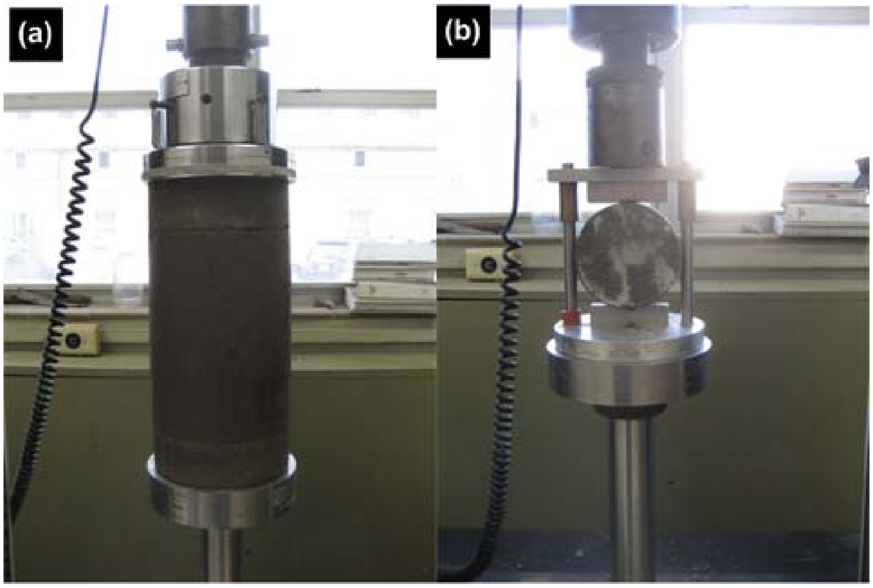


Figure 55. Unconfined Compressive Strength (a) and Indirect Tensile Strength Test.

Triaxial Compressive Strength

The triaxial testing, Tex-117-E test method, "Triaxial Compression for Disturbed Soils and Base Materials," was used to characterize the aggregate materials that did not possess any cohesion and required confinement in order to hold the specimens together during testing. The specimens were subjected to a constant confining pressure, σ_3, and then loaded under an increasing axial stress, σ_1, until failure. The results of the triaxial compression test are presented using the Mohr's diagram, where ordinate represents shear stress and abscissa represents normal stress values. The minimum requirements for the triaxial compression tests are defined in TxDOT Item 247 and include:

- **Grade 1:** min σ_1 = 45 and 175 psi (at σ_3 = 0 and 15 psi, respectively).
- **Grade 2:** min σ_1 = 35 and 175 psi (at σ_3 = 0 and 15 psi, respectively).
- **Grade 3:** no requirements specified.
- **Grade 4:** as shown on the plans.

Capillary Suction Test (Tube Suction Test)

For durability evaluation, capillary suction test called tube suction test (TST), Tex-144-E test method, was carried out. The TST was originally developed for assessing the moisture susceptibility of aggregate base materials as "good, marginal, and poor" (Scullion and

Saarenketo 1997; Guthrie et al. 1998). The moisture susceptibility is based on the mean surface dielectric value of compacted specimens measured by percometer after a 10-day capillary soak (Figure 56). The dielectric value is most sensitive and directly related to the amount of unbound water that exists within the aggregate matrix. The specimens with final dielectric values less than 10 are expected to provide a good performance, while those with the dielectric values above 16 are expected to provide a poor performance as base materials. Specimens having final dielectric values between 10 and 16 are expected to be marginally moisture susceptible.

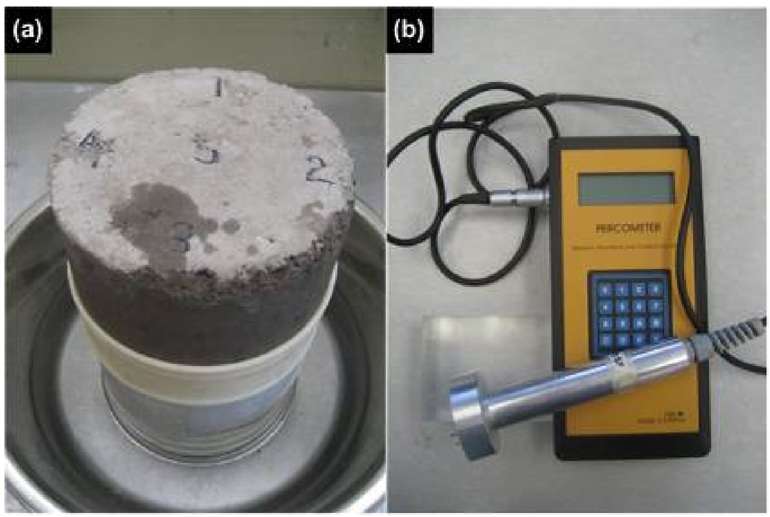


Figure 56. Tube Suction Sample (a) and Percometer (b).

The residual retained compressive strength was also determined after the modified tube suction test. The residual retained compressive strength test represents a measure of the moisture susceptibility of the base material. The retained strength of the samples after the capillary soak period is viewed as an indicator of the mixtures moisture susceptibility as it simulates field conditions and provides a long-term durability assessment of the base material.

Seismic Modulus Test

As shown in Figure 57, the free-free resonant column test (FFRCT) was used to determine the modulus of road base material. FFRCT normally determines Young's modulus by measuring the velocity that an elastic wave propagates through a cylindrical specimen (Nazarian et al. 2005; Hilbrich and Scullion 2007). The 6 in. diameter by 8 in. height cylindrical specimen is placed on the stand. A light tap with a hammer instrumented with a load cell is applied to one end of the test specimen whereas an accelerometer is securely mounted at the end of the sample. Two sensors are connected to a computer data acquisition system. The seismic modulus, E, is calculated using the following equation:

$$E = \rho\left(2F_pL\right)^2 = \rho\left(V_p\right)^2 \quad (3)$$

Where, E = Young's modulus; ρ = mass density; F_p = resonant frequency; L = the length of the specimen; and V_p = the compression wave velocity.

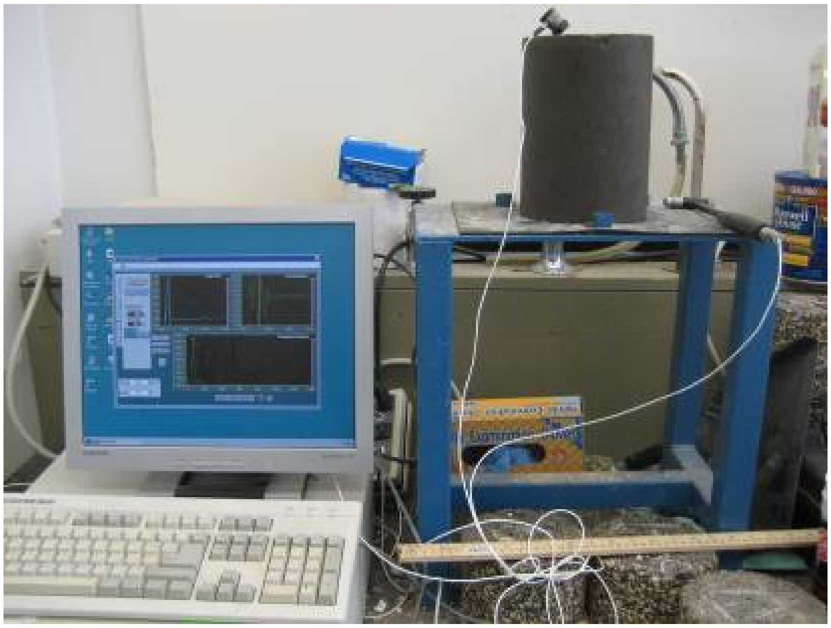


Figure 57. Free-Free Resonant Column Test.

Test Results and Discussion

Moisture-Density Relationship

The moisture and density curve is presented in Figure 58. The moisture-density relationship revealed the following characteristics of the MDF material: optimum moisture content (OMC, W_{opt}) = 21.2 percent and maximum dry density ($\gamma_{d-\max}$) = 99.8 lb/ft^3. However, it should be noted that the moisture and/or volatile content of "as-is" material was 9.1 percent. Thus, an additional 12.1 percent moisture was added to the material to achieve optimum.

Unconfined Compressive Strength and Indirect Tensile Strength

Figure 59 shows the average unconfined compressive strength (UCS) results for MDF-A, MDF-B, and 3 percent cement-treated MDF-A mixtures after 7-day curing. As can be noted, both mixtures containing MDF-A and MDF-B materials have similar UCS values (26.5 psi and 25.3 psi, respectively) regardless of their different gradations. These values do not meet the minimum allowable strength (35 psi) for Item 247 Grades 1 or 2.

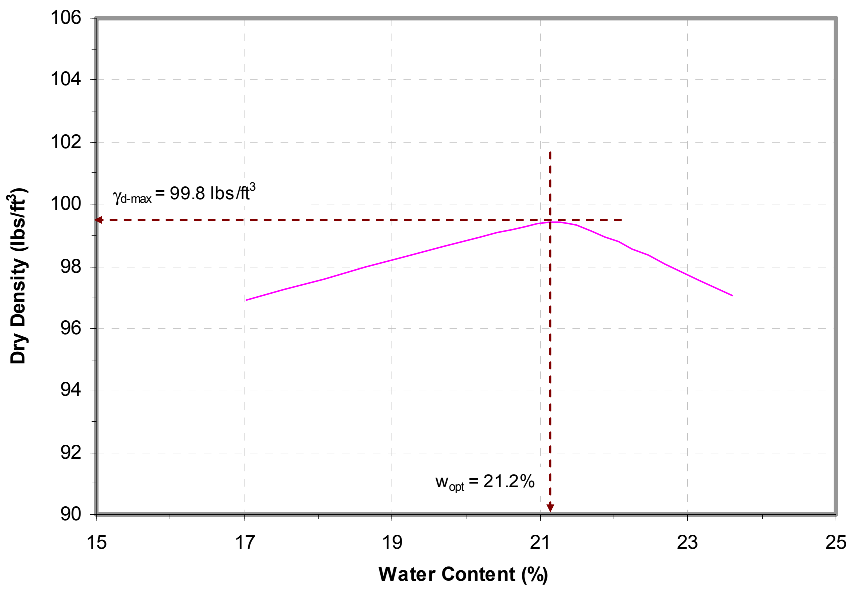


Figure 58. Moisture Density Relationship of MDF Material.

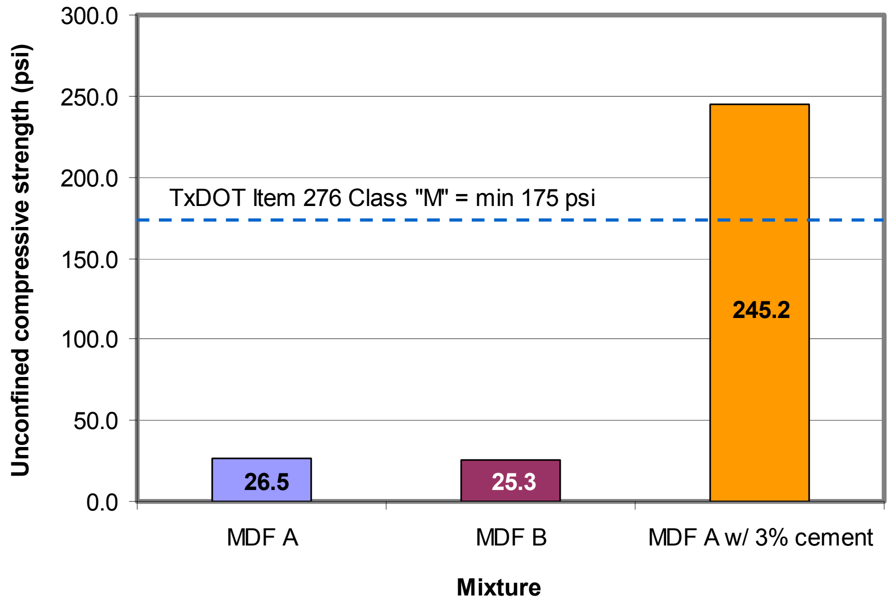


Figure 59. Unconfined Compressive Strength of Different Mixtures.

The strength of MDF material depend on the reaction between pretreated MDF waste, sand, cement, and water in the process to produce the final material. Especially, the degree of hydration of cement dominated by the water/cement ratio plays the important role in the strength development of the MDF material. Cement hydration is mainly controlled by the amount and availability of water at the cement particle surfaces.

As shown in Figure 60, at a water/cement ratio of about 0.38, the volume of the hydration products, i.e., the cement gel, exactly matches that of the fresh cement and water. This means a very dense structure in hardened cement paste. At lower values, hydration will be stopped before completion, even if an external source of water is available. At water/cement ratios higher than this, an amount of unfilled space between the original grains, in the form of capillary pores, increase.

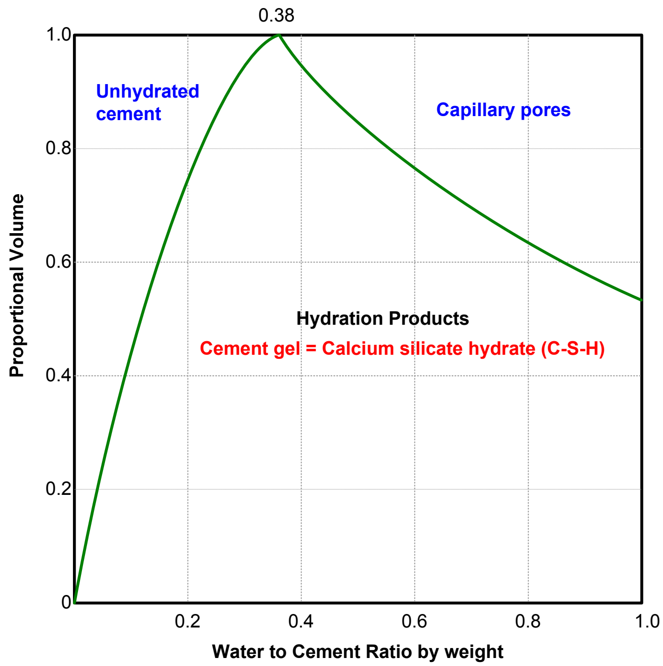


Figure 60. Volumetric Composition of Hydrated Hardened Cement Paste (after Hansen 1970).

In other words, the insufficient water/cement ratio causes the cement to not be fully hydrated, while the higher water/cement ratio produces higher porosity in the cement system, and consequently lower strength. Therefore, an unoptimized material production process makes the strength of "as-is" MDF materials low. This is supported by the high in situ moisture content of "as-is" MDF material, producing higher porosity in the matrix of MDF materials.

Interestingly, when 3 percent by dry solids weight of cement was added to the mixture, the UCS was drastically increased. TxDOT Item 276 "Cement-Treated Base" specifies three classes, L, M, and N of 300 psi, 175 psi, respectively, "as shown on the plans." The cement-stabilized mixture with an additional cement content of 3% met the requirement for Class M.

Figure 61 presents the indirect tensile (ITS) strength of the MDF-A mixture after 1-day and 7-day curing. This is the as sampled with no additional cement. In general, a longer curing period resulted in higher ITS. As expected, the specimens had low ITS as shown in unconfined compressive strength testing.

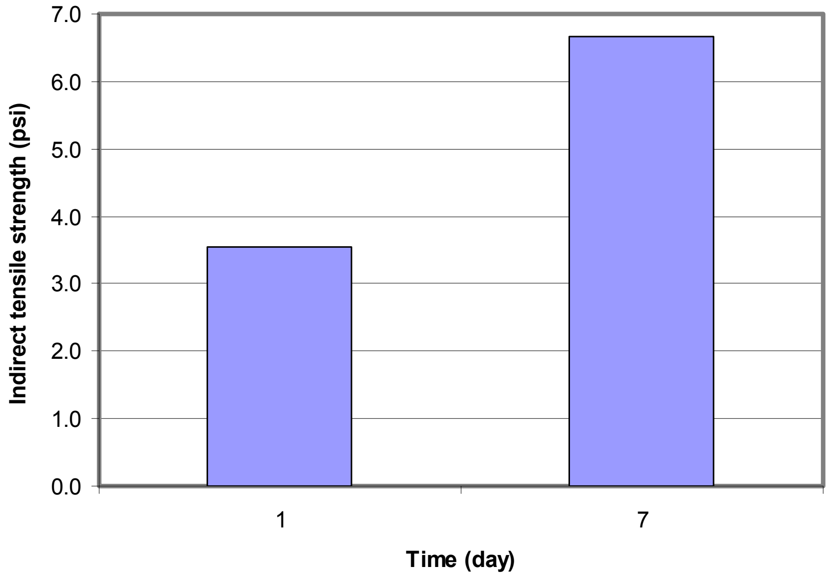


Figure 61. Volumetric Composition of Hydrated Hardened Cement Paste.

Triaxial Compressive Strength

Three samples containing MDF-A material were prepared for each confining pressure. Immediately after molding, the specimens were wrapped in filter paper, placed on and covered by porous stones, and enclosed in the triaxial cells. The cells were transferred into the moist-curing room (77°F and 100% R.H.), placed in a water bath, and subjected to a constant weight surcharge as well as a confining pressure of 1 psi. The triaxial cells were then allowed to cure under the capillary conditions for 10 days.

The results of the triaxial compression of the untreated MDF-A specimens are shown in Figure 62. At the zero confinement pressure, the average axial compressive strength of the untreated ash samples reached 32.9 psi; whereas, at the 15-psi confinement, the average axial strength reached 111.0 psi.

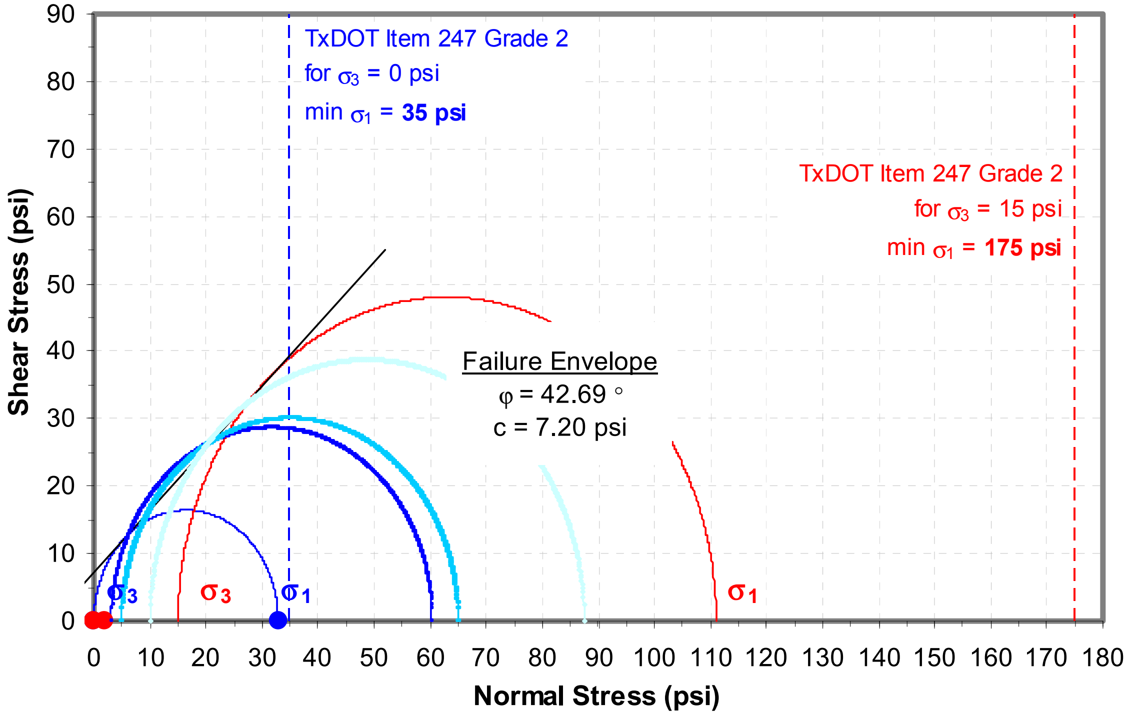


Figure 62. Volumetric Composition of Hydrated Hardened Cement Paste.

Another characterization of the MDF material can be made on the basis of its shear strength (as per ASTM D 3397 and Tex-117-E). For this, a tangent line (failure envelope) to both stress semi-circles is drawn. The intersection of the failure envelope with the shear stress axis defines the cohesion value, c, whereas the slope of the envelope defines the angle of internal friction, φ. Tex-117-E test method prescribes a transfer the constructed failure envelope to the "Chart for Classification of Subgrade and Flexible Base Material" shown in Figure 63 and classify the material to the nearest one-tenth of a class. According to a superposition of the failure envelope and the chart, the untreated MDF-A material can be classified as Class 2.2 aggregate, falling in between the "Fair" and "Borderline" grades for a flexible base material.

Capillary Suction Test (Tube Suction Test)

Capillary suction tests were conducted for assessing the moisture susceptibility of base material when exposed to prolonged capillary soak conditions. The development of both dielectric value (DV) and absorbed moisture content is shown in Figures 64 and 65. As expected, for all mixtures, as moisture content increases, DV also increases. Both MDF-A and MDF-B mixtures exhibit higher average DV, 32.5, and 27.9 at 10 days, respectively, whereas the cement stabilized specimen stayed below 16 at the same age. As stated, this indicates that both MDF-A and MDF-B mixtures have high moisture susceptibility with the corresponding poor DV over 16. Addition of cement improved the moisture susceptibility resistance of the MDF mixture and resulted in DV nearly half of those exhibited by the untreated mixtures.

The average compressive strength values of the samples after capillary suction test were compared to the baseline strengths after the 7-day moist curing obtained earlier. The relative retained strength values of both untreated and 3% cement-stabilized mix designs exceeded the threshold value of 75% recommended by TxDOT. However, overall UCS value for both untreated MDF mixtures did not meet the TxDOT minimum allowable strength for Grade 2 flexible base (35 psi).

