



Appendix A

Emerging Technologies Memorandum

Capital – Alamo Connections Study



Emerging Technologies

Capital Alamo Connection Study

Transportation Planning and Programming – TxDOT Austin

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Introduction

This paper is not about providing recommendations; it is about listing opportunities. What used to be a fanciful future as seen in cartoons and Science Fiction like *The Jetsons* or *Star Trek* now looms at the edge of our present. We are on a collision course with the most radical changes in transportation that the world has ever seen. It's not radical in terms of *what* it is, as humans have dreamed of all of these technologies and strategies for decades. It is radical in terms of *how quickly* it will become fully operational, and a part of our lives. The automobile appeared in the early 1900's as a toy, but did not truly begin to shape society until after WWII. This next set of innovations will not take 40 years to alter our transportation systems, they have already started.

With the emergence of technologies such as driverless cars, flying cars, smart highways, drones, and high-speed transit modes, there is an opportunity to explore new ways to provide mobility for our future. In addition to these new alternatives to consider, there are a number of objectives that should be addressed in every transportation project today. The focus is no longer on simply widening highways and adding more cars; practitioners now aim to reduce congestion by moving people more efficiently, reducing greenhouse gas emissions, as well as improving reliability and safety. The main goal is to move people and goods in a faster, safer, and more reliable manner by finding a balance in the interaction with all other technologies.

These emerging modes could transform the way we plan for and evaluate alternative transportation improvements along major transportation corridors. One example is I-35 between Austin and San Antonio, also known as the Capital-Alamo Corridor. Planners and engineers need to understand a new technology's potential, as well as limitations, in order to create comprehensive transportation solutions. Decision-makers need to be informed about the applications of such technologies in other areas including its main benefits and disadvantages, to effectively weigh their potential contribution in providing transportation solutions.

This paper presents a summary of the emerging technologies that are of key interest to transportation practitioners today, and that can potentially provide long-term solution(s) to the Capital-Alamo Connection Study. The listed technologies can be grouped into four main categories based on the required right-of-way (ROW) and operation. The groups are 1) Smart Highways and Integrated Corridor Management, 2) Connected and/or Autonomous Technologies, 3) High-Speed Dedicated-Path Technologies, and 4) Air Transportation.

Smart Highways and Integrated Corridor Management

Advancements in this category focus on the improvement of current highways by either repurposing existing lanes or installing new devices that allow improved connectivity and lay the groundwork for future communication between vehicles and transportation infrastructure. Such technologies include Smart Highways, which involve installing

connectivity features under or within pavement, and Integrated Corridor Management (ICM), which involves using technology to improve flow of traffic on highways.

Smart Highways

Smart highways encompass technologies that are integrated into roadway pavement. These technologies can, among other things, generate solar energy, improve autonomous car operations, improve lighting, and/or monitor road conditions.

One example of a smart highway technology is the Smart Pavement™ which consists of precast concrete sections embedded with digital technology and fiber optics to permit communication with vehicles and the internet. This provides real-time information to drivers about traffic, roadway conditions, and crashes. Smart Pavements will also create connectivity between the roadway and autonomous vehicles, providing navigational aids while capturing traffic and usage data.

This technology is being tested in several states (including Missouri and Kansas); and some private entities are entering into long-term agreements with local DOTs to test and implement it on roadways. One example is Colorado DOT which is currently working with the private entity Integrated Roadways to install smart pavement that detects run-off-the-road incidents, and automatically summons aid in such circumstances.

Another smart highway technology is the Solar Roadway. The Wattway project, which opened has been tested on a section of I-85 in Georgia, and the SR3 in Idaho, are prominent examples. Both projects are testing solar-powered highways to capture energy from a large surface area and use that energy to generate power for roadway lighting, as well as for electric vehicle charge stations. The technology is still in the testing stages to address issues related to its durability, efficiency, and cost.

Integrated Corridor Management

ICM is a tool to enhance mobility, traffic flow, and travel time reliability while maximizing the use of existing transportation infrastructure. A number of strategies have been deployed in locations around the country to manage highway traffic by controlling flow from ramps, varying speed limits on highways, and repurposing lanes. ICM strategies rely on comprehensive information about current conditions on the roadway such as congestion levels and incidents. The following section describes some of these tools.

The benefits of ICM rely on its *management*. Different strategies are used to control the amount of flow and improve mobility along a freeway. The implementation of managed lanes depends on the type of facility, objectives of the project, availability of ROW, current operational characteristics, and



Ramp Metering design

environmental/public concerns.

Ramp Metering

Ramp metering controls the flow of traffic from a ramp onto a freeway. It operates by releasing vehicles individually at a rate that is dependent on the main-lane traffic volume and speed at a given time. Some of the main benefits of ramp metering include improved traffic flow and reduced congestion, improvement in mobility along the freeway, increased safety, reduction in vehicle emissions and fuel consumption. This method is considered one of the most cost-effective ICM tools since its benefit-to-cost of implementation ratio is relatively high.

Variable Speed Limits

This strategy involves the installation of dynamic speed message signs on gantries over each lane of traffic that alert drivers of upcoming congestion. Vehicles can travel more efficiently by obeying recommendations on travel speeds. The variable speed limit tool is thought to be most effective when congestion is impending and when slowing down would improve traffic flow by limiting stop-and-go movements. It also has major safety benefits as it alerts drivers of the need to slow down before they encounter the queue of stopped vehicles ahead. This strategy can be used in conjunction with other ICM technologies such as temporary shoulder use and variable message signs.



Variable speed limits on I-270 in St. Louis, MO

The University of Missouri in collaboration with the Missouri DOT experimented with this strategy on I-270, a major four-lane highway in St. Louis. The results were mixed, highlighting some of the method's drawbacks such as an increase in queue lengths (39 to 53 percent) and travel times (4 to 8 percent), and some of its benefits which include a major drop in rear-end collisions and overall improvement in safety. The study also noted a 20 percent decrease in lane changing conflicts.