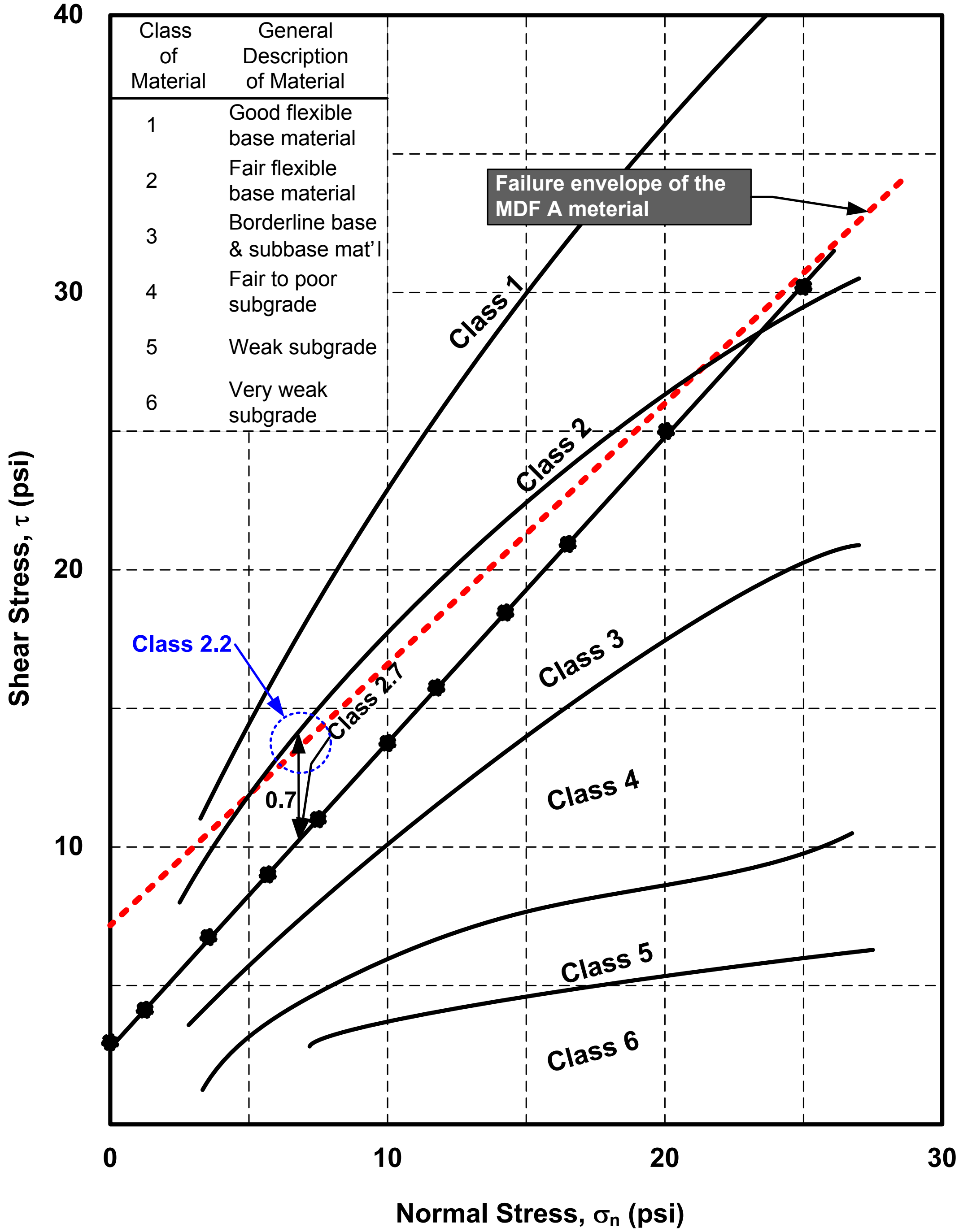


Figure 63. Chart for Classification of Subgrade and Flexible Base Material.

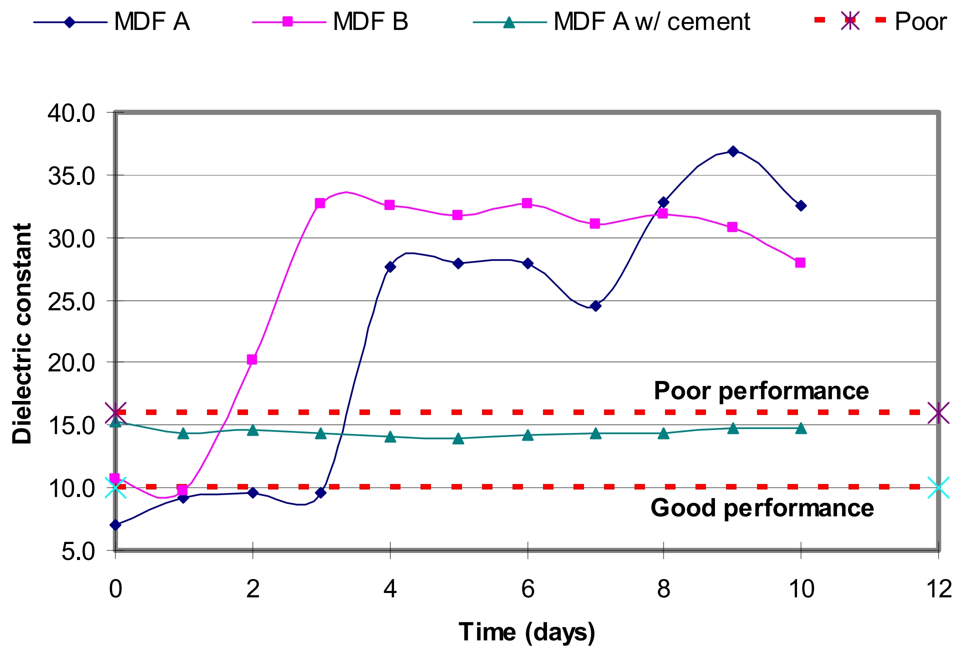


Figure 64. Dielectric Value Development over Time.

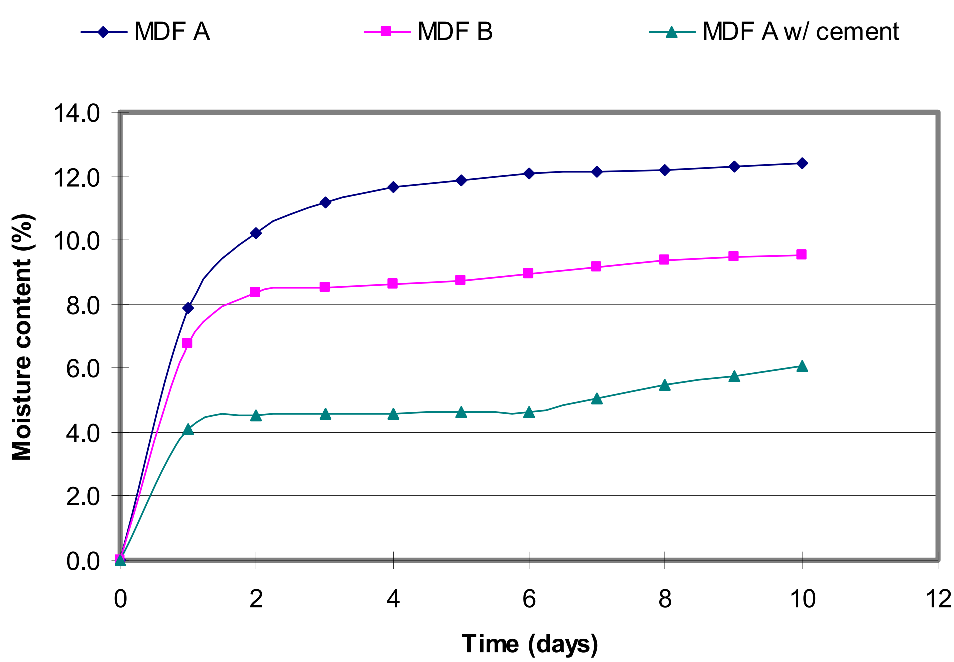


Figure 65. Moisture Content Changes over Time.

Table 16. Tube Suction Test (TST) Results.

Mixture	Final		UCS[3]		Retained UCS (%)
	DV[1]	M.C[2]	Before TST	After TST	
MDF A	32.5	12.4	26.5	23.4	88.2
MDF B	27.9	9.5	25.3	25.7	101.7
MDF A w/ cement	14.8	6.0	245.2	262.9	107.2

[1]DV: Dielectric value; [2]M.C.: Moisture content; [3]UCS: Unconfined compressive strength

Seismic Modulus Test

Figure 66 presents the growth in seismic modulus during curing of mixtures containing MDF materials. While the seismic modulus (SM) of the cement-stabilized MDF mixture significantly increases over time, both untreated MDF mixtures slowly increased.

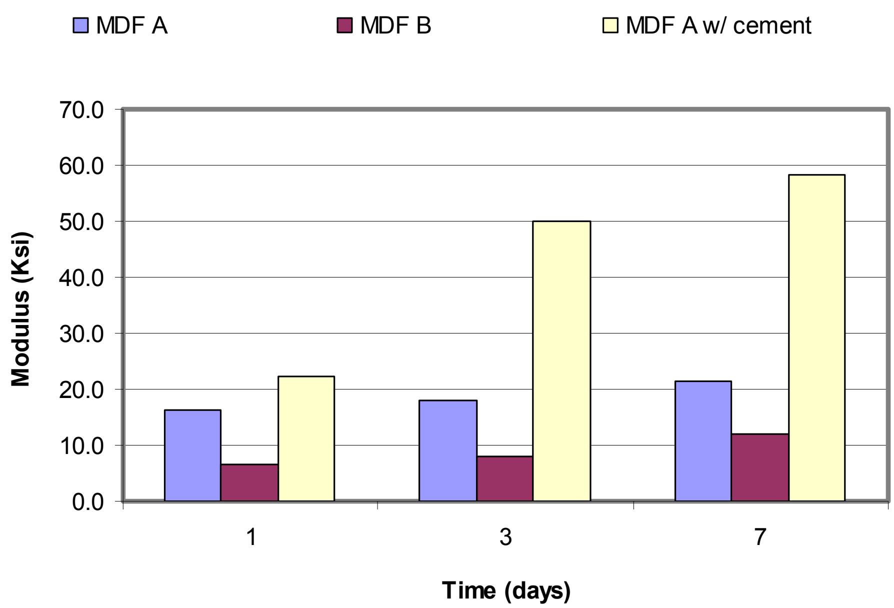


Figure 66. Seismic Modulus Development over Time for Different Mixtures.

As expected, the SM of the cement-stabilized mixture was higher than that of untreated MDF mixtures. Currently, there is no magic SM number to determine a good base-course material, but typical values of SM for granular base materials range from 23,000 psi to 35,900 psi. Thus, the MS for untreated MDF mixtures seems to be lower than that of typical base materials.

Summary

The unconfined compressive strength, triaxial compressive strength, indirect tensile strength, moisture susceptibility, and seismic modulus test data showed that the untreated stockpiled MDF material is not capable of producing satisfactory base-course values to meet Item 247 specification requirements. When compared with the typical base-course requirements identified in Item 247, the MDF material tested was lower than many of these requirements. Although minimum strength values were not achieved, it is recognized that the MDF is not a granular base material, so its comparison to base specifications may not be entirely appropriate. Additionally, because of the specific procedures used to prepare specimens for testing, modifications to the material may have occurred that caused a detrimental effect to the strength testing performed. Additional work is recommended to determine if more appropriate testing procedures are required to reflect observed field performance or Inland Environmental's strengths obtained from their systematic testing.

Evaluation of the MDF with 3 percent cement treatment in the laboratory showed good performance. Further work to establish optimum stabilizer content and type would be recommended for this material.

FIELD PERFORMANCE EVALUATION ON MODIFIED DRILLING FLUID MATERIAL-APPLIED ROAD BASE SECTIONS

This section presents the post-construction assessment for road base-course sections constructed with MDF materials. Performance of MDF material was assessed in terms of in-service performance and field cored samples using non-destructive test methods. GPR, FWD, DCP, and rutting test were used for the in-service performance evaluation. For cored samples, moisture content, dry and wet density, stiffness and seismic modulus, unconfined compressive strength, and modulus of rupture were evaluated.

Test Roadway Section Description

An approximately 700-ft test section on FM 2674 in Wharton County, Texas, was tested as outlined in Figure 67. The modified drilling fluid material and a seashell base material were used from station 113+00 to 116+35 (ft) while a conventional unknown base-course materials was used from station 116+35 to 120+ 50 (ft).

Figure 68 also illustrates the typical cross section of existing pavement structure (station from 113+00 to 116+35), which consists of a 1 in. asphalt layer, 6 in.-base, and black clay subgrade. Two different materials were used in the construction of road base. The base-courses were constructed with the combination of the half of cement-stabilized seashell material and the half of MDF material (Figure 69).

Post Construction Evaluation

In Situ Evaluation Method

Ground Penetration Radar. GPR was used to assess base layer thickness and layer interface condition. Voids and water trapped in and between underlying pavement layer can be detected using image analysis and dielectic constant (DC) on the basis of an air-coupled or ground coupled system vehicle as shown in Figure 70.

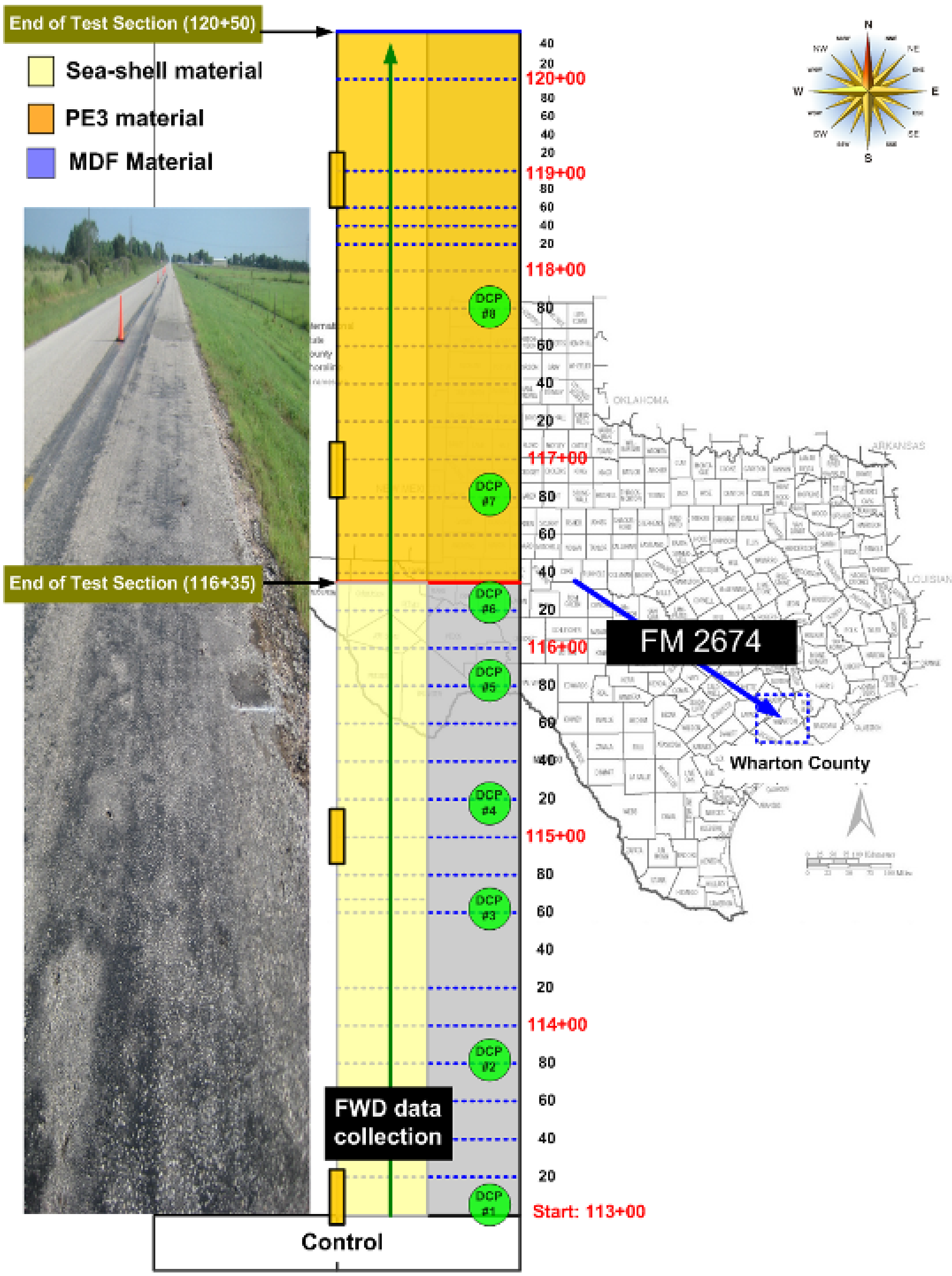


Figure 67. Field Test Section in Wharton County, Texas.

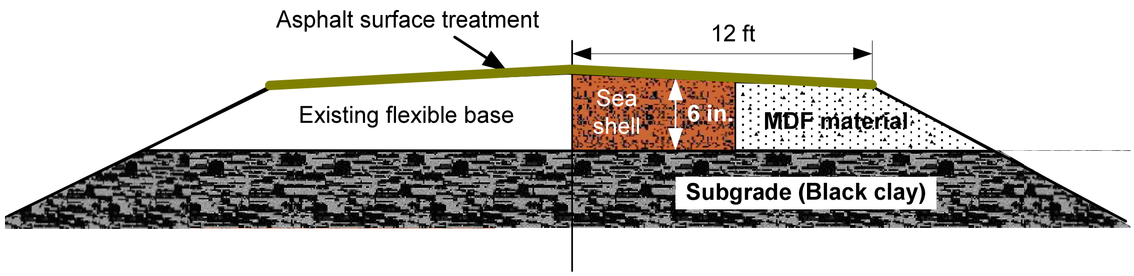


Figure 68. Typical Cross Section on FM 2674.

Figure 69. Typical Section on FM 2674.

Falling Weight Deflectometer. Deflection testing using FWD was used to evaluate the structural capacity for layer stiffness. The FWD applies dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. The response of the pavement is measured in terms of vertical deflection (Figure 71). The data generated from FWD are combined with layer thickness and, in turn, modulus calculation through backcalculation is used to evaluate pavement layers and underlying subgrade.

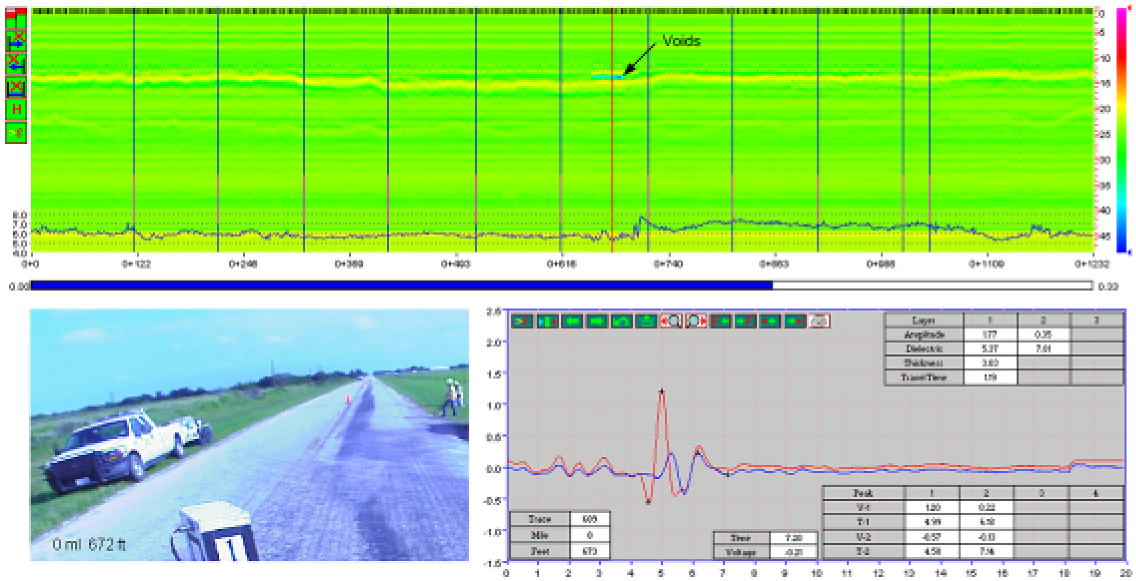


Figure 70. Example of the GPR Testing Image.

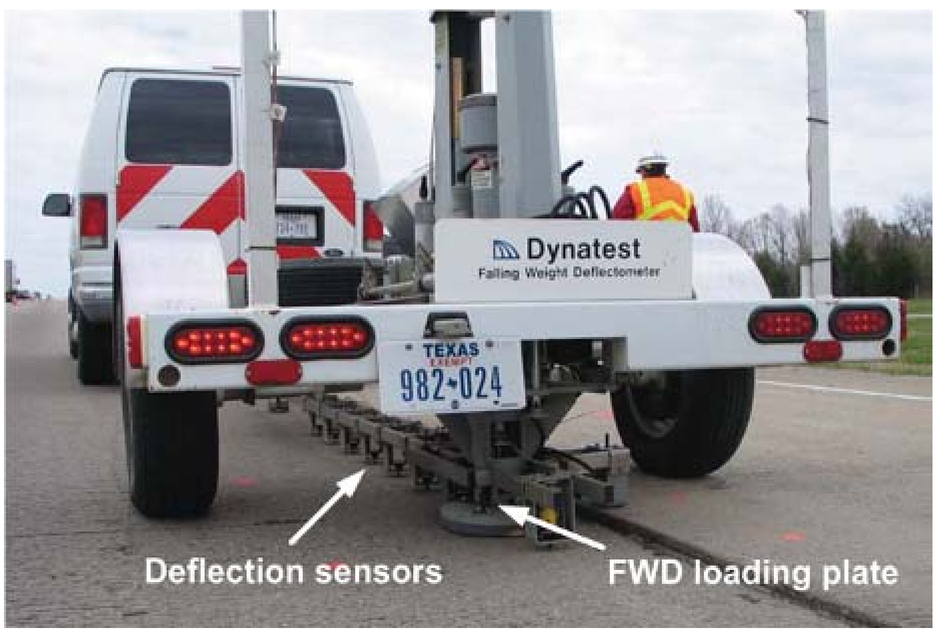


Figure 71. Trailer-Towed FWD (TxDOT Technical Advisory, 2008).

Dynamic Cone Penetration. DCP test was also conducted to measure the in situ strength of base and subgrade materials in terms of penetration resistance in mm/blow. The DCP testing is commonly used to estimate the elastic modulus of each layer because it is fast and easy. As presented in Figure 72, the 18.6 lb (8 kg) weight is raised to a height of 22.6 in. (575 mm) and then dropped, driving the cone into the material layer being tested. After measuring the penetration depth per drop (each blow), DCP penetration rate (PR) in millimeters per blow was computed. The derived PR is correlated to the California bearing ratio (CBR) values and subsequently used to compute elastic modulus of the material.

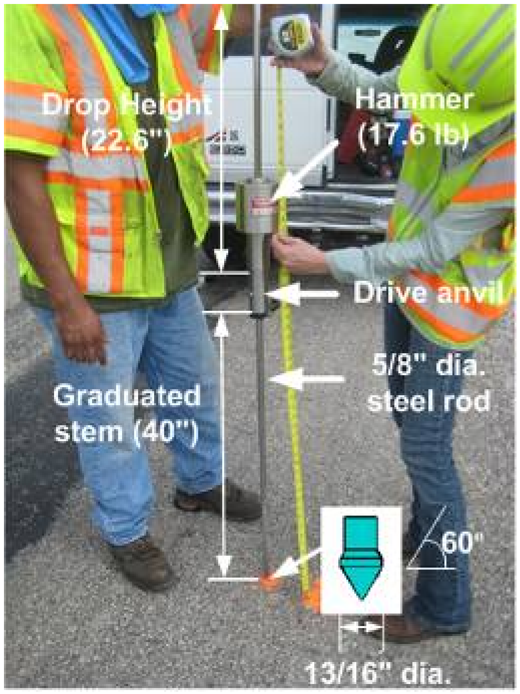


Figure 72. Dynamic Cone Penetration (DCP) Test.

Rutting. Rut depth was measured manually as shown in Figure 73.

Figure 73. Rutting Measurement.

Ground Penetration Radar Results. Figure 74 presents GPR profile from the left-wheel path on northbound FM 2674. While the blue area represents voids, yellow strips indicate base layers. The blue wave at the bottom indicates the surface dielectric constant (DC) value, which generally represents the moisture intensity of the subgrade. When a DC value is higher than 10, a wet condition below the base-course may exist.

As previously described, GPR image shows the uniform patterns over the whole wheel path because the same materials containing sea shell were used in this test section. The thickness of road base seems to be 3-4 in. and some voids between asphalt surface and base-course were detected. The average DC value for the whole wheel path was 7, which shows less moisture presence in this section.

The GPR image from the right-wheel path on northbound FM 2674 is shown in Figure 75. Section 1 constructed with seashell material has a thicker base-course than that of the others. Some voids were observed in the junction area between sections 1 and 2 under the asphalt surface. A significant amount of moisture was detected in sections 2 and 3. It seems that the base-course sections constructed with both MDF and PE3 materials are more sensitive than that used with seashell material.

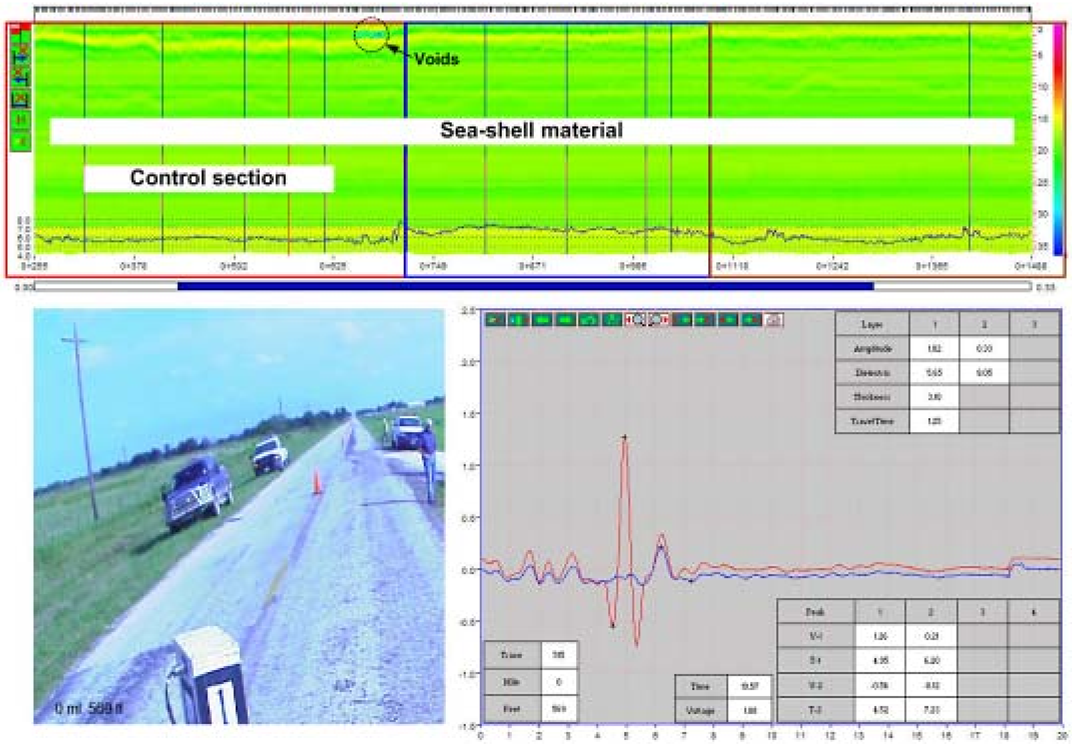


Figure 74. GPR Profile of Left-Wheel Path on Northbound FM 2674.

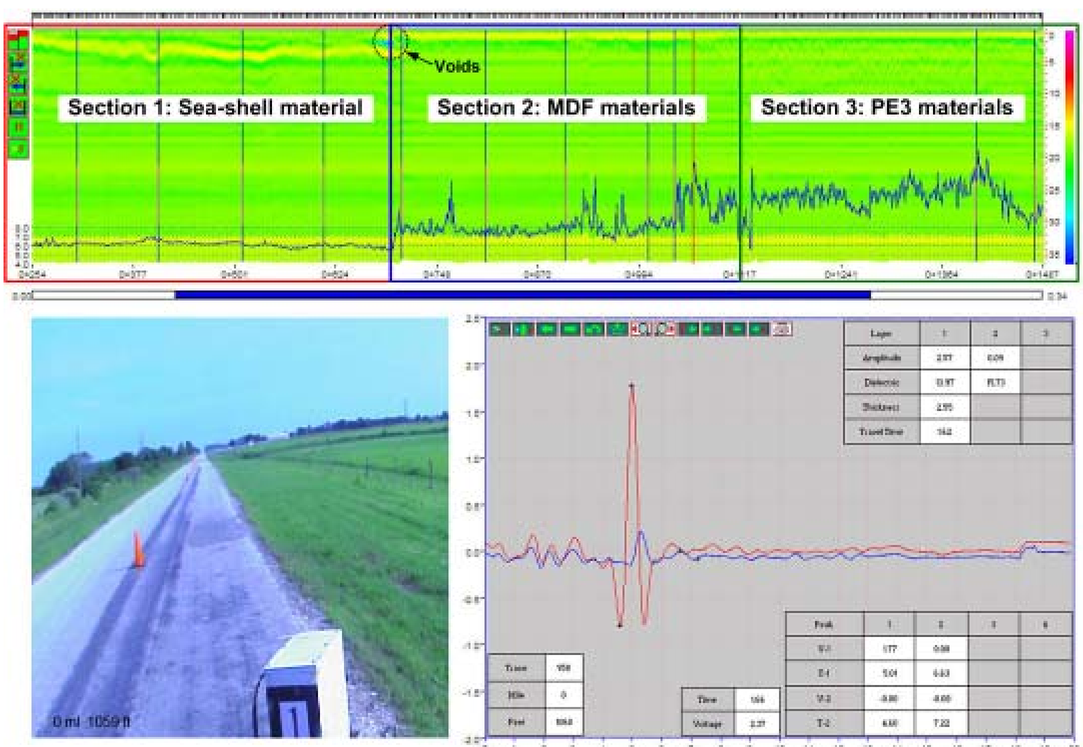
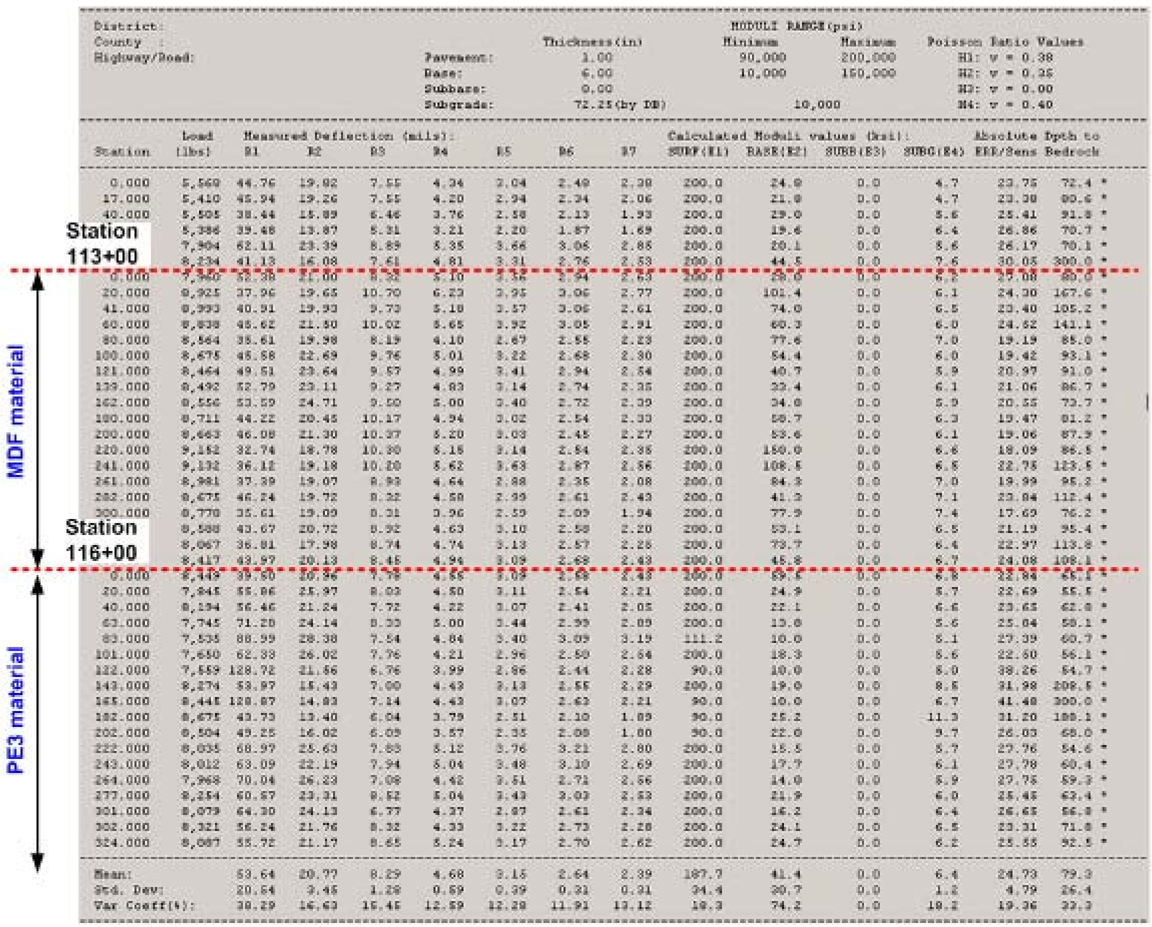


Figure 75. GPR Profile of Right-Wheel Path on Northbound FM 2674.

Falling Weight Deflectometer Results. FWD testing is commonly used to check overall structural capacity of pavement. In spite of theoretical related assumption for backcalculation analysis, FWD test is well established for investigation of pavement condition. Figures 76, 77, and 78 show FWD data, which were collected in right-wheel path on northbound FM 2674 at 20 ft intervals. The section treated with MDF material shows lower deflections than those of the PE3 material treated section in spite of almost the same thickness of base layer. Figure 77 also presents back-calculated modulus values for each station. The PE3 material treated section has a lower modulus value than that of the MDF material treated section. This may be due to wetter subgrade conditions detected from GPR results.



District:
County :
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	1.00	90,000	200,000	H1: v = 0.38
Base:	6.00	10,000	150,000	H2: v = 0.35
Subbase:	0.00			H3: v = 0.00
Subgrade:	72.25(by DB)	10,000		H4: v = 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
0.000	5,560	44.76	19.02	7.55	4.34	3.04	2.40	2.30	200.0	24.0	0.0	4.7	23.75	72.4 *
17.000	5,410	45.94	19.26	7.55	4.20	2.94	2.34	2.06	200.0	21.0	0.0	4.7	23.30	80.6 *
40.000	5,505	38.44	15.89	6.46	3.76	2.58	2.13	1.93	200.0	29.0	0.0	5.6	25.41	91.8 *
	5,386	39.48	13.87	5.31	3.21	2.20	1.87	1.69	200.0	19.6	0.0	6.4	26.86	70.7 *
	7,904	62.11	23.39	8.89	5.35	3.66	3.06	2.86	200.0	20.1	0.0	5.6	26.17	70.1 *
	8,234	41.13	16.08	7.61	4.81	3.31	2.76	2.53	200.0	44.5	0.0	7.6	30.05	300.0 *
0.000	7,960	52.38	21.00	8.32	5.10	3.36	2.94	2.63	200.0	29.0	0.0	6.2	27.08	80.0 *
20.000	8,925	37.96	19.65	10.70	6.23	3.95	3.06	2.77	200.0	101.4	0.0	6.1	24.30	167.6 *
41.000	8,993	40.91	19.93	9.73	5.18	3.57	3.06	2.61	200.0	74.0	0.0	6.5	23.40	105.2 *
60.000	8,838	45.62	21.50	10.02	5.65	3.92	3.05	2.91	200.0	60.3	0.0	6.0	24.52	141.1 *
80.000	8,564	35.61	19.98	8.19	4.10	2.67	2.55	2.23	200.0	77.6	0.0	7.0	19.19	85.0 *
100.000	8,675	45.58	22.69	9.76	5.01	3.22	2.68	2.30	200.0	54.4	0.0	6.0	19.42	93.1 *
121.000	8,464	49.51	23.64	9.57	4.99	3.41	2.94	2.54	200.0	40.7	0.0	5.9	20.97	91.0 *
139.000	8,492	52.79	23.11	9.27	4.83	3.14	2.74	2.35	200.0	33.4	0.0	6.1	21.06	86.7 *
162.000	8,556	53.59	24.71	9.50	5.00	3.40	2.72	2.39	200.0	34.0	0.0	5.9	20.55	73.7 *
180.000	8,711	44.22	20.45	10.17	4.94	3.02	2.54	2.33	200.0	50.7	0.0	6.3	19.47	81.2 *
200.000	8,663	46.08	21.30	10.37	5.20	3.03	2.45	2.27	200.0	53.6	0.0	6.1	19.06	87.9 *
220.000	9,152	32.74	18.78	10.30	5.15	3.14	2.54	2.35	200.0	150.0	0.0	6.6	18.09	86.5 *
241.000	9,132	36.12	19.18	10.20	5.62	3.63	2.87	2.56	200.0	108.5	0.0	6.5	22.75	123.5 *
261.000	8,981	37.39	19.07	8.93	4.64	2.88	2.35	2.08	200.0	84.3	0.0	7.0	19.99	95.2 *
282.000	8,675	46.24	19.72	8.32	4.58	2.99	2.61	2.43	200.0	41.3	0.0	7.1	23.84	112.4 *
300.000	8,770	35.61	19.09	8.31	3.96	2.59	2.09	1.94	200.0	77.9	0.0	7.4	17.69	76.2 *
	8,588	43.67	20.72	8.92	4.63	3.10	2.58	2.20	200.0	53.1	0.0	6.5	21.19	95.4 *
	8,067	36.81	17.98	8.74	4.74	3.13	2.57	2.26	200.0	73.7	0.0	6.4	22.97	113.8 *
	8,417	43.97	20.13	8.45	4.94	3.09	2.68	2.43	200.0	45.8	0.0	6.7	24.08	108.1 *
0.000	8,449	39.60	20.96	7.78	4.66	3.09	2.69	2.43	200.0	69.6	0.0	6.8	22.84	65.1 *
20.000	7,845	55.86	25.97	8.03	4.50	3.11	2.54	2.21	200.0	24.9	0.0	5.7	22.69	55.5 *
40.000	8,194	56.46	21.24	7.72	4.22	3.07	2.41	2.05	200.0	22.1	0.0	6.6	23.65	62.8 *
63.000	7,745	71.20	24.14	8.33	5.00	3.44	2.99	2.09	200.0	13.8	0.0	5.6	25.04	58.1 *
83.000	7,535	88.99	28.38	7.54	4.84	3.40	3.09	3.19	111.2	10.0	0.0	5.1	27.39	60.7 *
101.000	7,650	62.33	26.02	7.76	4.21	2.96	2.50	2.64	200.0	18.3	0.0	5.6	22.60	56.1 *
122.000	7,559	128.72	21.56	6.76	3.99	2.86	2.44	2.28	90.0	10.0	0.0	8.0	38.26	54.7 *
143.000	8,274	53.97	15.43	7.00	4.43	3.13	2.55	2.29	200.0	19.0	0.0	8.5	31.98	208.5 *
165.000	8,445	128.87	14.83	7.14	4.43	3.07	2.63	2.21	90.0	10.0	0.0	6.7	41.48	300.0 *
182.000	8,675	43.73	13.40	6.04	3.79	2.51	2.10	1.89	90.0	25.2	0.0	11.3	31.20	188.1 *
202.000	8,504	49.25	16.02	6.05	3.57	2.35	2.08	1.80	90.0	22.0	0.0	9.7	26.03	68.0 *
222.000	8,035	68.97	25.63	7.85	5.12	3.76	3.21	2.80	200.0	15.5	0.0	5.7	27.76	54.6 *
243.000	8,012	63.09	22.19	7.94	5.04	3.48	3.10	2.69	200.0	17.7	0.0	6.1	27.78	60.4 *
264.000	7,968	70.04	26.23	7.08	4.42	3.51	2.71	2.56	200.0	14.0	0.0	5.9	27.75	59.3 *
277.000	8,254	60.67	23.31	8.52	5.04	3.43	3.03	2.53	200.0	21.9	0.0	6.0	25.45	63.4 *
301.000	8,079	64.30	24.13	6.77	4.37	2.87	2.61	2.34	200.0	16.2	0.0	6.4	26.65	56.8 *
302.000	8,321	56.24	21.76	8.32	4.33	3.22	2.73	2.28	200.0	24.1	0.0	6.5	23.31	71.8 *
324.000	8,087	55.72	21.17	8.65	5.24	3.17	2.70	2.62	200.0	24.7	0.0	6.2	25.55	92.5 *
Mean:		53.64	20.77	8.29	4.68	3.15	2.64	2.39	187.7	41.4	0.0	6.4	24.73	79.3
Std. Dev:		20.54	3.45	1.28	0.59	0.39	0.31	0.31	34.4	30.7	0.0	1.2	4.79	26.4
Var Coeff(%):		38.29	16.63	15.46	12.59	12.28	11.91	13.12	18.3	74.2	0.0	18.2	19.36	33.3

Figure 76. FWD Data for Right-Wheel Path on Northbound FM 2674.

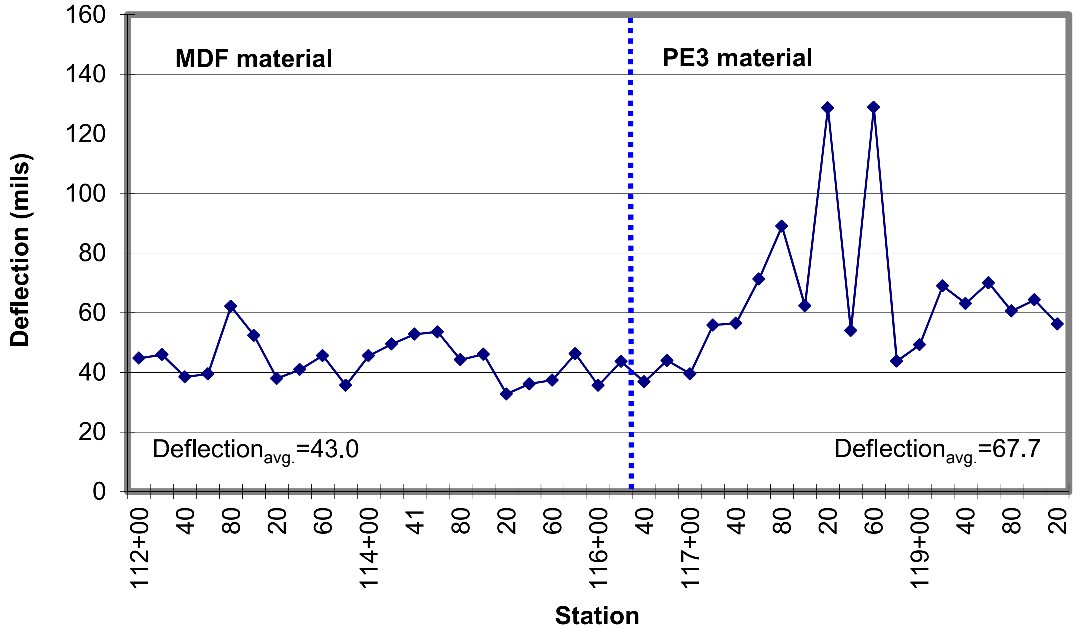


Figure 77. Deflection Values of Test Section.