Lane Management

Lane management involves the separation of one or more lanes from general purpose lanes on a freeway segment. Examples include High-Occupancy-Vehicle (HOV) Lanes, value-priced lanes, High-Occupancy Toll (HOT) lanes, and exclusive or special use lanes. Lane management relies on different factors including:

- Pricing including constant pricing as seen in traditional toll lanes or congestion pricing which involves surcharges at peak periods.



Mopac Express Lanes in Austin, TX

- Vehicle eligibility which restricts lane usage to certain vehicles such as trucks or HOV
- Access control such as express lanes with limited access over long stretches of the freeway to improve traffic flow.

Some managed lanes use a number of these factors simultaneously. For example, the Mopac Express Lanes in Austin, TX allow free access to public transit vehicles while all other vehicles pay a variable toll. Other approaches involve combining vehicle eligibility and access control so that there are transitways or busways which are separated by a barrier with limited access. This method has been deployed in several parts of the country including Texas highways. The toll version of this strategy has been considered for portions of I-35 but current policy does not support it. Non-revenue use of such lanes for longer distance traffic, or in future years to support strictly autonomous vehicle use could be beneficial.

Dynamic Shoulder Use

The FHWA defines dynamic (also known as part-time or temporary) shoulder use as the conversion of highway shoulders to travel lanes during some hours of the day as a congestion relief strategy. This strategy provides additional capacity when it is needed and preserves the use of shoulders as refuge areas during non-peak hours. The benefits of this approach include reduction in delay and congestion. It entails relatively low construction costs, but potentially higher maintenance costs compared to other methods due to the need for ongoing maintenance of the shoulders if thinner pavement designs were used in the original construction.



Dynamic Shoulder Use on I-35W in Minneapolis (Source: FHWA)

There are a variety of dynamic shoulder use options including:

- Left/Right Shoulder Open where the shoulder is used as a general purpose lane
- Vehicle Use Options which restrict the types of vehicles using the shoulder, such as limiting use to transit vehicles and HOV, or prohibiting trucks
- Speed Control Options which adjust the speed of the managed lane for safe merging operations

Dynamic shoulders have been implemented in several cities in the US, including Minneapolis, Miami, and Chicago with lengths varying from one to 290 miles. The most common implementation is bus-on-shoulder. General purpose dynamic shoulder use has been implemented on I-35W in Minneapolis (2009) and I-66 in Fairfax County, VA (2015).

Arterial Signal Coordination

This strategy involves the coordination of traffic signal timing patterns to smooth traffic flows by reducing stops and delays. It is usually applied on corridors with closely-spaced

intersections (<0.25 miles) and can be used to coordinate transit headways. The system is fully-responsive to traffic volumes. Agencies can implement this strategy on a small corridor, a limited grid, or region-wide. It usually requires coordination between local and state entities.

Connected and/or Autonomous Technologies

Connectivity and autonomous technologies are poised to reshape the mobility landscape and promise to make travel safer, more efficient, and more enjoyable. While these technologies are often lumped together, they actually describe two parallel innovations that can work together to transform the interactions between people, vehicles, and the infrastructure they move on.

Connectivity describes communications between vehicles (V2V), between vehicles and the infrastructure (V2I), and between vehicles and the internet (vehicle-to-cloud, or V2C). This communication is enabled by sensors embedded in vehicles, on transportation infrastructure, and/or on travelers, such as Bluetooth and cellular devices. This technology can be used, among other things, to communicate on-road conditions to integrated corridor management systems, safety systems of surrounding vehicles, and to on-demand mobility services such as Uber and Lyft.

Automation, on the other hand, describes a range of vehicle technologies that work to enhance or replace human-controlled vehicle operation. Automated vehicles are enabled by connectivity technologies used to gather information on road network conditions and communicate with other vehicles, as well as environmental sensors such as cameras, RADAR, and LiDAR mounted on vehicles. The Society of Automotive Engineers has identified five levels of vehicle automation that range from limited automation technologies requiring full driver engagement. The lowest level includes currently available features such as adaptive cruise control and advanced braking. On the opposite end of the spectrum, full automation will require no driver input during operation.

In tandem, connectivity and automation have a number of existing and potential benefits for mobility. They include:

- Reductions in crash rates by 90%, according to some¹. These will include an end to human errors caused by alcohol or drug impairment as well as distracted driving.
- Reduction in congestion due to fewer incidents, smoother braking, fine speed adjustments, and reductions in traffic shockwave propagation leading to reduction in congestion. Cooperative adaptive cruise control, an automated vehicle technology,

¹ Fagnant, D.J and Kara Kockelman. "Preparing a nation for autonomous vehicles"

deployed at 10, 15, and 90 percent market-penetration levels will increase lanes' effective capacities by 1, 21, and 80 percent respectively².

- On-demand mobility, providing access for those who cannot or choose not to drive.

Some of the potential drawbacks of these technologies include:

- An increase in per-capita VMT. As CAVs enable travelers to spend time they previously dedicated to driving on other tasks, the perceived cost of travel time will decrease, encouraging people to travel further and more frequently.
- The possibility of hacking, malicious tampering, privacy violations, and other security threats.
- Uneven deployment of automation technologies could create conflicts with human-operated vehicles.

The following sections provide a summary of several emerging connected and autonomous (CAV) modes that will affect the way we plan for the Capital-Alamo corridor. Such technologies include autonomous intercity buses, shared autonomous vehicles, driverless shuttles, and truck platooning.

Freeway Implications

In Iowa, the Department of Transportation is conducting a Planning and Environmental Linkages (PEL) study for a 300-mile segment of the I-80 corridor. Traffic forecasts indicate a current need to expand the facility to six lanes in the near future and by 2040 the need for additional two-lanes, for a total of eight lanes.



Dedicated CAV lane

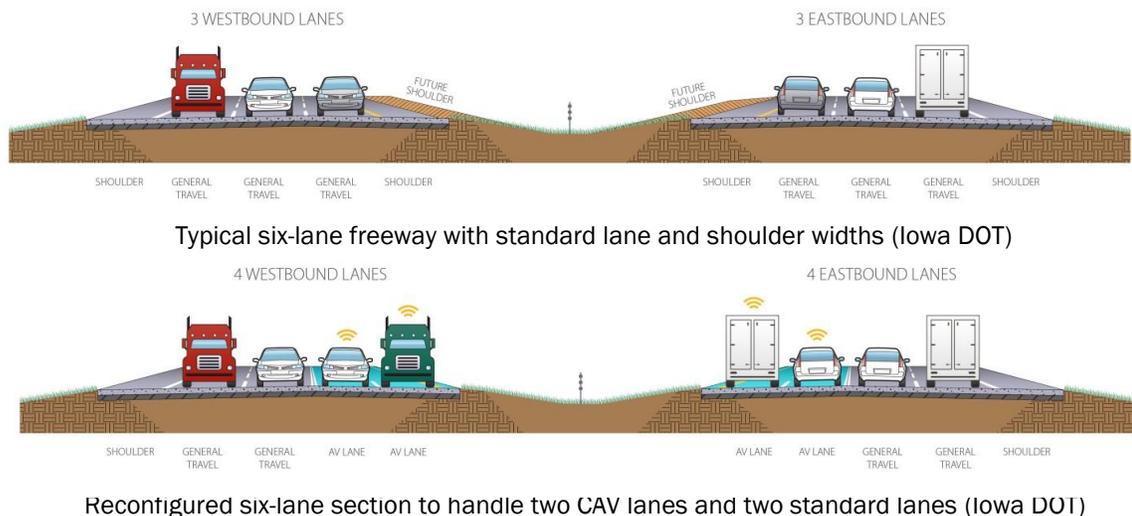
The PEL study identified the potential of CAV integration to eliminate the future need for an eight-lane facility. The adopted strategy is to build a six-lane facility initially with typical 12-foot lanes and full depth shoulders. As CAVs are integrated into the corridor, the typical section would be restriped to two 12-foot lanes and two 10-foot lanes capable of handling CAVs. This approach would save the Department billions of dollars in future capacity expansion, and provide improved infrastructure opportunities for the integration of these new technologies. Planners in Denver, Colorado (C-470), Seattle (I-5), and Wisconsin (I-94) are contemplating the same approaches to freeway expansion.

The following graphics present conceptual designs of the I-80 CAV lane implementation. The near-term expansion to a 60-ft. roadbed in each direction of travel (featuring the standard 3-

² Shaladover, S., Dongyan, S., and Xiao-Yun, L. "Impacts of cooperative adaptive cruise control on traffic flow"

12 ft. travel lanes flanked on both sides by 12-ft. shoulders) could be converted into a four-lane freeway (two standard vehicle lanes of 12 ft. each and two 10-ft. lanes for CAVs).

The narrower lanes for CAV vehicle use would recognize the more precise and consistent driving pattern of computerized steering in CAVs. The 60-ft. roadbed would not need to be expanded, as the inside shoulder could shrink to just four feet. A similar approach could be explored for reconfiguring I-35 between Austin and San Antonio.



Autonomous Intercity Bus

Intercity buses such as Megabus and Greyhound have been operating across the nation and in Texas for many years now providing discounted trips between the several cities. With the rise of CAVs, public interest, or at least acceptance is slowly shifting towards autonomous intercity buses. In addition to the major safety benefits that would result from that shift, the quality of the ride would likely improve with smoother braking and acceleration efforts, while reducing travel times and creating a more reliable service. China and Singapore are now the leaders in the testing of this potential mode.

Autonomous Intercity Bus Service – Singapore

Initial testing has relied on retrofitting standard buses into autonomous buses and driving them on urban transit corridor. Singapore's Land Transport Authority (LTA) is exploring this new technology to expand the transportation network capacity without the need for major infrastructure investments. A joint effort by LTA and NTU Transport Research Centre focuses on the development of a hybrid vehicle that is scheduled to begin public trials in 2018. Initially, the bus will run a route of less than one mile, which will be extended if the trial goes well; ultimately these buses are expected to travel between cities by integrating longer routes and dynamic routing within the next 10 years. Recent announcements indicate that a joint effort between NTU and Volvo has been initiated in to test electric autonomous buses in Singapore by 2019.

Yutong Autonomous Bus – China

The Yutong Autonomous Bus has been under development and testing for three years. It recently completed a 20-mile long circuit trip between Zhengzhou and Kaifeng in Henan Province, in regular traffic without any human assistance. The bus traveled at a speed of 40 mph through 26 signalized intersections and was able to change lanes and overtake vehicles. The technology is still under development and no information is available on its anticipated completion.



Yutong Autonomous Bus

Shared-Use Modes

While CAV will transform the way we operate vehicles, it is also likely that trends in vehicle technology will reshape vehicle ownership and use entirely. Shared-use mobility describes several emerging alternatives to vehicle ownership. One approach, car sharing, involves subscribing to a service that enables users to access vehicles on-demand from fixed locations. Car-sharing companies include Zip Car and Car2Go. Another common approach is the one used by transportation management companies (TMCs) like Uber and Lyft. These companies enable drivers to use their own vehicle to connect to people needing rides via on-demand smartphone applications. Another emerging trend in shared-use is fixed route services, such as Chariot, UberPool, and Lyft Line. These services use vans and larger vehicles to provide alternatives to transit services.