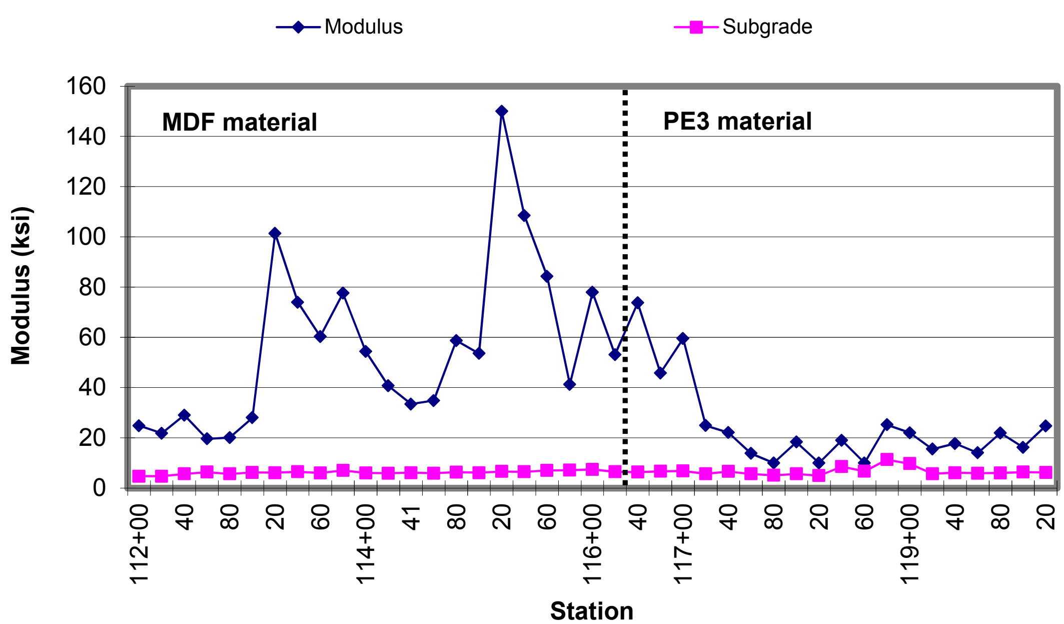


Figure 78. Modulus Values of Test Section.

Dynamic Cone Penetration Results. Figure 79 presents an example of the calculation of the penetration ratio dynamic cone penetration testing for locations 1 and 8. A plot of the DCP data is useful to find the slope of the linear trend line. The CBR and elastic modulus values were calculated using the following relationship (Webster et al. 1992):

$$\text{Log CBR} = 2.465 - 1.12\ (\log \text{PR}) \qquad \text{or CBR} = 292/\text{PR}^{1.12} \tag{4}$$

$$E = 2550 \times \text{CBR}^{0.64} \tag{5}$$

Where : PR = the DCP's penetration through the layer in units of mm/blow.

Typical elastic modulus for an unbounded aggregate base ranges from 15 to 45 ksi (or 0.05 to 0.1 in./blow), while that for stabilized flexible base modulus is 60 to 120 ksi.

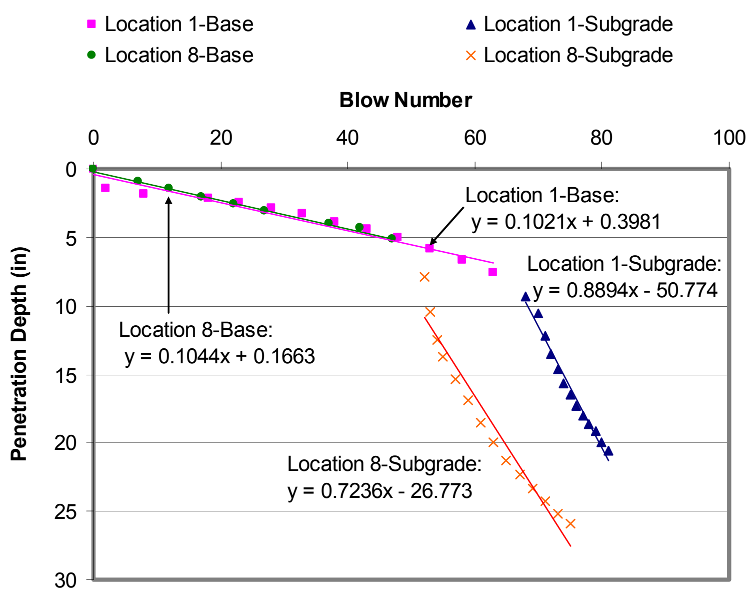


Figure 79. Dynamic Cone Penetrometer Results.

Figure 80 elastic moduli is calculated from DCP data at tested locations. The estimated elastic moduli range from 33 to 49 ksi, and they appear to be quite low. As previously stated, this low modulus for the base could result from a wet subgrade condition. The presence of standing water may contribute to degradation of the modulus for the base and subgrade by weakening the bonding between materials particles. There was no significant difference of the modulus between MDF and PE3 materials treated locations.

Figure 81 shows California bearing ratio (CBR) values computed from the DCP data for each section. Using equation (4), the CBR values of locations 1 through 8 were computed to be 100.4 to 56.3. It indicates that locations 1 and 2 are more than capable of handling the low-volume traffic loads. Although CBR values in the other locations are as low as 80, MDF base was performing adequately at this low traffic volume.

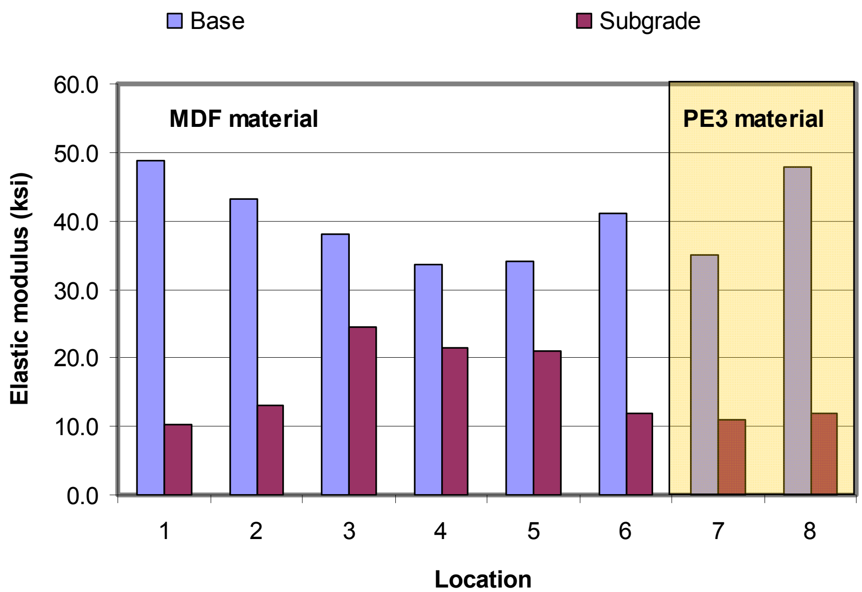


Figure 80. Elastic Moduli for Test Locations.

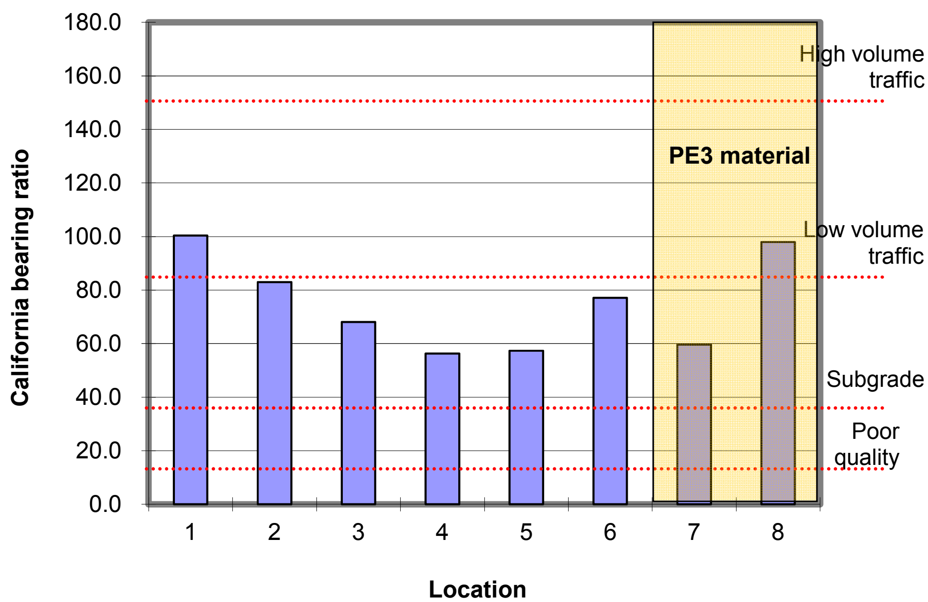


Figure 81. CBR Values of Test Locations.

Rutting Results. Figures 82 and 83 show rutting measurement locations, results, and pavement condition. The primary distress is rutting, which reaches 1 in. in some locations. The test section had some alligator and longitudinal cracking.

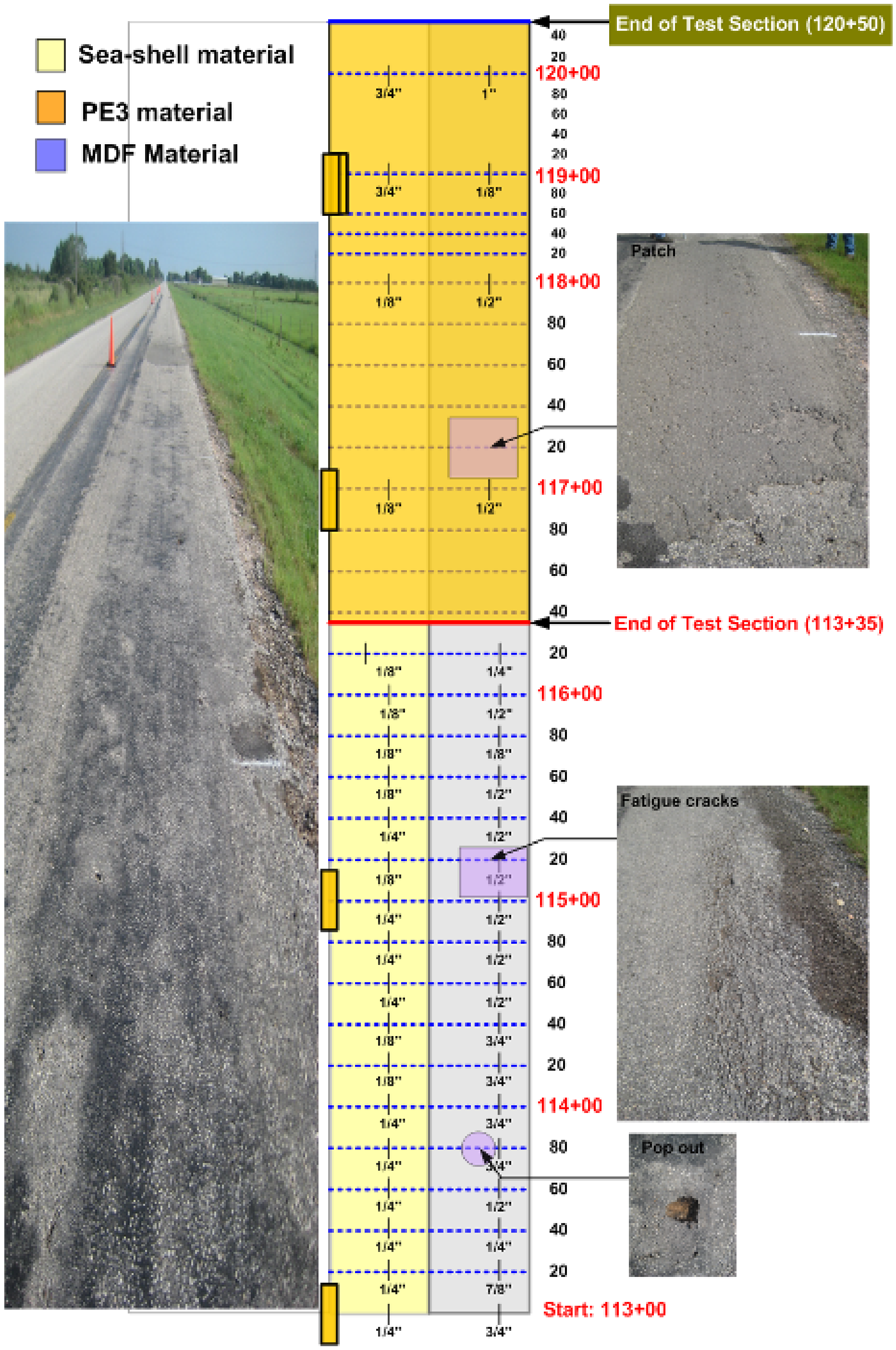
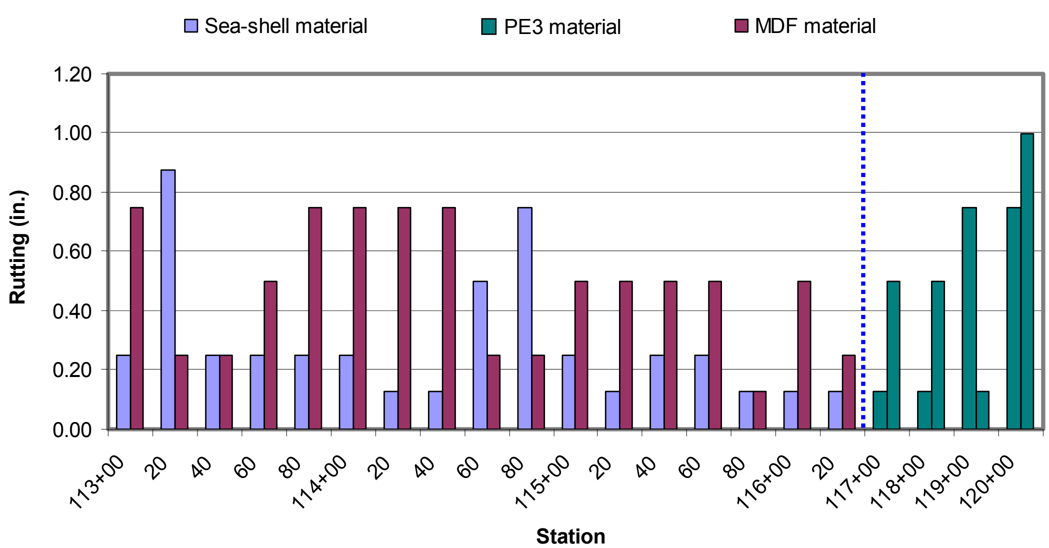


Figure 82. Rutting Test Locations and Rutting Values on FM 2674.

Figure 83. Rutting on FM 2674.

Figure 84 presents the comparison of rutting between different materials. MDF material treated base appears to produce higher rutting than the seashell base. The difference in rutting between MDF and PE3 materials is not very remarkable.



Sea-shell material (avg.)	PE3 material (avg.)	MDF material (avg.)
0.32 in.	0.48 in.	0.49 in.

Figure 84. Comparison of Rutting between Different Materials.

Assessment of Field Cored Samples

Evaluation Method for Cored Sample

Collection of Cored Sample. Coring of field samples was conducted to determine the thickness of all pavement layers and strength. But, during the coring process, all samples were broken because they seemed to be weak as shown in Figure 85. After trenching, slab samples were collected instead of coring in the field. Coring of the cylindrical sample from the slab specimen was unsuccessfully attempted in the laboratory (Figure 86). Therefore, the slab sample was evaluated in terms of moisture content, dry and wet density, stiffness and seismic property, unconfined compressive strength, and modulus of rupture.

In Situ Moisture Content. As described in Chapter 3, The TxDOT test method Tex-103-E "Determining Moisture Content in Soil Materials" was performed to the determine moisture content (MC) of in situ slab sample. A portion of the slab specimen was dried at 110°C (230°F) for a minimum of 16 hours or until a constant mass is reached. After that, the MC was calculated using weight change of specimen before and after drying.

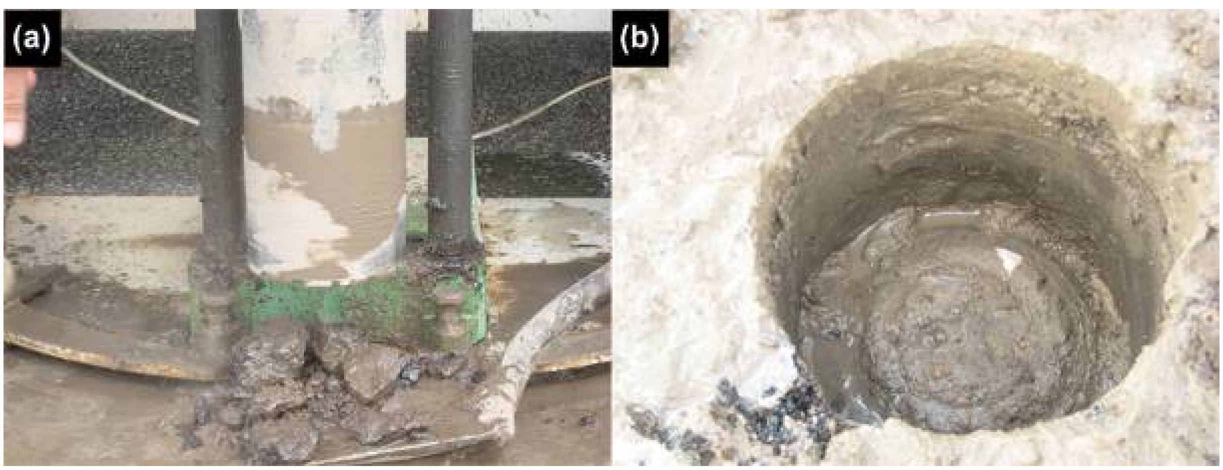


Figure 85. Coring of Field Sample.

Figure 86. Slab Sample.

Nuclear Density Gauge Testing. Nuclear density gauge (NDG) readings were taken to determine with wet and dry density and moisture content of in-situ slab specimen. The NDG is the non-destructive device for the quality control (Q/C) of base or subgrade compacted in road construction (Figure 87). The gauge operates by producing small doses of backscattered gamma waves. The radiation reflected from the material is detected at the base of the gauge and converted to material density when the gauge is calibrated to the specific material. The gauge also has a neutron source to determine the moisture content by detecting the hydrogen in a material sphere around the gauge.

GeoGauge Stiffness Testing. As presented in Figure 88, the GeoGauge stiffness test was used to determine the in-situ modulus of slab specimen. The GeoGauge is a non-destructive, hand-portable device, which rapidly measures the stiffness of material mixtures used in road base or subgrade construction. Young's modulus and shear modulus of the tested material is directly determined.

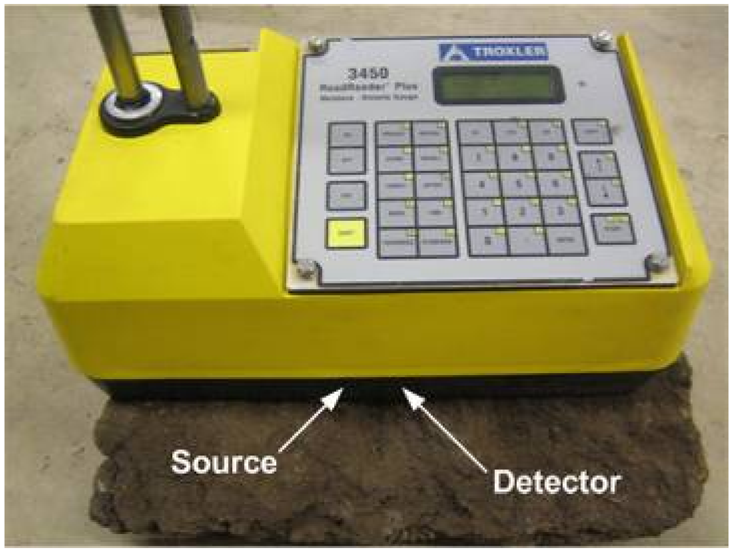


Figure 87. Nuclear Density Gauge Testing.


Figure 88. GeoGauge Stiffness Testing.

Seismic Modulus Testing. Portable seismic property analyzer (PSPA) shown in Figure 89 was used to obtain the seismic modulus of slab specimen. The PSPA, a high frequency seismic test device, consists of one source transducer and two signal receivers. The source transducer is used for triggering, while the receiver collects the signal. The average modulus of the exposed surface layer can be calculated using ultrasonic surface wave methods, which are analyzed to obtain a dispersion curve (velocity vs. wavelength) and then converted to modulus vs. depth.