With the emergence of fully-automated vehicles, these companies are to reduce costs by automating their vehicles. Uber, for example, has made a commitment to invest in 24,000 autonomous Volvo cars to create its first driverless fleet and has begun testing in early 2018. Recent studies³ indicate that Shared Autonomous Vehicles (SAV) are expected to enter our market within the next 10 years and change not only the way we travel but our car ownership patterns as well. In the context of the Capital-Alamo corridor study, SAVs can be seen as a last-mile solution for trip making. They can also be expanded to intercity travel with the help of I-35 AV-oriented improvements such as dedicated lanes.

Driverless Shuttles

Another last-mile CAV technology is the driverless shuttle. These vehicles are expected to run short distances on fixed routes serving designated stops. The vehicles have a capacity of five to ten passengers. This technology has been tested primarily on college campuses and

³ Collie, B., et al. "The Reimagined Car: Shared, Autonomous, and Electric Vehicle"

compact office developments. Some are even being tested on low-speed urban segments. The following are some examples of these tests.

EZ10 by EasyMile – Various locations

The EZ10 has been running on highways since 2008 and has transported over 1.5 million passengers in several locations around the world. It can carry up to 12 passengers, six standing and six seated. Trials have been completed in Singapore, and Helsinki, Finland, and the vehicles are now in full service. Testing has begun in Sophia Antipolis, France; Lausanne, Switzerland; and Concord, CA. The vehicle can be deployed in ‘metro’ mode where it stops at all stations, the ‘bus’ mode where it only stops upon request, and the ‘on demand’ mode which can be called like a taxi.



EZ10 by EasyMile

“Harry” by Oxbotica – London, UK

The new driverless shuttle, “Harry”, is being tested in a residential neighborhood in London along a two-kilometer riverside route on the Greenwich Peninsula. The main aim is to test the vehicle in a high-pedestrian environment at a speed of 10 mph, with abilities to stop immediately when something is in its path.



The Harry driverless shuttle

Arma by Navya – Las Vegas, NV

Trials on the Arma started in January, 2017. The shuttle was initially set to run at 12 mph on the less congested streets of Las Vegas. After successful tests in November, the service was expanded to the busy Las Vegas Strip. To better cater to the shuttle service, traffic lights and signals were updated so they could communicate with the vehicle. The shuttle currently runs along a three-stop route on the South Las Vegas Boulevard and Fremont Street in the city’s Innovation District between 11AM and 7PM, six days a week.



The Arma operating in Las Vegas

Truck Platooning

Truck platooning is an example of a CV technology that could, but does not have to, rely on autonomous abilities. Truck platoons are composed of two or more closely spaced trucks (separated by as little as 10 ft) traveling together. The technology relies on the ability of each truck to connect to the truck in front of it or to other trucks in the same “pack”. Some of the

benefits of truck platooning include the reduction in fuel consumption of 10 to 15 percent per vehicle, increased safety resulting from V2V communication, travel efficiency, increased driver convenience and comfort, smoother acceleration and braking which reduces damages to fragile cargoes, and a significant reduction in emissions. Researchers at Auburn University estimate that platooning would improve traffic flows once truck market penetration reaches 60 percent.

There have been several trials performed to test truck platooning technology, including test by the US Army in live traffic in 2016 and a test of video- and radar-enabled platooning conducted by the US DOT's Exploratory Advanced Research program. Several private sector pioneers have emerged in the field of vehicle platooning. The most prominent is Peloton Technology, which has raised \$18.4 million and anticipates roll-out of its platooning technology by the end of 2018. Peloton has already tested its' system on 15,000 miles of highway in six states.

The Texas A&M Transportation Institute (TTI) began assessing truck platooning in Texas in 2015 and has performed successful test runs on its campus⁴. The next phase, which is anticipated to be completed in 2019, involves testing the technology on Texas highways. Trunk Platooning is being monitored by the American Trucking Association but has not yet been endorsed, as it has only been tested off road and on track in controlled conditions. Cyber hacking and the safety of live testing of platoons has caused some states, such as Missouri, to be hesitant about the technology. However, nine states including Texas have cleared this technology through legislation or administrative approval, and an additional 20 states have expressed interest in platooning testing trials. Truck platooning is expected to be operational on our roads within five to ten years.

Capital-Alamo Implications

With regards to the Capital-Alamo Corridor, CAVs will play a role in improving mobility and safety as well as reducing congestion and travel times. Capacity increases are anticipated due to the smaller headways and the reduction in crash/incidents that will lead to significantly lower travel times. This could be enough to serve anticipated traffic growth on I-35, without the need for major expansion once there is full market penetration. Truck platoons are expected to improve efficiency and mobility of freight across the study area. SAVs and driverless shuttles will act as another last-mile solution for intra-city travel, which is essential for encouraging people to use more efficient forms of transportation in the larger study area.

While acknowledging that many of these technologies are far from full deployment, decision makers in the corridor should consider the range of possible impacts these technologies will have on mobility. Policies and regulations need to be set in place and infrastructure

⁴ Texas A&M Transportation Institute. "Follow the Leader: Two-Truck Automated Platoon Test is a Winner" (2016)

improvements, such as the installation of Dedicated Short-Range Communication (DSRC) devices and smart pavements, need to be implemented to make use of the full potential of CAVs. Dedicated lanes may need to be initially considered on freeways such as I-35 while the use of these technologies ramps up. At this early stage, the Capital-Alamo corridor is an ideal area to test CAV technology for inter-city travel.”

High-Speed Dedicated-Path Technologies

This section describes a number of dedicated-path technologies including high-speed rail, MagLev, Hyperloop, and the Freight Shuttle. What these emerging technologies have in common is the need for a dedicated, fixed guideway on which passengers and/or freight are moved. While some of these technologies can be readily implemented, others such as the Hyperloop, are still being tested and researched to eliminate any potential safety issues and provide optimum designs in terms of speed and cost.

High-Speed Rail and MagLev

High-Speed Rail (HSR) already operates in several countries. Its primary use is to move people between large population centers separated by long distances, at speeds ranging between 120 and 250 mph. New forms of HSR have been developed such as MagLev to provide a smoother and faster ride.

High-Speed Rail Applications

The Acela Express (operated by Amtrak) in the Northeast, currently the only HSR line in the US, links Boston, New York City, Philadelphia, and Washington, D.C. The California HSR, being designed to link the five largest cities in California, is constructing its first operating segment between Merced and Bakersfield, in 2021.

The Texas-Oklahoma Passenger Rail Study (TOPRS) proposes a HSR line between Oklahoma and Mexico. A preliminary EIS has been completed for this project and the findings indicate that the best location for this service would be east of SH 130 with a stop near the Austin-Bergstrom International Airport and another stop in San Antonio. Funding for this project remains undetermined.

Also in Texas, the privately-owned Texas Central Partners, LLC is designing a HSR line between Dallas and Houston known as the Texas Bullet Train. The line provides service to up to 400 passengers every 30 minutes. Despite the completion of the EIS for this project, State legislative actions regarding the provision of ROW for the project has been negative.



The Shanghai MagLev Train, first commercial MagLev line operating since 2003.

Maglev Applications

The MagLev train is a form of HSR that uses magnetic repulsion to levitate the train and propel it forward on a specified guideway therefore creating minimal friction between the vehicle and the track and resulting in a smoother, quieter ride. The power required to levitate the vehicle is relatively low allowing most of the energy to be used to overcome wind drag. This results in significantly higher speeds than traditional rail technologies, making the MagLev the world's fastest trains with a record speed of 374 mph.

Both high speed and low speed MagLev trains are in operation today. While there are several low speed systems currently being used throughout the world, high speed systems are only found in Japan, Korea, and China. Plans are underway to expand MagLev systems in each of these countries. Companies such as American Maglev, TransRapid, MagnaMotion, and The Northeast MagLev (TNEM) have focused on developing the technology in the United States; but all have been faced with the lack of legislative and financial support.



The proposed Texas Bullet Train between Dallas and Houston

Positives & Negatives of HSR

- + Proven technology – it has been implemented in the US and other parts of the world
- + Attention and interest - it continues to receive public interest due its success
- + State interest – the technology is already being considered in Texas
- + Terrain – requires flat terrain which makes it suitable for Texas
- Cost – the capital and operating costs could be high
- Uncertainty – in safety, security, operational longevity, and maintenance requirements

- Operation – high speeds can only be achieved with long station spacing, meaning smaller communities between Austin and San Antonio could not be served.

Capital-Alamo Implications

With an HSR implemented within the study corridor, a reduction in congestion might be expected due to the diversion of passenger traffic from personal vehicles. However, the implementation of this technology in the State in the near future is not certain due to the

Speed/Radii ⁵
125 MPH / 7,000'
150 MPH / 10,000'
186 MPH / 16,600'
200 MPH / 18,000'
220 MPH / 22,000'
250 MPH / 28,000'

⁵ Turning radius (converted from meters to feet)

Texas legislative opposition.

Most recently, the Texas Senate and House Transportation Committees filed a total of 25 pieces of legislation during the 2017 session that could hinder a private company's ability to build a HSR line from Dallas to Houston. Specifically, the bills focused on prohibiting the use of eminent domain for HSR ROW, prohibiting the use of state funds for a privately-owned HSR line, and prohibiting state agencies from using state funds for planning, constructing, and operating HSR in the state. While only those bills prohibiting state funding of private initiatives were enacted into law, legislative hurdles will continue to be a concern in the implementation of new high-speed and costly technologies in Texas.

Hyperloop

The Hyperloop technology involves the movement of freight and passengers in pods through reduced pressurize tubes. By reducing pressure inside the tube, wind resistance is lowered, resulting in higher speeds. The pods are levitated on a pocket of air or magnetic repulsion within the tubes and are propelled using motorized fans. Latest designs of the Hyperloop feature pods with capacities of 8 to 28 passengers. Anticipated speeds for this technology are significantly higher than any existing rail system, up to 780 mph, and headways are estimated to be between 30 to 90 seconds, which is equivalent to 1,260 to 3,360 passengers per hour per direction.

Hyperloop Applications

The Hyperloop was first introduced to the public in 2012 by Elon Musk, and efforts have been made to open-source the design to attract other groups who could contribute to the improvement of the concept. Some of the most prominent Hyperloop efforts include:

Hyperloop Pod Competition by Space X

SpaceX, an Elon Musk company, is building a one-mile long subscale track at its headquarters in Hawthorne, CA. In 2016, it open-sourced the Hyperloop technology to 27 teams from across the world in the first Pod Competition aimed to advance the development of functional prototypes and encourage innovation by challenging teams to design and build the best high-speed pod. Due to successful designs that resulted from the first competition, a second competition was scheduled for 2017 and 2018 focusing on maximizing speed, safe deceleration, and propulsion.



Elon Musk's SpaceX Competition

Hyperloop One

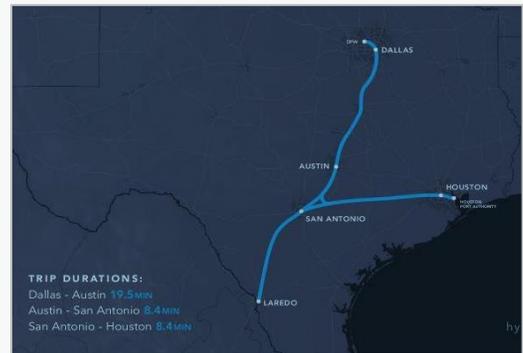
Hyperloop One is a Los Angeles-based company that has built a 1,640-foot long full-scale test track. It conducted its first pod motor tests in 2016 and has completed full-scale tests in 2017. The company is currently developing routes for their system in five different countries and has set a goal to be moving cargo by 2020 and passengers by 2021.