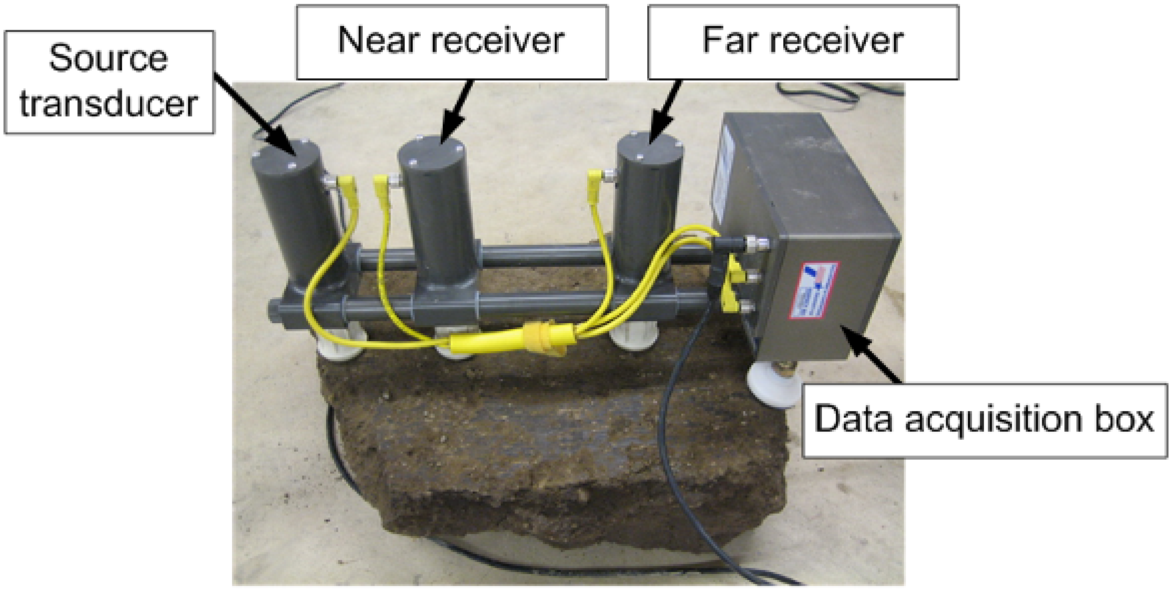


Figure 89. Portable Seismic Property Analyzer (PSPA) Testing.

Compressive Strength and Modulus of Rupture Tests. Because a cylindrical core sample could not be obtained, slab specimens were cut into the proper cube and beam shapes for strength and modulus of rupture test. And then, the compressive strength and modulus of rupture tests were performed according to ASTM C 109 and ASTM C 293 specifications as presented in Figures 90 and 91, respectively.

Figure 90. Compressive Strength Test.

Figure 91. Center Point Flexural Strength Test.

Test Results and Discussion

Table 17 summarizes the test results of moisture content, density, compressive strength, modulus of rupture, stiffness, and Young's modulus obtained from various tested methods for a field cored slab sample. Moisture contents (MC) of slab obtained from the Tex-113-E test, and nuclear density gauge samples are 15.9 percent and 13.0 percent, respectively.

Wet and dry densities of slab sample were determined to be 119.4 lb/ft^3 and 113.8 lb/ft^3, respectively. The slab sample has a higher dry density than laboratory determined dry density (99.8 lb/ft^3). Interestingly, although the testing methods are different, the compressive strength of the cored slab sample is higher than that of laboratory tested sample.

Table 17. Test Results of Field Cored Specimen.

Test method	Properties	Unit	Values[1]	Lab. Test[2]
Tex-113-E	Moisture Content	(%)	15.9	12.1
Nuclear Density Gauge	Moisture Content	(%)	13.0	
	Wet density	(lbs/ft^3)	118.4	-
	Dry density	(lbs/ft^3)	133.8	99.8
ASTM C 109	Compressive strength	(psi)	67.0	26.5
ASTM C 293	Flexural compressive strength	(psi)	9.3	-
GeoGauge	Stiffness	(MN/m)	4.7	-
	Young's modulus	(ksi)	5.9	-
PSPA	Young's modulus	(ksi)	14.5	-

[1] Test results show average values of at least three specimens.
[2] Laboratory test results described in Chapter 4.

VISUAL EVALUATION OF ROADWAYS CONSTRUCTED WITH MDF IN COLORADO COUNTY

In March 2011, TTI visually evaluated several roadways in Colorado County, which had been constructed using Inland Environmental's MDF as a roadbase. A brief description of each of these along with photographs is shown below.

Oakridge Ranch Road

This is a private road for a rural subdivision as shown in Figures 92 and 93. It is about 6 miles in length. The MDF material was hauled from Inland Environmental to the site and placed using a motor grader. No water was added. The roadway took several weeks to complete and was under traffic and various weather conditions during that time. A surface treatment is planned. The roadway was in good condition.

Figure 92. Oakridge Ranch Private Road.

Figure 93. Oakridge Ranch Private Road (Road Surface).

Greendale Road

This road was constructed by county forces and serves a small subdivision. The base course was supplied by Inland Environmental and constructed using a motor grader and conventional rolling equipment. No water or stabilizers were added to the MDF. The photographs in Figures 94 and 95 show the roadway after an MC-30 prime has been applied. The prime was well penetrated into the base. It was scheduled to receive a surface treatment using an AC-5 and Grade 3 aggregate the day after the photo was taken. Commissioner Tommy Hahn has used this MDF material as a base course for more than 8 years because of its significantly reduced cost, and he is pleased with its performance.

Figure 94. Greenbriar County Road, Primed with MC-30 (1).

Figure 95. Greenbriar County Road, Primed with MC-30 (2).

County Road to Saltwater Disposal Facility

The performance of this roadway is impressive as shown in Figure 96. It was also constructed as described above except that the surface is hot mix. The bottom photo in Figure 97 shows where the trucks turn into the disposal facility. Commissioner Hahn stated that it is about 8 years old and carries 80,000 lb trucks daily.

Figure 96. County Road to Saltwater Disposal Facility (1).

Figure 97. County Road to Saltwater Disposal Facility (2).

SUMMARY AND RECOMMENDATIONS

Summary of Results

A laboratory and field investigation was conducted of MDF material produced by Inland Environmental. This MDF material is a relatively high pH, low plastic, clay sand material, mainly consisting of quartz and barite. Samples obtained by TTI indicated that there were more fines in the MDF than permitted for Grades 1 through 3 as specified by Item 247. Key results from some of the tests on lab-compacted samples can be summarized as follows:

- Optimum Moisture Content 21.2 percent (Note: stockpile moisture including volatile content is about 10 percent and no additional water was added to the material in the field for roadway construction).
- Unconfined Compressive Strength = 26 psi.
- Triaxial Classification = 2.2.

After the addition of 3 percent cement, the unconfined compressive strength jumped to 246 psi. Field performance of the MDF material was evaluated on FM 2674 where a patch was made using this material about 6 years ago by Yoakum District maintenance forces. Approximately 300 ft of this material was placed and another 300 ft of a conventional material being used by maintenance was placed at the same time. Dynamic cone penetrometer, falling weight deflectometer, ground penetrating radar, and visual evaluations were performed on the patched areas. Field performance of the MDF patch was comparable to the conventional base patch material; however, the FWD results indicated that stiffness for the MDF is twice that of the conventional base patch. Field cores of the MDF patch were tested in the laboratory and exhibited compressive strengths more than twice that of laboratory produced samples. The difference may be explained by using testing techniques that were not necessarily appropriate for this material.

A visual field performance evaluation was conducted of several non-TxDOT roadways constructed of MDF as a base course in Colorado County. These low-volume roadways all exhibited good field performance.

Recommendations

This MDF material has some unique engineering properties, and tests performed on samples compacted at optimum moisture content according to TxDOT standard procedures do not reflect field performance characteristics. Optimum moisture content is significantly higher than the moisture content used during construction. Differences in strength between field cores and lab compacted samples indicate the material may gain strength with time, which is not captured by current lab test protocols. Based on the field performance evaluations, the MDF material has potential for use as:

- Embankment.
- Subbase materials.
- Patching material.
- Base material for low-volume roadways.
- Shoulders.
- Base for maintenance activities.

Current TxDOT procedures, however, for lab and field compaction of roadway base or embankment materials require compaction to an optimum moisture and density. Additional testing is required to develop testing protocols and construction specifications suited to this material and, if appropriate, incorporate a strength-gain with time criteria. To proceed with full-scale implementation the following is recommended:

- Conduct more FWD testing on the full-scale non-TxDOT roads in Colorado County.
- Conduct an expanded laboratory test program to develop a practical specification, which includes both laboratory test requirements and construction recommendations.
- The material should be certified by the TCEQ program and will need to pass the equivalent of the DMS 11000 specification to ensure no environmental concerns are raised by the product.

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WORK ORDER 20:
ASSESSING THE COST ATTRIBUTED TO PROJECT DELAYS

EXECUTIVE SUMMARY

All departments of transportation (DOTs) face delays on highway projects. They often have anecdotal accounts of the significant financial impact that the delay of a highway project had on project costs, local businesses and commuters, and other users of the highway. But in many cases hard data on the financial impact are lacking. This project for the Texas Department of Transportation (TxDOT) aims to develop a simple but sound methodology for estimating the cost of delaying most types of highway projects. The project draws on two main resources to produce reliable estimates of impacts:

- Existing data from projects completed in fiscal year (FY) 2009 and reported in TxDOT's Design Construction Information System (DCIS).
- Methodologies developed for other applications that can be applied to estimating the cost of project delay.

DELAY DURING PROJECT PHASES

Delay can occur in any phase in the project:

- **Planning/scoping phase:** Delay can be significant when litigation is initiated.
- **Development phase:** Permitting (environmental, fish and wildlife, railroad, etc.), right-of-way acquisition, and utility agreements can be significant causes of delay.
- **Contracting phase:** Generally, this phase has less incidence of delay but can still have issues.
- **Construction phase:** This phase has numerous opportunities for delay and is often the delay most visible to the public.

Project delay almost always has costs associated with it, which is not to say that all project delay is a waste of time and public money. In many instances of project delay initiated by TxDOT, the reason for the delay is to make an improvement in the design or construction of the project that will ultimately deliver better value to the public.

ESTIMATION MODEL

This project developed a simplified model that incorporates 16 user-controlled variables and produces estimates of the effect of project delay on personal and commercial travel and the cost to the general economy. Three projects of varying size were used as examples:

- The "small project" illustrates delay to an $11.4 million, four-lane roadway project in a rural setting. The project's 33-month delay produced an additional $3.5 million cost to the economy, or *$96,000 for every month of delay.*
- The "medium project" illustrates delay to a $49.6 million, urban freeway project. The project's 58-month delay produced an additional $17.8 million cost to the economy, or almost *$300,000 for every month of delay.*
- The "large project" illustrates delay to an $82.2 million interstate highway improvement in a large metro area. The project's 11-month delay produced an additional $5.1 million cost to the economy, or *$447,000 for each month of delay.*

CASE STUDIES

Finally, the report includes three atypical case studies that demonstrate a range of delay issues, all with costs attached including litigation costs and termination fees paid to contractors. These costs are in addition to the types of costs calculated in the model discussed above.

PURPOSE AND SCOPE OF THE REPORT

This report helps identify the costs of delays to completing roadway projects, and a methodology for estimating those additional costs to the state and to users. The report also addresses three basic elements related to project delay:

- Definitions and types of project delay.
- Methodology for estimating project-specific delay costs.
- Case studies that demonstrate the application of the methodology.

For this report, the Texas Transportation Institute (TTI) examined recent TxDOT projects that meet the following requirements:

- Construction projects (e.g., new construction, reconstruction, and rehabilitation).
- Projects that had sufficient data requirements in order to be analyzed (e.g., projects in metropolitan planning organization [MPO] jurisdictions with readily available travel demand data).

The following types of transportation projects were excluded from this analysis:

- Projects that experienced delays due to lack of funding.
- Transportation projects with a total project investment of less than $7 million.
- Maintenance projects.

In most cases examined in this study, delay occurred because the project missed a milestone according to the project schedule dates established by the project engineer and the respective TxDOT district. This study did not examine the scheduling process that occurs during the planning/scoping phase of the project life cycle to see if that aspect of a project (i.e., overly optimistic schedules) might be an inherent source of delay.

TERMINOLOGY

The following glossary defines certain terms and phrases used within this report. It also clarifies what is and is not included in the various types of costs associated with project delays. Appendix A contains a list of acronyms used in this document.

Direct Costs of Project Delay—actual out-of-pocket costs borne by any stakeholder affected by a delay in project delivery. Most of the direct costs accrue to TxDOT and, therefore, are passed on to the public in the form of less-efficient use of taxpayer resources.

Indirect Costs of Project Delay—hidden costs that are borne by stakeholders, often a much greater amount than the direct costs of project delay. Indirect costs include:

- Wasted traveler fuel and time.
- Economic impacts in the vicinity of the project.
- Loss of business efficiency for those businesses that rely on the transportation system for their productivity.

Project Delay—In estimating the difference in planned and actual project completion date, this report assumes that the *planned* completion date is the date from the notice to proceed plus the number of days allowed for construction. The *actual* completion date is when the project is open for public use.

Project Stages—usually divided into four distinct stages: planning, development, contracting, and construction. Delays that occur during the various stages typically affect different stakeholders (e.g., the state, contractors, businesses, or the public) in different ways. Once a project has been identified, its life cycle includes defined stages and milestones. Figure 98 illustrates the general project stages, basic activities that occur in each stage, and some of the major milestones.

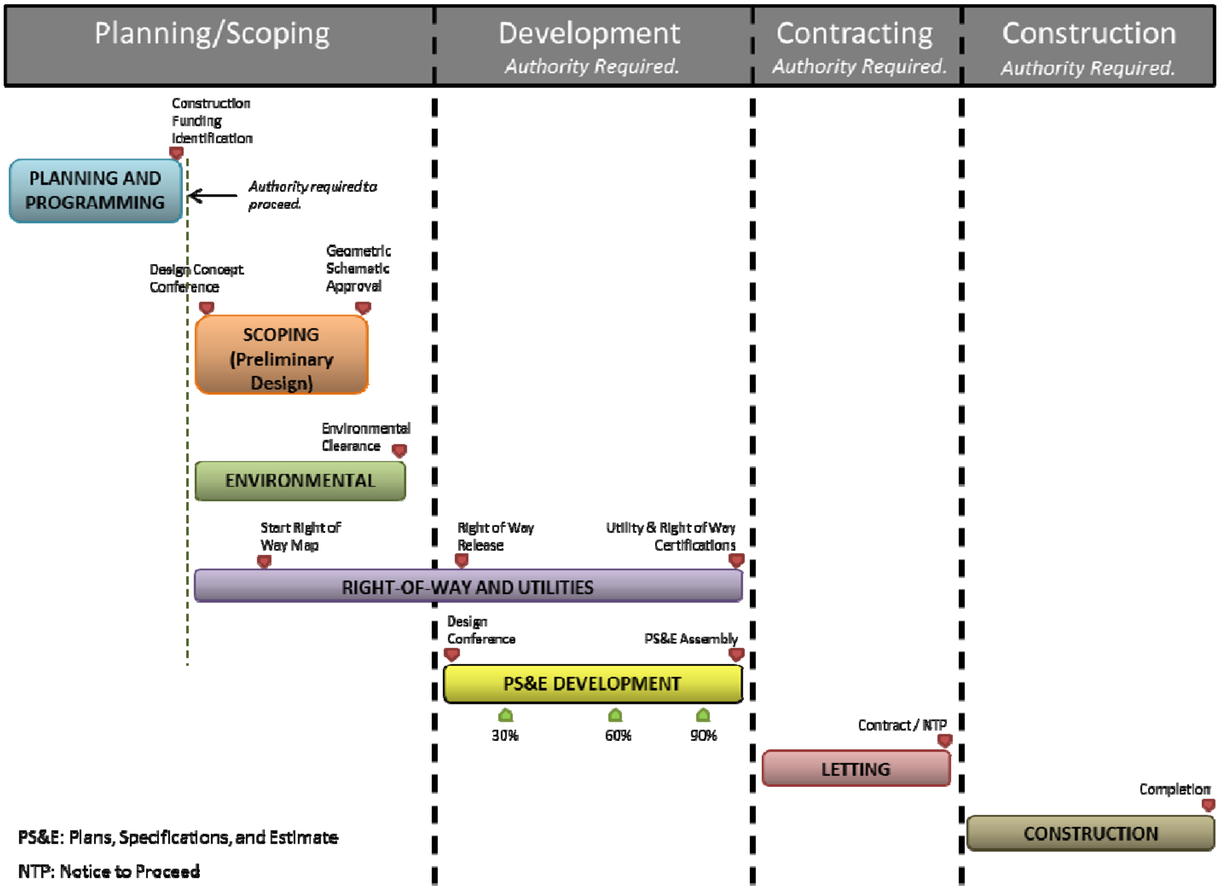

Figure 98. Life Cycle of a Typical Roadway Project.[1]

[1] C.A. Quiroga, E. Kraus, J.H. Overman, and N.A. Koncz. *Integration of Utility and Environmental Activities in the Project Development Process.* Report 0-6065-1, Texas Transportation Institute, http://tti.tamu.edu/documents/0-6065-1.pdf.

WHO BEARS THE COST OF PROJECT DELAY?

Ultimately, the public bears the cost of project delay. Three major groups of stakeholders are affected by project delay:

- The agency.
- The public.
- Contractors (and their suppliers).

Figure 99 provides a conceptual schematic diagram of how direct and indirect costs at various stages of the project timeline can affect these stakeholders.

The costs of project delays can be classified as either direct or indirect costs to the public, the agency, or contractors. Some costs to the agency or contractors associated with contract delay are recoverable by the entity incurring the cost; others are not. As shown in Figure 99, ultimately, all costs are eventually borne by the public.

Direct costs are divided into three categories:

- **Agency costs.** The cost cited in Figure 99 is the expense associated with additional engineering services. These costs may or may not be recoverable. In some cases, the agency can recover the costs if they are due to errors by others. If the costs are not recoverable, the expense becomes an indirect cost that is ultimately paid by the public.
- The cost in extra fuel and time wasted by the public because of project delay. The public is not reimbursed for that cost.
- **Contractor costs.** The contractor absorbs costs due to unproductive labor (e.g., the contractor is told by the agency or some other authority to cease construction or has to, for some other reason, pay labor costs on a standby basis). The agency may reimburse the contractor. But for the agency, the cost is likely not reimbursable and is ultimately borne by the public. If the cost is not reimbursable to the contractor directly, it becomes an indirect cost to the contractor that is ultimately transferred to the agency or the public in some other form (e.g., higher contract prices in the future).

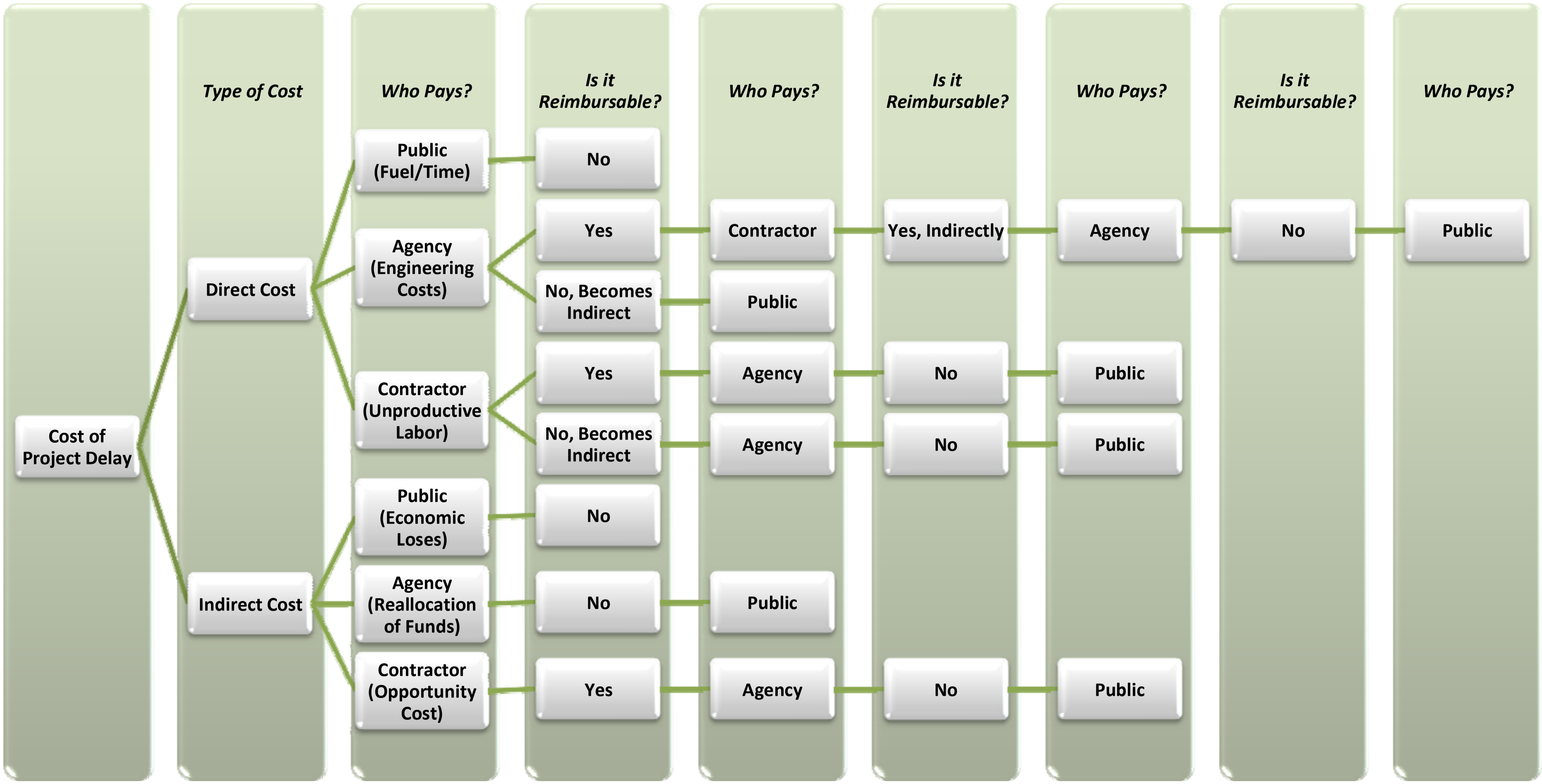

Figure 99. Stakeholder Impacts of Direct and Indirect Project Costs.

COSTS TO THE PUBLIC

Direct and indirect costs paid initially by the agency are ultimately borne by the public. For example, when a project is delayed early in the process, engineering, right-of-way, material, labor, or other cost elements may increase because of the delay. This is a direct cost of project delay that is ultimately paid by the public.

Additionally, because TxDOT has a finite supply of funds with which to operate in a given year, the increased costs will likely mean that other previously scheduled and budgeted projects will have to be postponed and their benefits delayed. These are considered indirect costs to the public.

Costs to Travelers in the Affected Corridor

Two of the most recognized costs to the public are associated with wasted time and fuel cost. We all place a value on our time. When a project is delayed and improvements to the particular corridor postponed, the benefits associated with that improvement (e.g., higher speeds and shorter commute times) are not realized. Furthermore, with the slower commute speeds, fuel efficiency may be reduced, resulting in higher fuel costs for travelers.

Costs to Businesses and Their Consumers

One of the most important cost aspects of project delay is the impact on businesses and consumers. Businesses are affected by roadway congestion in much the same way as motorists. As speeds are reduced, operating costs (i.e., driver time, vehicle operating costs, fuel costs, etc.) are increased. Ultimately, these costs are passed on to the consumer. But there can be other, more pervasive impacts as well.

Almost all surveys that ask businesses about factors that influence location decisions show similar results. They indicate that businesses most value the following when deciding where to locate a facility:

- A fair and reasonable tax system.
- An educated and available workforce.
- Access to markets.

Reduced mobility affects businesses in two ways: it reduces the supply of qualified workers who live within a reasonable commute distance, and it increases the cost of accessing markets, causing increased shipping costs for both raw materials and finished products.

With respect to labor markets, as mobility is reduced and commute times lengthen, the labor pool within a one-hour commute to a particular location is reduced. To attract a wider number of potential employees, some companies may find it necessary to offer higher wages to offset the higher costs of commuting. If they do, those higher wages are potentially reflected in higher finished product cost, hindering the company's ability to compete in a market. If the costs of higher wages are not reflected in higher product costs, then income to the company's shareholders is reduced.

Similarly, reduced mobility affects the cost of finished goods when fuel cost, driver time, and vehicle-operating costs are increased because of lower speeds on the roadways.

COSTS TO CONTRACTORS

Contractor costs also increase because of project delay. If a project is delayed after a contractor has mobilized a workforce and obtained equipment, consumables, and other materials, the contractor must often absorb those costs. This reduces income to the company and to its shareholders. To the extent that those costs are recoverable, they are passed on to consumers during a subsequent project.

In addition, the uncertainty associated with project delays can impede a contractor from bidding on other projects. These lost opportunities can reduce competition, which may result in higher construction bids on other projects.

CONCLUSION

With few exceptions, the public ultimately bears the cost of delays—traveler costs, added transportation costs in retail products, loss of business efficiency (resulting in higher costs and lower profits), and fewer public (TxDOT) dollars available to spend on a variety of project needs.

SAMPLE METHODOLOGY FOR ESTIMATING COST IMPACTS OF PROJECT DELAY

TYPES OF EXAMPLE PROJECTS

Table 18 shows three different example projects:

- "Small projects" range in cost from $7 million to $20 million.
- "Medium projects" range in cost from $20 million to $80 million.
- "Large projects" cost more than $80 million.

The small project illustrates the costs associated with a four-lane roadway in a rural setting. In this example, the roadway is a 2.7-mile-long widening project on FM 1488 in the Houston District. The project stretched from just east of SH 242 to just west of IH 45. The two-lane roadway was widened to a four-lane divided roadway. The project began in March 2009 after 33.5 months of delay. The cost associated with this delay is estimated at $96,000 per month, or a total of more than $3.5 million.

The medium project depicts the cost associated with an urban freeway project, in this instance a 2.6-mile-long widening project on US 59 in the Houston District. The project segment stretched north of FM 1314 to just north of Northpark Drive. The freeway was widened to consist of eight main lanes with two three-lane frontage roads. After almost five years of delay, the project began in August 2002. The estimated cost of delay per month was $297,000 per month, or a total of $17.8 million over the entire delay period.

The final example is the large project, showing costs associated with an interstate project in a large metro area—an interchange reconstruction project at IH 10 and IH 410 in the San Antonio District. The 1.5-mile-long project was from south of Callaghan Road to south of North Crossroads. This project began in July 2002 and experienced an 11-month delay during construction. The cost of delay per month was an estimated $447,000 per month, or $5.1 million for the entire 11-month period.

Table 18. Sample Costs to the Public Resulting from Project Delays.

Estimated Cost of Project Delay			
Project Description			
Project-Related Variables			
	Small Project	**Medium Project**	**Large Project**
Project Cost (Millions)	$11.4	$49.6	$82.2
Total Months Project Was Delayed	33.5	58.8	11.1
Change in Highway Cost Index (HCI) (during Delay)	11%	29%	3%
Travel-Related Variables			
Length of Project	2.7	2.6	1.5
Average Daily Traffic—Before Improvement	21,000	91,000	158,000
Average Daily Traffic—After Improvement	26,000	99,000	196,000
Travel Speed—Before Improvement	46	58	59
Travel Speed—After Improvement	50	60	61
Percent Trucks—Before Improvement	4.5%	10.0%	3.9%
Percent Trucks—After Improvement	4.5%	10.5%	3.9%
Commonly Used Assumptions			
Persons per Vehicle	1.25	1.25	1.25
Value of Time—Cars	$16.28	$16.28	$16.28
Value of Time—Trucks	$107.42	$107.42	$107.42
Cost of Fuel—Cars	$3.78	$3.78	$3.78
Cost of Fuel—Trucks	$3.95	$3.95	$3.95
Return on Investment Associated with Economic Impacts	8.0%	8.0%	8.0%
Monthly Cost of Project Delay			
Wasted Time from Project Delay—Personal	$26,363	$31,248	$63,902
Wasted Fuel from Project Delay—Personal	$19,260	$8,510	$7,421
Wasted Time from Project Delay—Commercial	$6,557	$18,410	$13,689
Wasted Fuel from Project Delay—Commercial	$1,094	$3,334	$1,413
Total Direct Cost to Travelers	**$52,180**	**$58,167**	**$85,012**
Construction Cost Increase per Month (based on HCI)	$32,957	$191,956	$283,624
Sub-total, Direct Costs	**$85,137**	**$250,123**	**$368,636**
Economic Impact of Project Delay	$10,841	$47,170	$78,172
Total Cost of Project Delay *per Month*	**$95,978**	**$297,293**	**$446,808**
Total Cost of Project Delay	**$3,551,431**	**$17,764,387**	**$5,127,080**

DISCUSSION OF PROJECT EXAMPLES

In the small example, an $11.4 million project was delayed a total of 33.5 months. The following conditions on the roadway were present:

- 21,000 vehicles in average daily traffic.
- Commercial trucks making up 4.5 percent of vehicles.
- 1.25 persons per automobile.
- 46 miles per hour average speed before the improvements.
- 50 miles per hour average speed after the improvements.
- An 11 percent increase in the price of construction during the time the project was delayed.[2]

The small project, as shown in Table 18, demonstrates that when applying standard values of time for both individuals and commercial vehicles—and assuming a conservative 8 percent return on investment in roadway infrastructure[3] (national studies indicate the return is more likely in the 10 to 12 percent range)—the 33.5-month delay had a total cost of $3.5 million, or almost $96,000 per month.

Of that cost, slightly over $85,000 per month was the result of construction price increases estimated by using the HCI. Almost all of this increase resulted from the significant increases in commodity prices (e.g., cement, base material, steel, asphalt, and fuel) experienced during the period. Almost $33,000 per month was the result of delays in commuter and business delivery times, while a little more than $20,000 per month was the result of increased fuel costs associated with higher consumption at slower speeds. Finally, almost $11,000 per month was associated with the economic impact of delay.

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[2] Project inflation calculations taken from the Highway Cost Index produced by the Texas Department of Transportation (http://ftp.dot.state.tx.us/pub/txdot-info/cst/hci_binder.pdf).

[3] M. Ishaq Nadiri and Theofanis P. Mamuneas. "Contribution of Highway Capital to Output and Productivity Growth in the US Economy and Industries." http://www.fhwa.dot.gov/policy/gro98cvr.htm.

In the medium example, a $49.6 million project was delayed a total of 58.8 months. The following conditions on the roadway were present:

- 91,000 vehicles in average daily traffic.
- Commercial trucks making up 10 percent of vehicles.
- 1.25 persons per automobile.
- 58 miles per hour average speed before the improvements.
- 60 miles per hour average speed after the improvements.
- A 29 percent increase in the price of construction during the time the project was delayed.[4]

The medium project, as shown in Table 18, demonstrates that when applying standard values of time for both individuals and commercial vehicles—and assuming a conservative 8 percent return on investment in roadway infrastructure[5] (national studies indicate the return is more likely in the 10 to 12 percent range)—the 58.8-month delay had a total cost of $17.8 million, or almost $300,000 per month.

Of that cost, slightly over $250,000 per month was the result of construction price increases estimated by using the HCI. Almost all of this increase resulted from the significant increases in commodity prices (e.g., cement, base material, steel, asphalt, and fuel) experienced during the period. Almost $50,000 per month was the result of delays in commuter and business delivery times, while almost $12,000 per month was the result of increased fuel costs associated with higher consumption at slower speeds. Finally, almost $50,000 per month was associated with the economic impact of delay.

In the large example, an $82.2 million project was delayed a total of 11.1 months. The following conditions on the roadway were present:

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[4] Project inflation calculations taken from the Highway Cost Index produced by the Texas Department of Transportation (http://ftp.dot.state.tx.us/pub/txdot-info/cst/hci_binder.pdf).

[5] M. Ishaq Nadiri and Theofanis P. Mamuneas. "Contribution of Highway Capital to Output and Productivity Growth in the US Economy and Industries." http://www.fhwa.dot.gov/policy/gro98cvr.htm.

- 158,000 vehicles in average daily traffic.
- Commercial trucks making up 3.9 percent of vehicles.
- 1.25 persons per automobile.
- 59 miles per hour average speed before the improvements.
- 61 miles per hour average speed after the improvements.
- A 3 percent increase in the price of construction during the time the project was delayed.[6]

The large project, as shown in Table 18, demonstrates that when applying standard values of time for both individuals and commercial vehicles—and assuming a conservative 8 percent return on investment in roadway infrastructure[7] (national studies indicate the return is more likely in the 10 to 12 percent range)—the 11.1-month delay had a total cost of $5.1 million, or almost $450,000 per month.

Of that cost, almost $370,000 per month was the result of construction price increases estimated by using the HCI. Almost all of this increase resulted from the significant increases in commodity prices (e.g., cement, base material, steel, asphalt, and fuel) experienced during the period. Almost $78,000 per month was the result of delays in commuter and business delivery times, while almost $9,000 per month was the result of increased fuel costs associated with higher consumption at slower speeds. Finally, almost $80,000 per month was associated with the economic impact of delay.

The expansion of the roadways allowed substantially more throughput, though only modest changes in speed. Because of the induced demand associated with expanded roadways, speeds can actually stay the same or slightly decrease as more vehicles use the roadway. When that occurs, vehicles are drawn to the new/expanded facility from other highways and/or arterial streets, thereby improving travel times, reducing wasted fuel, and generating a positive economic

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[6] Project inflation calculations taken from the Highway Cost Index produced by the Texas Department of Transportation (http://ftp.dot.state.tx.us/pub/txdot-info/cst/hci_binder.pdf).

[7] M. Ishaq Nadiri and Theofanis P. Mamuneas. "Contribution of Highway Capital to Output and Productivity Growth in the US Economy and Industries." http://www.fhwa.dot.gov/policy/gro98cvr.htm.

effect on those particular roadways. In general, however, the magnitude of the impact of project delay depends on traffic volume and speed, percent trucks, spikes in construction costs, and duration of delay.

Also, because of the number of variables involved (and their relative importance depending upon roadway location, roadway type, availability of transportation alternatives, traffic mix, cost of materials, etc.), in almost every instance where a project is delayed, the cost of delay can vary significantly. As a result, every instance of construction delay, even on roadways that appear to be similar in nature, can result in a different cost of delay estimate. See Appendix B for a description of the variables and methodology used for the cost calculations.

SUMMARY

This brief research project examined the costs that result when a roadway project is delayed. It examined both direct and indirect impacts of project delays and found that the public almost always bears the costs, either directly through wasted fuel and time or indirectly through less-efficient use of the limited supply of roadway funds. This project did not directly examine the *value* of any of the delays, though it was evident while examining the data that many delays actually produced benefits that equaled or exceeded the *cost* of the delay.

The simple methodology developed in this project allows TxDOT to quickly estimate the cost of delay to a roadway project. Using that methodology, researchers examined three actual projects. The smallest of the three resulted in project delay costs of $96,000 per month, while the largest project resulted in project delay costs of $447,000.

While the methodology is simple, there is no rule of thumb because project delay costs depend on several variables, primarily location, traffic, construction costs, and travel speeds. The methodology also includes a monthly local economic impact component, which for the three examples ranged from $10,000 per month to $78,000 per month.

The appendices to this report contain data, terminology, and methodologies developed in this research:

- Appendix A—List of Acronyms.
- Appendix B—Description of Calculations Used in Estimating Project Delay Costs.
- Appendix C—General Information Regarding Delays.
- Appendix D—Additional Examples of Project Delay.
- Appendix E—Typical Causes of Delay.
- Appendix F—Delayed Projects Studied.

Appendix D illustrates case examples of projects or circumstances that either have a largely undefined impact or are too complex for this straightforward methodology to assess the delay impacts.

APPENDIX A—LIST OF ACRONYMS

AGUA	Aquifer Gardens for Urban Areas
CAMPO	Capital Area Metropolitan Planning Organization
CE	Categorical Exclusion
DCIS	Design Construction Information System
DEIS	Draft Environmental Impact Statement
EA	Environmental Assessment
EIS	Environmental Impact Statement
FEIS	Final Environmental Impact Statement
FHWA	Federal Highway Administration
FONSI	Finding of No Significant Impact
FY	Fiscal Year
HCI	Highway Cost Index
MPO	Metropolitan Planning Organization
NEPA	National Environmental Policy Act
PS&E	Plan, Specification, and Estimation
RMA	Regional Mobility Authority
ROD	Record of Decision
ROW	Right of Way
TTI	Texas Transportation Institute
TURF	Texans United for Reform and Freedom
TxDOT	Texas Department of Transportation

APPENDIX B—DESCRIPTION OF CALCULATIONS USED IN ESTIMATING PROJECT DELAY COSTS

VARIABLES

The output of the model provides both direct and indirect cost estimates. Direct cost estimates include wasted time and fuel for both personal and commercial travel. Indirect cost includes the economic impact of project delay. The spreadsheet-based model uses variables divided into three categories to calculate direct and indirect costs associated with project delay. Those variables include the following.

Calculations Tab

- **Project Cost**—in millions of dollars. This is the contracted amount.
- **Average Annual Daily Traffic before the Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Average Annual Daily Traffic after the Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Percent of Trucks before Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Percent of Trucks after Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Persons per Vehicle**—a default value of 1.25 persons per personal vehicle.
- **Average Speed before Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Average Speed after Improvement**—determined for the segment that most closely represents the roadway segment under construction.
- **Length of Segment in Miles**—determined from the construction contact.
- **Personal Value of Time**—determined by using the value of personal time used in the most recent *Urban Mobility Report* published by TTI.
- **Commercial Value of Time**—determined by using the value of personal time used in the most recent *Urban Mobility Report* published by TTI.

- **Return on Investment**—the default is 8 percent annually, based on a Federal Highway Administration report by Nadiri and Mamuneas.
- **Percent of Increase in Highway Cost Index**—determined by using the Highway Cost Index published monthly by TxDOT.
- **Total Months of Delay**—determined using the dataset of highway construction projects furnished for this study by TxDOT.

Fuel Tab

- **Fuel Price**—the current fuel price.

Economic Impact Tab

- **Multiplier**—an estimate of the general multiplier for economic activity based on the state's economic profile.
- **Percent Profit**—the average profit margin across all business based on the state's economic profile.

CALCULATIONS

The following general steps are used in calculating an estimate of the cost of project delay:

- Convert daily traffic into monthly traffic volume.
- Calculate the travel time for the segment under construction for both before the improvement was started and after it was completed.
- Calculate the total hours of travel over the segment for both before the improvement was started and after it was completed.
- Calculate the total personal hours of travel using the number of personal vehicles traveling the segment multiplied by average occupancy. Calculations are performed for both before and after the improvement.
- Calculate the total vehicle hours of travel for commercial vehicles. Calculations are performed for both before and after the improvement.

- Calculate the net hours of delay by subtracting the “before” and “after” delay for both personal and commercial travel.
- Multiply the excess hours of delay for personal and commercial travel by the respective value of time to obtain the delay cost associated with the construction delay.
- Determine the net cost of fuel for commercial vehicles using a fuel/speed curve developed for use in TTI’s *Urban Mobility Report*, comparing the amount of fuel consumed at the “before” speed versus the “after” speed, and using the respective volumes for the two periods.
- Multiply the difference in fuel consumption at the “before” speed and the “after” speed by the prevailing retail fuel price to obtain the fuel cost for personal and commercial travel associated with the construction delay.
- Calculate the economic impact by multiplying the capital investment by the rate of return (assumed to be 8 percent per annum) plus the annual return multiplied by the assumed rate returned to profit.
- Calculate the cost of construction inflation by taking the difference between the contract amount at the date the project begins minus the discounted value of the contract at the date the project was originally scheduled to begin. Use the HCI to calculate the discount rate.

APPENDIX C—GENERAL INFORMATION REGARDING DELAYS

This appendix contains a general explanation of three typical areas in which projects can be delayed: regulatory delays, environmental review delays, and legal actions. Because of the statutory nature of these processes, TxDOT must follow defined procedures throughout each area until the final resolution.

REGULATORY DELAYS

The National Environmental Policy Act (NEPA) requires federal agencies to outline the environmental impact their proposed actions will have and to assess the impacts of alternative actions.[8] TxDOT projects funded in any part by federal monies are required to gain environmental approval through the NEPA regulatory process defined by three levels of analysis as shown in Table 19.

Table 19. NEPA Levels of Analysis.

NEPA Level	Description
Categorical Exclusion (CE)	This status is given to those projects that do not significantly impact the environment.
Environmental Assessment (EA)	An EA must be conducted when the environmental significance is unknown. The results of an EA can lead to one of the following: • Finding of No Significant Impact (FONSI). • Environmental Impact Statement.
Environmental Impact Statement (EIS)	An EIS is a more in-depth report that must include consideration of alternatives and public involvement. The EIS consists of four steps: 1. Notice of Intent (NOI). 2. Draft EIS (DEIS). 3. Final EIS (FEIS). 4. Record of Decision (ROD).

[8] U.S. Environmental Protection Agency. Environmental Impact Statement Process. http://www.epa.gov/compliance/nepa/eisdata.html.

If a final EIS is not submitted within three years from the date of the draft EIS, or there have been no major steps to advance the action three years after a final EIS (e.g., authority to begin final design or to acquire right of way), a written evaluation should be prepared to determine if a supplemental EIS is warranted.[9] A supplemental EIS is necessary if considerable changes have been made to the project, or there is significant new information available. A supplemental EIS is developed like any other EIS, excluding the need for scoping. Furthermore, once a project has received an ROD, FONSI, or CE, a verification that the designation remains in place should be made prior to any major approvals or grants.[9]

ENVIRONMENTAL REVIEW DELAYS

Projects that do not necessarily fall under NEPA regulations may still have environmental impacts that must be addressed. The safety of roadway users and the cost of avoiding environmental impacts are factors that must be weighed against environmental and aesthetic interests. A concerned citizen or environmental group may delay the project by requesting changes that mitigate the harm or by bringing suit in a state court (as opposed to a NEPA suit in federal court).

LEGAL ACTIONS

When a lawsuit is filed in reference to a proposed or active project, the party bringing suit may seek an injunction to bring current work to a halt regardless of the stage of progress. If the court grants the injunction, the project will be suspended in its entirety or in part until a court can hear arguments from both sides and rule on the matter. If the injunction is denied, the opposing party can still file suit with the hope of either receiving a favorable ruling before damage has been done or TxDOT addressing the problem to avoid the additional cost and delay.

[9] CFR Title 23, §771.129. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title23/23cfr771_main_02.tpl.

APPENDIX D—ADDITIONAL EXAMPLES OF PROJECT DELAY

TTI selected three additional projects as examples to illustrate the different causes of delay, costs associated with the delay, and potential complexity in estimating delay costs from one project to another. The following projects were selected:

- US 281 (Bexar County) in the San Antonio District (major highway expansion delayed several years).
- SH 45 Southeast (Travis County) in the Austin District (new connector highway delayed several years).
- SH 16 (Bandera County) in the San Antonio District (safety improvements delayed several months).