They Hyperloop One Model

Hyperloop Texas

In January 2017, Hyperloop Texas was one of the 35 participating teams in the first SpaceX competition. Hyperloop Texas consisted of a 640-mile route called The Texas Triangle that would connect Dallas, Austin, San Antonio, Houston, and Laredo.



The Texas Triangle Hyperloop Concept

Positives & Negatives

- + High speed – designers say the speed of a Hyperloop pod can exceed the speed of air transportation and other high speed rail transit modes.
- + Flat terrain – the technologies requires a flat terrain which is compatible with parts of the study corridor terrain.
- + Small physical footprint – the physical footprint of a Hyperloop system could be considerably smaller than traditional wheel-on-rail systems due to its ability to contain most of the operating system within a tube/track.
- + Worldwide public interest – the technology continues to receive large investments in research and development worldwide.
- + State interest – significant funding and research is being expended on the technology with a Texas design team (Hyperloop Texas) being one of the finalists in the design competition.
- Still being tested – the technology is currently only at the full-scale beta test phase; requiring extensive research and development before public use.
- Large turning radii – moving through a tube at such high speeds requires very gradual turns or changes in elevation. By comparison, the maximum grade for a 70 mph highway is 1,800 ft.
- Cost – large expenses expected for construction and maintain such a technology.

Speed/Radii

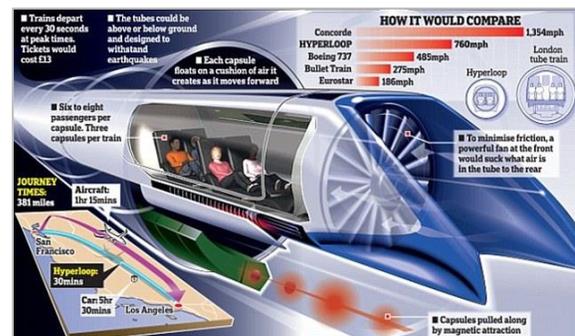
22 MPH / 67'
67 MPH / 600'
130 MPH / 2,400'
310 MPH / 13,200'
450 MPH / 26,700'
780 MPH / 82,000'

- Uncertainty – in the technology’s safety, security, cost, operational longevity, and maintenance.

Capital-Alamo Implications

Given that the technology could serve the movement of freight as well as passengers, the application could directly impact mobility in the project corridor by taking both freight and passenger traffic off of I-35. The terrain in the corridor is relatively level which is suitable for the installation of the Hyperloop tubular system; however, very large horizontal curves might be needed to accommodate the high speeds of the train which are not compatible with existing highway designs.

The hope that this technology could create a positive impact in the project area within the reasonable future is optimistic. Beyond the physical and financial hurdles to its implementation, the Texas legislative process must be considered. While most bills that negatively impact the development of non-highway related transportation infrastructure have failed to date, legislative hurdles must be considered when evaluating the viability of developing Hyperloop or any other dedicated path mode of transportation in the state of Texas.



The Hyperloop Vision

Autonomous Freight Shuttle System

The autonomous Freight Shuttle System (FSS) is designed to accommodate high density traffic between origins and destinations that are less than 500 miles apart, such as between seaports, ports of entry, and major urban centers. FSS can carry up to 54-foot long containers thus relieving truck traffic on roadways. The technology exhibits cruising speeds of 65 mph, has an energy efficient electric mechanism, and has fully autonomous operation. Each shuttle, carrying a single tractor-trailer or container, moves on an elevated, dedicated guideway and uses proven technologies.



Freight Shuttle System Guideway (Source: TTI)

The FSS was initially designed in 1998 by TTI. In 2005, Freight Shuttle International (FSI), LLC was formed to pioneer the development of this technology. In 2016, the Alpha FSS transporter was completed, tested, and unveiled to the public.



Freight Shuttle System prototype (Source: TTI)

FSS can be operated within existing ROW or on private property. The system needs less than ten feet of ROW on the ground. Construction of FSS is envisioned to use a prefabricated system that is constructed from the top of the deck, creating minimal impact on traffic during construction. Since the shuttles travel on an elevated ROW,

there is minimal interaction with other vehicles, improving safety and reliability both for general travelers and for users of the freight service. FSI expects to run shuttles 24 hours a day with headways of as little as 10 seconds. Thus, each directional guideway could serve the equivalent of 360 trucks per hour.

For a privately funded FSS, there could be opportunity for revenue capture by public agencies via agreements for the right to operate in public ROW. Public-private partnerships provide opportunities for a long-term relationship and return on investment.

The Freight Shuttle System Applications

The FSS was identified by the US Treasury Department as a beneficial project for the Zaragosa Port of Entry in El Paso, TX. The proposed FSS would move cargo containers across the border via a dedicated bridge. The system would be nearly 12 miles long and cost over \$1 billion dollars. The goal is to secure private funding to cover the majority of the cost. The technology is expected to also have a significant impact on expanding capacity at the Zaragosa Bridge corridor, thus reducing congestion and delay. Part of the congestion reduction would be achieved via use of special scanners to speed up the customs clearances of each container.