Each case study examines the type of delay incurred, a timeline of actions taken, and the ultimate result of the delay, as of 2009. Researchers did not select projects because they represent the *typical* delayed project or signify *usual* resolutions to overcome delays. Rather, researchers chose these projects because they illustrate the magnitude and complexity of actions taken to resolve the issues that cause project delay. Project delays examined in these cases fit into one or more of the following categories: regulatory, environmental, and/or legal. Appendix C contains a general description of the processes associated with each category and how they can cause project delays.

US 281—SAN ANTONIO

The US 281 project is an example of an initially straightforward project that became very complex because of multiple and fractured delays. TxDOT employed a variety of improvements to reduce the impacts of the various delays.

The segment of US 281 in San Antonio studied stretches north from Bitters Road (south of Loop 1604) to Borgfeld Road (Figure 100).[10] Major intersections included in this

[10] Map source: Alamo Regional Mobility Authority, http://www.alamorma.org/index.cfm/projects/us-281-eis/.

improvement are Loop 1604, Sonterra Boulevard, Encino Rio Road, Evans Road, Stone Oak Parkway, and Marshall Road.

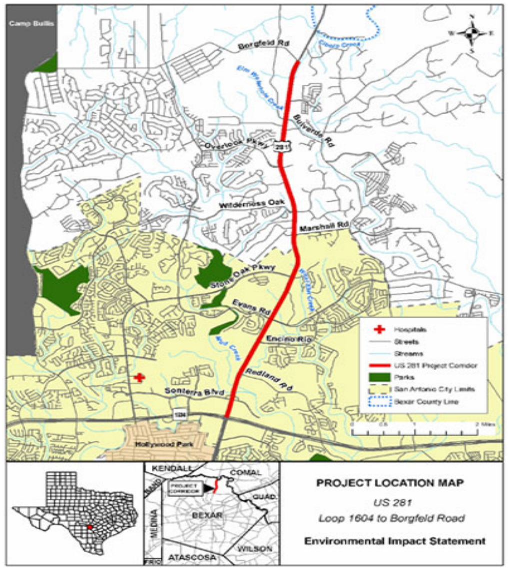

Figure 100 Map of US 281 Expansion Project.

While the project involved multiple legal battles, this study focuses primarily on delays caused by the environmental regulatory process. Lawsuits filed by citizens' groups required the environmental studies to be repeated and, at times, restarted the regulatory process required to gain environmental clearance.

Because of the delays, several short-term fixes have been proposed as separate projects requiring no environmental analysis to help alleviate the congestion. Improvements to the US 281/Loop 1604 interchange were eventually developed as one of these separate projects, independent of the sizeable US 281 North expansion project.

Timeline

Original Environmental Assessment

In 1984, the US 281 North expansion from Bitters Road to Evans Road was given environmental clearance after an EA was conducted. In the early 1990s, a segment of this project was constructed from Bitters Road to Sonterra Boulevard.

In 2000, the environmental clearance for construction from Sonterra Boulevard to Evans Road was reevaluated because more than 15 years had passed since the first EA was conducted.

In 2001, development from Loop 1604 to Evans Road was approved by the MPO. The MPO dedicated about half of the estimated needed funds ($42 million) in its 2002–2004 Transportation Improvement Program.

In 2003 and 2004, the US 281 North project was studied to determine whether tolling new lanes would be a practical funding solution, and the following year the MPO voted to construct the new lanes as privately funded toll facilities.

In 2005, TxDOT received unsolicited bids for a privatized toll project. That same year environmental clearance was granted for the segment stretching from Evans Road to Borgfeld Road.

2005: First Lawsuit

Construction of an $80 million expansion segment from Loop 1604 to Marshall Road was halted at the end of 2005 when local environmental groups—Aquifer Guardians for Urban Areas (AGUA) and Texans Uniting for Reform and Freedom (TURF)—sought a court order enjoining the continuation of construction. The Federal Highway Administration (FHWA) withdrew environmental approval because of the lawsuit, and a new EA commenced.

2007: Second Environmental Assessment[11]

In 2007, TxDOT completed a two-year, $2 million EA that combined all projects on US 281 from Loop 1604 to Borgfeld Road. As a result, FHWA published a FONSI that ended the construction moratorium. That same year, Texas passed legislation that changed the way privatized transportation tolling operated, and the Alamo Regional Mobility Authority (RMA) took control of the US 281 project.

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[11] Alamo RMA. Alamo RMA Responds to Latest Lawsuit Filed by TURF, February 26, 2008. Memorandum, FY 06 Lettings, Dianna F. Noble, P.E., January 3, 2007.

2008: Second Lawsuit

In 2008, AGUA and TURF once again brought suit to question the environmental clearances that were currently in place. During the suit, TxDOT requested a 60-day stay to review the records. During this period of review, TxDOT found irregularities in the procurement of scientific services, leading FHWA to retract the previously issued environmental clearance. Any future expansion projects in the US 281 corridor would be required to prepare a more complex EIS. Three weeks after the FHWA pronouncement, the Alamo RMA began pursuing an EIS that they estimated would take three to five years to complete. Consequently, the district judge administratively closed the second lawsuit.

2009: Categorical Exclusions

With the US 281 North expansion projects on hold awaiting a new EIS, the Alamo RMA continued to search for new ways to relieve congestion and improve safety within the limits of the law. In March 2009, the Texas Transportation Commission approved $80 million in federal stimulus funding to aid a separately proposed $130 million improvement project at the US 281/Loop 1604 interchange. The project would include construction of four direct connectors from Loop 1604 to US 281. The Alamo RMA conducted new biological surveys of the area and held two public hearings. In February 2010, FHWA and the U.S. Fish and Wildlife Service approved a CE by granting the interchange project environmental clearance. A portion of the federal stimulus funds must be spent by 2015.

In the fall of 2009, another project to transform a segment of US 281 into a "Super Street" received environmental clearance through a CE. This conversion will aid in congestion relief without the addition of new lanes until the EIS is completed.

2010: Third Lawsuit

In August 2010, AGUA filed suit claiming that the US 281/Loop 1604 interchange project violates the Endangered Species Act and endangers the Edwards Aquifer. In December, AGUA filed an injunction to stop the impending construction for the duration of the suit.

Current Status

A district judge issued an advisory in February 2011 stating that he would rule on the injunction to halt the interchange project within six months. On March 2, 2011, construction began on the US 281/Loop 1604 interchange and will continue while awaiting the court's ruling. Furthermore, the EIS for the US 281 North expansion project is underway, and final approval is estimated for 2013. Figure 101 displays the project timeline, when the original delay began, and when the short-term projects were implemented to help reduce congestion. In addition to the project timeline, Figure 101 also shows the length of delay the agency and the public encountered because of the project.

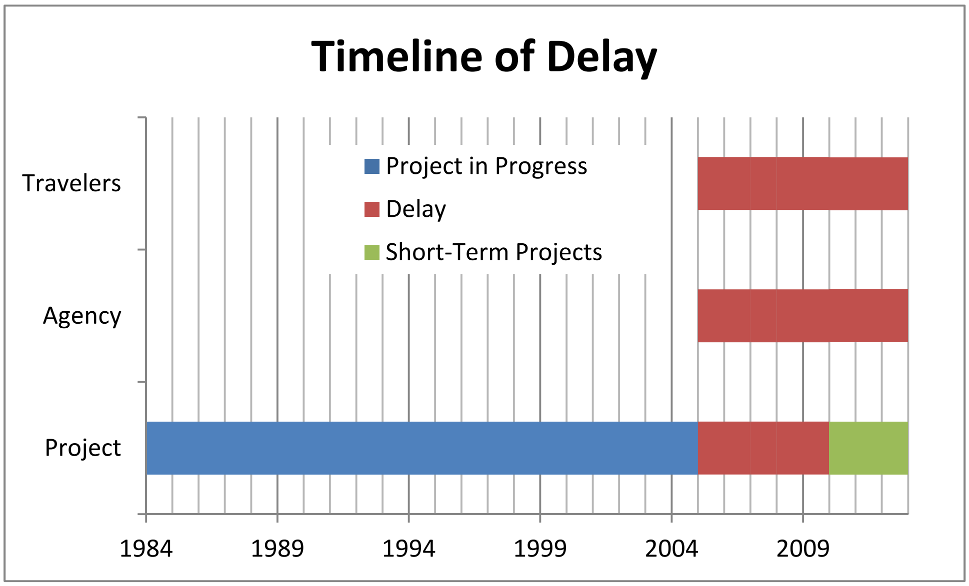

Figure 101 Historical Timeline of US 281 North Expansion Project Delay.

Costs

US 281 North Expansion Project

Before the first lawsuit in 2005, the low bid to construct the expansion was $83,653,101. The cost to terminate the project that same year was $7 million excluding litigation expenses. Today, the low bid for the same scope of work is estimated to be $2.5 million more than the 2005 bid.

US 281/Loop 1604 Interchange Project

The Loop 1604 interchange project was a short-term project created to help relieve congestion while the US 281 North expansion project was put on hold. The interchange, which is not a tolled project, was partially funded with federal stimulus dollars. The Alamo RMA stated that if the injunction is granted, the delay could cost them up to $30,000 a day.[12]

In addition to the $9.5 million costs specifically mentioned above, additional personal, business, and economic costs are also associated with the project delay.

SH 45 SOUTHEAST—AUSTIN

The SH 45 Southeast project is an example of a project on a new alignment, which is generally not suitable for a simplified analysis. This project connects two major highways in a growing network. In the absence of "before" conditions for comparison, a delay impact analysis on a project of this type would require the use of the local travel demand model maintained by the MPO to identify the number of prospective users.

The segment of SH 45 in Austin studied is a 7.4-mile stretch running east/west between IH 35 at FM 1327 and the junction of SH 130 and US 183 (Figure 102).[13] Major intersections along the four-lane tolled highway include IH 35, North Turnersville Road, FM 1625, and SH 130/US 183. The roadway was proposed as an alternate route for through traffic that would aid in relieving congestion on other major routes (such as IH 35 through downtown Austin). This project encountered delays involving a lawsuit based upon the NEPA's EIS requirements.

[12] Vianna Davilla, quoting RMA Director of Community Development Leroy Alloway. "Interchange Work Starts in Face of Controversy." *San Antonio Express-News*, March 3, 2011.

[13] Map source: TxDOT, http://www.texastollways.com/austintollroads/english/map.htm.

Figure 102 Map of SH 45 Southeast Project.

Timeline

Original Schedule

In 2003, the DEIS required by NEPA was completed, and a public hearing was held that summer. That fall, the FEIS was submitted, and FHWA granted the project environmental clearance in 2004. That same year, TxDOT awarded a contract to design and build the highway in the following two years to Zachry Construction Company.

2004: Lawsuit

In 2004, local environmental groups Save Our Springs Alliance and Save Barton Creek Association brought suit in federal district court to stop the project. Together the membership of these two groups totals approximately 4,500 people. They claimed the EIS failed to consider an adequate range of alternate routes and did not fully examine the impacts (direct, indirect, secondary, and cumulative). They argued that to completely assess the secondary and cumulative impacts of the southeast project, the future southwest project would need to be analyzed in conjunction. The future southwest segment (segment 3) would cross the Edwards Aquifer recharge zone. The suit and project were put on hold so a new environmental study of the southeast segment could be performed.

2007: Project Restarted

The new environmental study was completed two years later, reaching the same conclusions as the previous analysis. FHWA approved the new study in the summer of 2006, and the federal court dismissed the case. In April 2007, a new contract was awarded to Balfour Beatty Infrastructure, Inc., and T.J. Lambrecht Construction, Inc., and construction began the following July. SH 45 Southeast opened in June 2009. Figure 103 illustrates the project timeline including when the delay began and when the project restarted. Also shown is the length of delay encountered by the agency and the public because of the lawsuit.

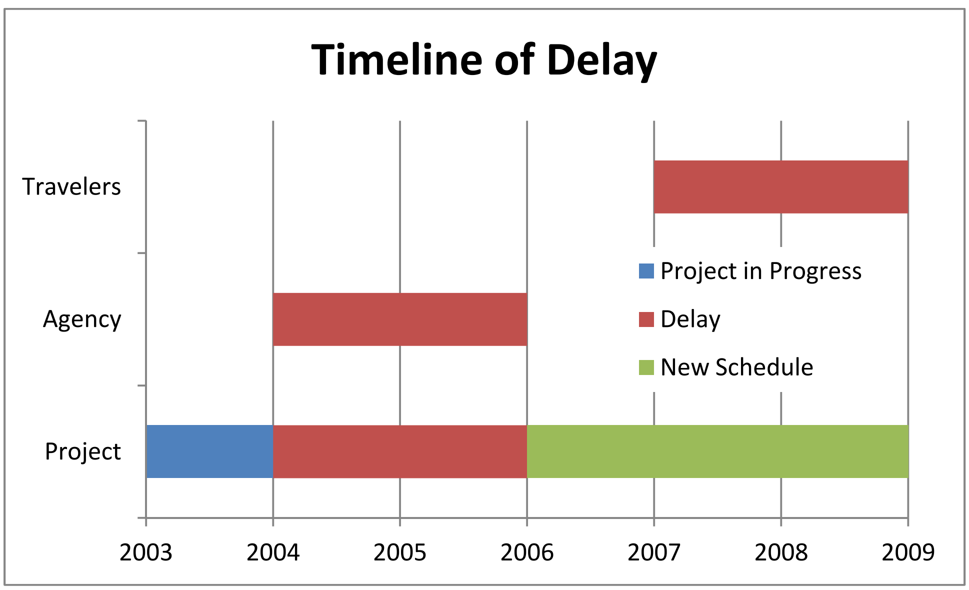

Figure 103 Historical Timeline of SH 45 Southeast Project Delay.

Costs

The project was originally estimated at $154.3 million as part of a $2.2 billion toll road package approved by the Capital Area Metropolitan Planning Organization (CAMPO). The estimate included $137.4 million for construction costs. TxDOT paid $1.6 million to terminate the project in 2004. The ensuing environmental analysis cost an additional $300,000. During the two years the environmental analysis was being conducted, the cost to acquire right of way rose roughly $5.2 million. Since the project was originally awarded as a design/build project as opposed to design/bid/build, the engineering plans remained incomplete. This meant that an additional $950,000 had to be spent to finalize the engineering plans.[14] The new low bid for the construction portion of the project was $139.7 million—$2.3 million more than the original estimate.

Additionally, a project under construction on SH 130 was impacted by the SH 45 Southeast delay, and expenses to settle the matter with the developer cost TxDOT approximately $15.5 million. In total, the costs associated with project delay on this project exceed an estimated $22.6 million plus an uncalculated amount of commercial and personal delay and economic costs.

SH 16—BANDERA

This SH 16 road safety improvement project runs 8 miles from Winans Crossing toward Medina in Bandera County (Figure 104).[15] The rural state highway originally consisted of two 10-ft-wide lanes with no shoulders. The improvements would widen the existing lanes to 12 ft and add 5-ft shoulders to each side. The current TxDOT standards call for 7 ft of clear zone. The clear zone provides a safe area for drivers to stop or recover their vehicle after veering off the travel lane and is measured from the edge of the travel lane.[16] This project was challenged with a state lawsuit concerning the removal of five mature pecan and black walnut trees located at the

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[14] Texas Department of Transportation. Draft Testimony, "Accelerating the Project Delivery Process: Eliminating Bureaucratic Red Tape and Making Every Dollar Count." House Transportation and Infrastructure Committee Subcommittee on Highways and Transit, February 15, 2011.

[15] Copyright 2010 Navteq; copyright 2010 Microsoft.

[16] TxDOT Glossary. http://onlinemanuals.txdot.gov/txdotmanuals/glo/c.htm.

intersection of SH 16 and Kyle Ranch Road. These trees, estimated to be 180 to 310 years old, sit directly adjacent to the original road and were scheduled for removal to facilitate the widening of the road.

Timeline[17]

2005: Rural Transportation Meeting

In late 2005, a rural transportation meeting was held to present local projects to the community. TxDOT had performed an environmental study that identified these trees on state property. The original proposal called for removal of five trees, with TxDOT planting 10 new trees in the surrounding grove on state land.

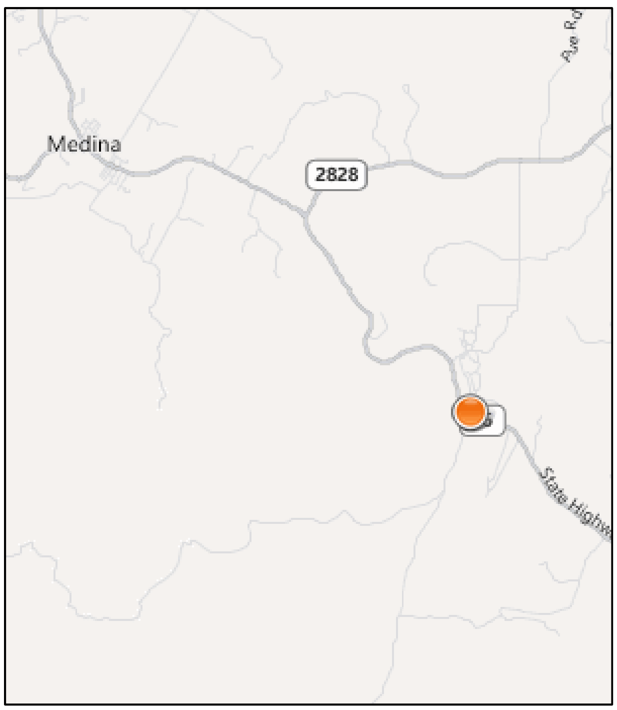


Figure 104 Map of SH 16 Project.

[17] Texas Department of Transportation v. Kyle, No. 04-06-00762-CV, May 9, 2007.

2006: Lawsuit

In February, TxDOT's Environmental Affairs Division classified the project as a CE needing no further environmental study.

In May, local landowners whose property is adjacent to the intersection met with TxDOT to voice their concerns. TxDOT amended the plans to include a guard rail that would run between the road and the trees, thus reducing the number of trees to be removed to two.

On June 1, the landowners filed suit in state court seeking to stop TxDOT from removing any of the trees and classifying the project as a CE. A temporary restraining order was granted, and a hearing was held on June 26.

On June 26, at the hearing's conclusion, the judge requested the parties agree on a temporary injunction. TxDOT immediately requested the case be removed to federal court. The state court denied TxDOT's request and granted the temporary injunction, stopping TxDOT from removing any tree within one-half mile of the intersection in question.

On October 31, the federal court also denied TxDOT's request for removal to federal court, stating that TxDOT is not a federal agency and was not subject to federal rules. The project's funds did not include federal monies that would require NEPA approval.

On November 1, the temporary injunction was renewed. Construction was completed for the remainder of the project with the exception of the contested intersection.

2007: State Appeal

In early 2007, TxDOT filed an appeal stating that the state trial court was not the correct court to decide the matter. TxDOT argued that it has sovereign immunity. However, sovereign immunity does not exist if the state is depriving the other party of a vested property right. The court agreed with TxDOT that the landowners do not have a vested interest because the trees are located on state land. The Fourth Court of Appeals of Texas reversed the decision of the trial court and removed the injunction, thus allowing TxDOT to proceed. On August 1, 2007, the two trees in question were removed. Figure 105 illustrates the project timeline showing when the delay began and when the project was allowed to resume in the contested area. Additionally, Figure 105 shows the length of delay the agency and the public encountered.

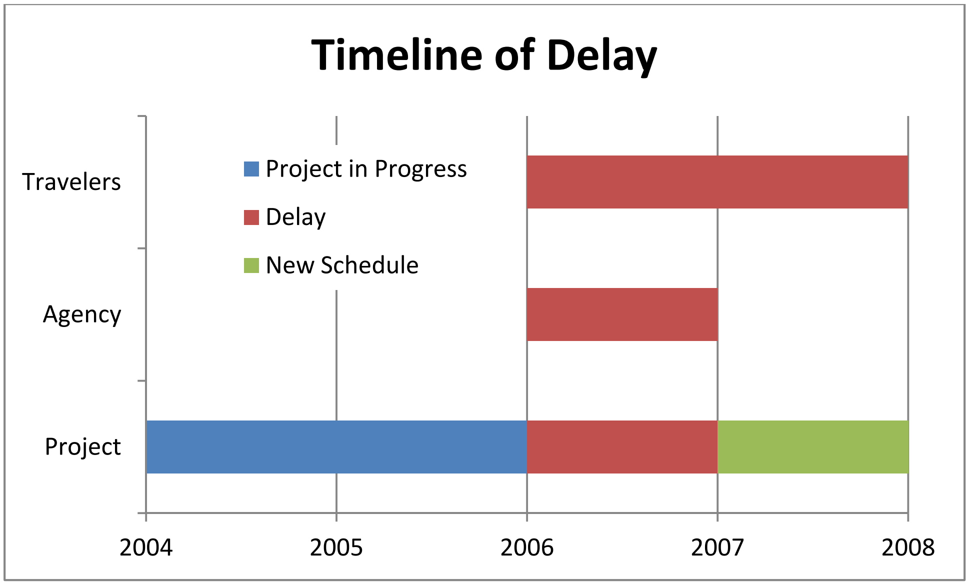


Figure 105 Historical Timeline of SH 16 Project Delay.

Costs

The project was originally estimated at $5.0 million, funded from the sale of $600 million in bonds in 2004 for safety projects across the state.[18] The final amount paid to the contractor totaled $4.4 million. There was also additional cost to TxDOT that could not be explicitly identified by this research project. In addition to those unidentified costs, the public was denied the additional safety benefits provided by wider lanes and paved shoulders while awaiting the court's ruling.

[18] Jessica Hawley. "Trees Cause Debate in Root of Community." *The Bandera Bulletin*, May 9, 2006.

APPENDIX E—TYPICAL CAUSES OF DELAY

During each stage of a project, numerous events can cause project delays. Table 20 summarizes the typical causes of delay for a roadway construction project during the four major phases of a project. While the nature of delays can vary among the four stages of a project (planning, development, contracting, and construction), the results are quite similar: impacts on travelers and businesses.

First, with respect to delays during the planning/scoping phase, while the number of potential reasons for delay is relatively small, the length of delay associated with these reasons can be significant. This is particularly the case if the project becomes the subject of litigation.

Although delays during the project development phase can have numerous causes, they are typically invisible to the public unless they have been told a project would start construction by a certain time (e.g., summer 2012). If the construction has not started as anticipated, local stakeholders, citizens, and local media may want to know the causes of the delay. One exception to the concept that delays during development are invisible to the public is when litigation occurs. Such litigation mostly occurs during a statutory review process (e.g., environmental clearance or U.S. Corps of Engineers clearance) or during right-of-way acquisition.

Delay during the contracting phase is typically minimal, with a project only being delayed one or two months from the original letting date due to last-minute procedural missteps and/or project management inefficiencies.

The public generally understands that once a project begins construction, there will be a period of inconvenience while the project is underway. As TxDOT and local media announce the anticipated duration of construction, the public takes a grin-and-bear-it attitude, looking forward to the completion of the project. Delays during construction, however, are the most visible and draw substantial attention.

Table 20. Typical Causes of Project Delay.[19]

Planning/Scoping

• Project priority changes in relationship to other projects
• Federal/state legislation
• Interagency coordination
• Project management issues:
  o Poor project definition
  o Lack of documentation of assumptions
  o Missed milestones
• Funding
• Litigation

Development

• Project management issues:
  o Poor project definition
  o Lack of documentation of assumptions
  o Missed milestones
• Railroad permits not obtained as anticipated
• Acquisition of necessary right of way (ROW) not completed as anticipated
• Utility accommodation agreements not completed as anticipated
• Mandatory review processes (e.g., environmental and fish and wildlife) not completed as anticipated
• U.S. Corps of Engineers permits not obtained as anticipated
• Local funding agreements not executed as anticipated
• Delay in plan, specification, and estimation (PS&E) preparation (either in-house or by consultant)
• Litigation

Contracting
• Unanticipated letting events (e.g., bids greatly exceeding engineer's estimate) • Delayed assembly of PS&E/letting package • Projects pulled from letting schedule • Bid protests • Litigation

[19] The information contained it Table 20 is a compilation of data from multiple sources:

- Meeting with TxDOT, Associated General Contractors of Texas, and Highway Contractors in Austin, Texas, June 8, 2011.
- R.D. Ellis and H.R. Thomas. "The Root Causes of Delays in Highway Construction." Transportation Research Board 82nd Annual Meeting, Washington, D.C., January 2003.
- J. Ahn and R.E. Minchin, Jr. "Identifying Causes for Delay in Highway Construction Projects." Transportation Research Board 87th Annual Meeting, Washington, D.C., January 2007.

Table 20. Typical Causes of Project Delay (Continued).

Construction (after Contract Award)

• Additional work desired by TxDOT
• Additional work desired by another party
• Contractor delays
• Project management issues:
  o Lack of communications, collaboration, and cooperation
  o Lack of approval authority
  o Coordination with stakeholders (local governments and other agencies)
• Utility conflicts/untimely utility accommodations
• Unacquired ROW
• Railroad conflicts (scheduling of work and project prioritization)
• Permitting issues/approvals
• Unforeseen project site conditions:
  o Differing subsurface conditions
  o Archeological impacts
  o Endangered species impacts
  o Environmental impacts
• Design errors/omissions
• Unfavorable weather
• Insufficient work effort:
  o Skilled workforce shortages
  o Equipment shortages
  o Material shortages/price increases
• Events (e.g., holidays, special events, and local events)
• Changes solely for public convenience
• Act of God
• Litigation

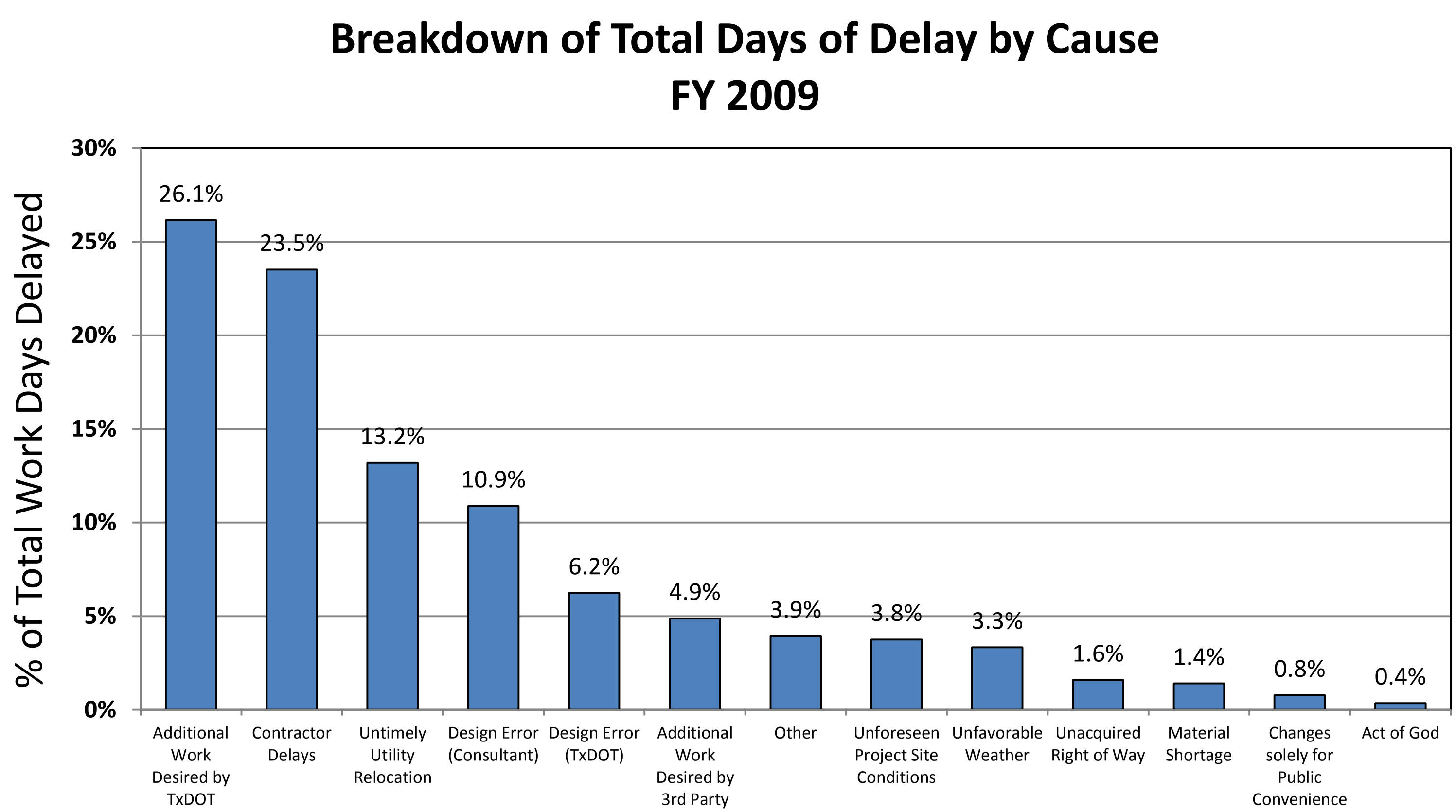
Figure 106 shows the percentage of total days of construction delay by cause of delay. This information was gathered from data collected by TxDOT's Construction Division. In FY 2009, 26.1 percent of the total days of delay was attributable to additional work desired by TxDOT. The second biggest percentage of total days of delay is attributable to contractor delay. In total, these two categories of delay accounted for almost half of all days of delay.

With respect to the additional work desired by TxDOT, in most cases, the delay is more specifically associated with having the opportunity to address a known issue (e.g., other repairs and expanding the limits) while a contractor is on site and a contracting mechanism is in place. Contractor delays are most often associated with weather and waiting for resolutions regarding utility relocation, ROW acquisition, and other agreements/clearances (e.g., U.S. Corps of Engineers, potential wildlife area impacts, and unknown/potential archeological sites).

Figure 107 shows the same dataset distributed simply by the number of projects affected by delay without respect to the number of days involved. For example, of the approximately 870 projects closed in FY 2009, 223 had at least one day of delay associated with additional work desired by TxDOT.

Of course, projects that experience delay may have delay caused by more than one factor. Figure 108 shows the distribution of delay by cause. For example, if a project suffered a delay because of a design error by the consulting engineering firm and then later experienced a delay due to weather, both reasons for delay are shown in this graph. As a result, the total frequency of delay across all causes will sum to greater than 100 percent.

Finally, while project delay almost always has cost associated with it, not all project delay is a waste of time and public money. In many instances of project delay initiated by TxDOT, the reason for the delay is to make an improvement in the design or construction of the project that will ultimately deliver better value to the public.



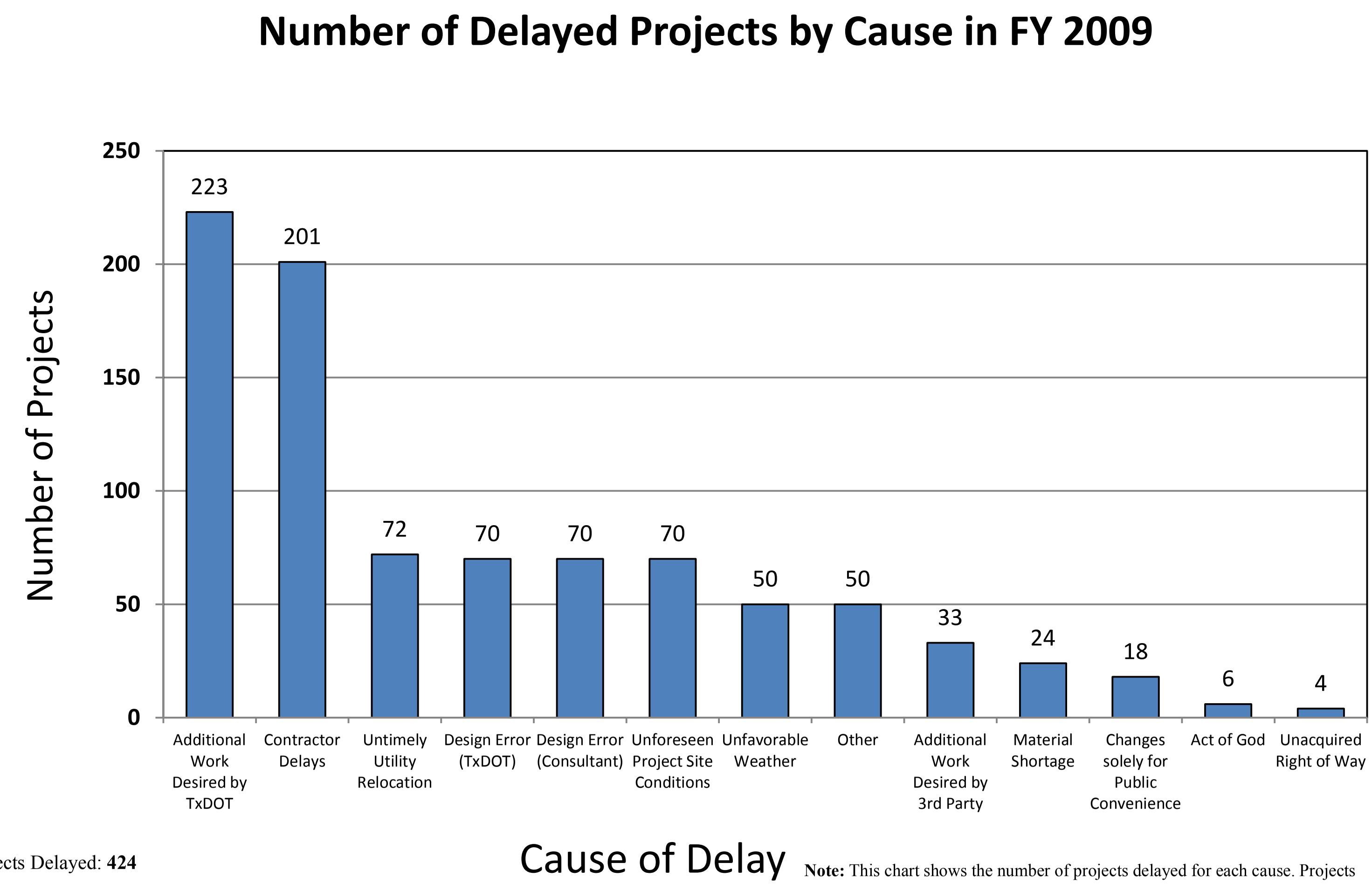
Total Days of Delay: **35,141**

Total Bid Days for Projects with Delay: **84,365**

Total Bid Days for All Projects: **164,288**

Note: This chart shows the percent of projects delayed for each cause. Projects that experienced two different causes of delay during the project life cycle appear once in each category. Therefore, some projects may appear twice. This analysis only includes projects that had the final estimate approved in FY 2009. Delay information obtained from TxDOT.

Figure 106. Breakdown of Total Days of Delay by Cause, FY 2009.



Total Projects Delayed: **424**

Total Projects: **868**

Percentage of Projects with Delay: **49%**

Note: This chart shows the number of projects delayed for each cause. Projects that experienced two different causes of delay during the project life cycle appear once in each category. Therefore, some projects may appear twice. This analysis only includes projects with the final estimate approved in FY 2009. Delay information obtained from TxDOT.

Figure 107. Number of Delayed Projects by Cause, FY 2009.

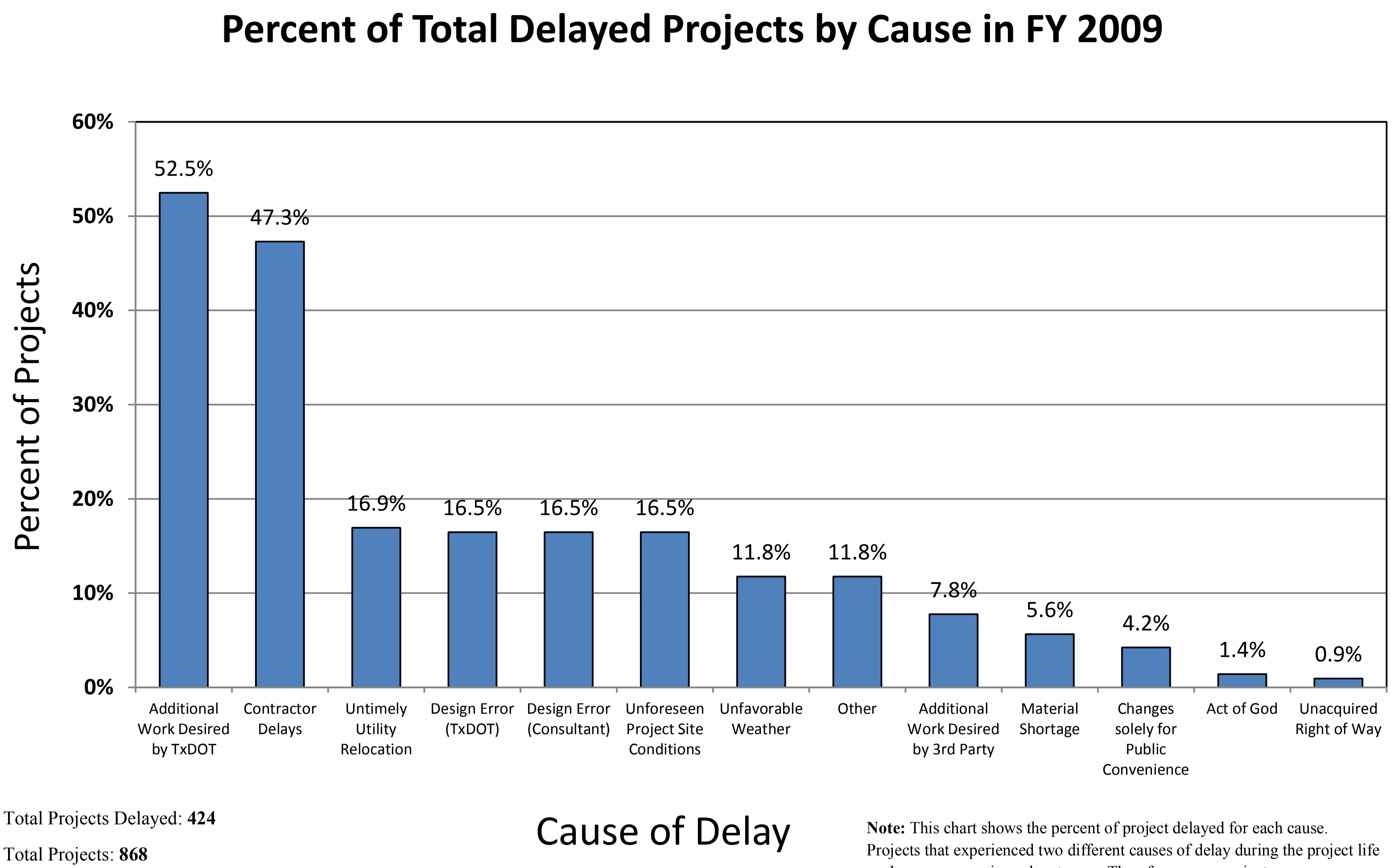


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Figure 108. Percent of Delayed Projects by Cause, FY 2009.

APPENDIX F—DELAYED PROJECTS STUDIED

Project location information, before-and-after average vehicle speed, and other information were required to determine both direct and indirect costs associated with project delay. Therefore, TTI researchers analyzed projects in the Austin, San Antonio, El Paso, Houston, and the Dallas/Fort Worth areas only because the MPOs in these regions provided the minimum data requirements needed for a robust analysis. The list of projects examined is included in Table 21.

TTI researchers obtained travel demand data provided by large MPOs to calculate speed differentials from improved vehicle movements. Researchers used travel demand data obtained from these projects to develop total cost of delay scenarios for small, medium, and large projects. The specific projects with reported delays used in this analysis were obtained from DCIS, TxDOT's Construction Division, and select TxDOT districts. Note that "TTA" in Table 21 refers to the Texas Turnpike Authority.

Table 21. List of 26 Delayed Projects Studied by Total Bid.

Rank	District	CSJ	Highway	Length (Miles)	Project Description	Bid (Total Obligated Amount)	Project Phase When Delay Occurred	Total Days of Delay
1	TTA	3136-01-126	LP 1	1.7	Convert non-freeway to freeway	$107,960,584	Construction	99
2	TTA	0683-06-015	SH 45	1	Convert non-freeway to freeway	$103,017,730	Construction	528
3	TTA	0683-01-069	SH 45	2.5	Widen non-freeway	$101,577,358	Construction	187
4	Dallas	1068-04-083	IH 30	4.7	Widen from six to eight lanes and add interchanges	$96,841,618	Construction	156
5	San Antonio	0072-12-159	IH 10	1.5	Reconstruct IH 10 410 Interchange (crossroads) (Phase 2)	$82,237,875	Construction	332
6	Dallas	0048-08-037	IH 35E	9.8	Upgrade to standards freeway	$62,597,022	Construction	273
7	San Antonio	0072-12-130	IH 10	3.1	Upgrade to standards freeway	$61,990,150	Construction	256
8	Houston	0177-05-057	US 59	2.6	Widen to eight main lanes and two three-lane frontage roads	$49,231,631	Design	
9	Houston	0177-05-057	US 59	2.6	Widen to eight main lanes and two three-lane frontage roads	$49,231,631	Construction	
10	Houston	0027-08-108	US 90A	0.9	Widen to eight-lane divided with improvements at ditch H	$39,243,649	Construction	51
11	Fort Worth	0134-08-030	US 380	10.5	Reconstruct two lanes to four-lane divided rural	$36,540,038	Design	
12	Houston	0027-08-144	US 90A	1.3	Widen to eight-lane divided with diamond interchange at Dulles	$21,881,454	Construction	86
13	Houston	0179-03-024	SH 35	7.7	Widen to four-lane divided rural	$19,702,202	Construction	201
14	Fort Worth	0902-48-708	CS	3.4	Widen from two-lane to four-lane divided urban highway	$19,069,431	Design	
15	Fort Worth	0081-02-045	US 377	2.9	Reconstruct to four-lane divided urban	$12,983,276	Construction	
16	San Antonio	0521-06-124	IH 410	3.7	Rehab existing main lanes and reconstruct shoulders	$12,388,367	Construction	243
17	Houston	0523-10-033	FM 1488	2.7	Widen two lanes to four-lane divided (Pass Through Financing)	$11,463,848	Design	
18	Houston	0179-01-028	SH 35	4	Widen to four-lane divided, widen bridges, and install new bridges	$10,716,917	Design	
19	Houston	0179-01-028	SH 35	4	Widen to four-lane divided, widen bridges, and install new bridges	$10,716,917	Construction	
20	Austin	0114-04-048	US 290	3.8	Widen to four-lane divided rural section	$10,716,016	Construction	162
21	Fort Worth	3125-01-010	FM 3029	1.1	Reconstruct and widen from five to six lanes with raised median	$9,873,767	Construction	
22	Austin	0204-01-049	US 79	1.5	Widen non-freeway	$9,351,883	Construction	384
23	Houston	0027-08-108	US 90A	0.9	Widen to eight-lane divided with improvements at ditch H	$9,238,220	Design	
24	Fort Worth	1068-01-187	IH 30	1.6	Reconstruct to four-lane divided with raised median	$8,559,000	Construction	434
25	Dallas	2374-04-046	IH 20	12.3	Rehab existing freeway	$7,870,576	Construction	69
26	Fort Worth	0718-02-025	FM 156	1	Widen to four lanes with continuous left-turn lane	$7,502,998	Construction	