Positives & Negatives

- + Technology is ready for market application – successful low-speed testing was completed in 2016
- + Reduction in corridor congestion – by diverting the transportation of some goods from trucks to the shuttle
- + Reduction in traffic conflicts – due to the elevated guideway
- + Reduction in truck-generated pavement damage
- + Lower emissions – due to the use of electric motors
- + Reduction of medium-distance truck trips – since it covers medium freight movements which are usually performed by long distance trucks
- + Speed and reliability in delivery – due to autonomous operation, independent from other transporters
- + Privately financed, operated, and maintained

- Lack of flexibility – due to fixed route of elevated track with limited access/egress points
- ROW needs create conflicts with existing transportation systems or land uses
- Need for intermodal transfers – at the first and last mile connections

Capital-Alamo Implications

In the context of the Capital-Alamo Corridor, the FSS could be used to reduce truck congestion, infrastructure maintenance costs, and highway construction needs. Since the study corridor is shorter than the 500-mile maximum service length for the FSS, the shuttle could be suitable for the transportation of freight between the different intermodal facilities, along an elevated ROW above or parallel to I-35. The technology has been fully vetted through proof-of-concept tests and the opportunity for public-private partnerships provides potential for funding outside of the traditional highway funds.

Air Transportation

This section introduces aerial modes that could potentially divert traffic from highways by moving people and freight along more direct routes. Such modes include passenger aerial systems for single or multiple passengers, as well as delivery drones that cater to last-mile freight provisions. Despite the larger-scale success of this technology in the form of commercial airplanes, legislative hurdles are likely to hinder the smaller-scale use of this mode for personal travel due to security and safety concerns.

Passenger Aerial Systems

Passenger aerial systems encompass a variety of modes and include human and automated piloting. The most common example of a passenger aerial system is the flying car, which can operate like a traditional airplane, using a runway, or take off and land vertically. No flying car technology is currently ready for mass production, though several companies expect their technologies to be operational by 2020. One company, Terrafugia, has already begun taking orders to reserve some of its vehicles for future purchase.

Driverless aerial passenger vehicles have been developed and are being tested in at least three locations – China, the USA (Nevada), and Dubai. Such vehicles are designed to carry one passenger weighing no more than 220 lbs. and traveling over a distance not exceeding 30 miles before recharging. Early planning is also underway for multiple passenger Unmanned Aerial Systems (UAS) that could act as a form of mass transit. Though this mode has not yet been fully developed, it is planned to operate as an unmanned commercial airline flight (no pilot) and is expected to enter testing soon. The driving force behind this testing is major airline companies including Boeing and Airbus. UAS helicopters have been developed and are currently in use to serve the military.

Another form of aerial travel is the Aerial Ropeway Transit (ART), also known as the Gondola Lift. ART is now being introduced in urban environments as a relatively affordable and reliable automated alternative to moving people between two fixed points. Currently, the longest ART is 3.5 miles long and is located in Hong Kong.

AeroMobil 4.0 by AeroMobil

This flying car hybrid was first shown to the public in April 2017 at Top Marques Monaco show. It is currently taking preorders that will ship in 2020, at a price of \$1.3 to \$1.7 million. The company plans to produce 500 vehicles. The Slovakian-designed vehicle uses a runway for take-offs and landings but is in compliance with existing regulatory frameworks for cars and airplanes. It is a two-seated vehicle that can transform from car to plane in under 3 minutes. It can accommodate a driving range of 700 km (434 mi) and a flight range of 750 km (466 mi) at 75 percent of its top speed. On the ground, the hybrid can reach a top speed of 100 mph and a speed of 220 mph in air. It has safety features that help it glide down to Earth with the help of a parachute in the event of loss of power.



AeroMobil in airplane mode



AeroMobil in car mode

Lilium Jet by Lilium

Designed and conceived in Munich, the Lilium jet is an all-electric personal jet/air taxi that operates through vertical takeoff and landing. It is currently being tested remotely but is not planned to be autonomous. Reportedly, the vehicle can travel 186 miles at speeds up to 186 mph. The company plans to offer a five-seat version of the vehicle after the two-seat model has been successfully operated.



Lilium Jet testing lab in Munich

The Lilium jet will require a large network of small, landing pads in and around urban areas for safe takeoff and landing. The idea is that individuals would not need to own a unit but could simply pay per ride like a conventional taxi. The expectation is for the public to be able to book flights by 2025.



Lilium Jet in flight

The Transition by Terrafugia

The Transition®, designed by the Massachusetts-based company Terrafugia, is another flying car design that features some autonomous capabilities to improve safety but would be controlled by a pilot. Similar to other designs, the vehicle is a two-seater and is meant to operate as a regular automobile on ground and as an airplane in air with the ability to transition from one mode to the other in under a minute. It uses unleaded automotive gasoline and has a flight range of 400 miles with a top speed of 100 mph. The vehicle is expected to be operational by 2020.



The Transition Vehicle in car mode

Ehang 184 by Ehang, Inc.

The Chinese company, Ehang, first unveiled the Ehang 184 Autonomous Aerial Vehicle in 2016. Unlike the previously mentioned flying cars, the Ehang 184 is a fully autonomous self-driving aerial vehicle that can carry a single person weighing up to 220 lbs. and can travel at speeds up to 63 mph. The vehicle can travel a maximum distance of 30 miles before it needs recharging. The vehicle is equipped with safety features that allow it to land safely even if its rotor arms stop working, and is connected to a remote control center as backup. Dubai is looking to use these vehicles in the near future as taxis. The price of each ranges between \$200,000 and \$300,000.



The Ehang 184 unveiled in 2016

Flying Taxis by Uber

Uber is teaming up with the governments in Dallas-Fort Worth and Dubai to test its flying taxis. It is also working with real estate firms such as Hilwood Properties in Dallas to identify sites where it can build takeoff and landing pads, called “vertiports”, as well as charging stations. It is in the process of negotiating with five aircraft manufacturers to produce its electric vehicles with vertical takeoff and landing capabilities. The company aims to demonstrate its first flying taxis in 2020.



Uber's vertiports and charging stations

Pop.Up by Airbus and Italdesign

First unveiled at the Geneva Autoshow in 2017, Pop.Up is a combination of a self-driving car and a drone. The idea is that the passenger would travel in a self-driving electric capsule that can either attach to a chassis with wheels or be picked up by a drone powered by a battery in times of congestion while the chassis remains on the ground and completes the trip on its own. The capsule also has the ability to connect to a train or Hyperloop to complete a trip. The designers of this technology aim to complete a functional system within a 10-year timeframe.



The Pop.Up chassis on wheels and drone

Aerial Ropeway Transit (ART)

This aerial modes has been around for decades, carrying passengers to ski slopes and high-elevation touristic locations. Now this mode is being applied to urban settings worldwide. The cabins can transport up to 200 passengers at a time and the system is fully powered by electricity and diesel engines for backup in the event of power outage.



The Mi Teleférico in Las Paz, Bolivia (2014)

Previously thought suitable only in rugged terrains, this form of transport is now being considered for urban commute of all types due to its small footprint, energy efficiency, and low construction cost. Moreover, the ART does not need to follow existing roadways which may lead to more efficient routing. The longest ART today is 3.5 miles and is limited to single fixed routes with no branching.



Proposed New York East River Skyway between Brooklyn and Lower East Side Manhattan

Capital-Alamo Implications

While personal aerial vehicles could transport people within the Capital-Alamo corridor at much higher speeds (particularly if congestion continues to build), there is still a great deal of uncertainty regarding the application of these modes. ART is the only technology ready for implementation, and it would be applied to last-mile transportation services between major transportation hubs and nearby concentrations of jobs or housing. If that is the case, the anticipated benefits would be found in an urban setting and would not necessarily serve travel across the entire study area.

On the other hand, personal aerial vehicles (PAVs), owned by individuals, could permit travel within the larger study area. However, PAVs, like all the aerial technologies discussed here, would require proper infrastructure like air traffic control systems and new regulations on

how and where such transports could be operated to ensure safety and security. These topics are not currently being addressed by lawmakers locally or nationwide.

Freight Aerial Systems

A number of companies, such as UPS, Ford, DHL, and Amazon have begun investigating the application of unmanned aerial systems for last-mile freight deliveries. Such concepts usually include a combination of delivery trucks and drones that in combination transport packages to individual homes and businesses. The consensus is that the application of UAV delivery is still years away as it is still limited by several factors such as range of travel, payload, weather conditions, security, and other regulations.

Ford Autolivery by Ford Motor Company

The Ford Autolivery model combines self-driving trucks with Unmanned Aerial Vehicles (UAV) that nest inside the truck and are released to perform last-mile deliveries to a recipient's front door. This technology is still in its early stages of testing.



Ford Autolivery Concept

DHL Parcelcopter by Deutsche Post DHL Group

First tested in 2013 by DHL in Germany, the Parcelcopter succeeded in completing a 12 km test trip to deliver urgent pharmaceutical goods from mainland Germany to a nearby island. It was tested again in 2016 in severe alpine conditions where it had to adapt to rapidly changing weather and severe temperature fluctuations. Most recently, the Parcelcopter has succeeded in completing tests involving five-mile long flights completed in approximately eight minutes. The trip would normally take more than 30 minutes by car. The technology will continue to be tested.



DHL Parcelcopter Unmanned Aerial

Amazon Prime Air by Amazon

Amazon has recently designed a drone delivery system to transport packages to customers in 30 minutes or less. The service, known as Prime Air, aims to shorten delivery times significantly, improving service, reducing safety concerns, and making delivery more efficient. The first successful tests of the service were performed in the United



Amazon Air Prime Service

Kingdom in December, 2016. The current system can carry packages of up to 5 lbs. and is only permitted to be used during daylight hours under clear weather conditions.

UPS Parcel Delivery by United Parcel Service Ropeway

UPS began testing drone deliveries in February, 2017 in Tampa, FL. Their drone service is designed to make short trips between a parked delivery truck and recipients' front door. The current drones can fly up to 30 minutes and recharge at docking stations housed in the UPS vehicle. Their weight capacity is still undetermined. UPS anticipates great savings and improvements in efficiency equivalent to \$50 million per year.



UPS Drone Delivery Service

Capital-Alamo Implications

The main benefits of freight aerial systems will be experienced in urban areas in the context of last-mile package delivery to concentrations of receivers. Given the maximum payload that can be carried by such vehicles and limited distances they can travel, longer distance service is not feasible at this time. More corridor-wide delivery of goods will require substantial policy and operational improvements to be implemented.

Conclusion and Recommendations

The plans we are developing today for the next 25 years must make allowances for some or all of the technologies mentioned in this paper. Smart Highways and Integrated Corridor Management must begin integration immediately. Such strategies can slow the growth of congestion in the near time and cater to growing forecasted demands in the future.

CAVs will be operational before we can make full provision for their use, but by the mid-term of this plan, their impact - both for good (improved safety) and potentially bad (increased demands for travel by automobile) will be keenly experienced. The creation of smart technology that permits vehicles and transportation infrastructure to communicate with each other must be in place. The adoption of existing highways to harness the benefits of CAV will also be necessary.

High-Speed Dedicated-Path Technologies are largely already available, but neither the Federal nor State Government has the financial resources to pay for them. Private sector interests could pursue these services, but will only do so as they make economic sense for the private companies. They do not make economic sense today.

New forms of air Transportation are exciting, and have some immediate application for last-mile connections (ART and drone freight deliveries in particular). But passenger aerial

systems are going to require major investments in new air traffic control systems and a slew of regulations/policies governing how they can be used. Combined with their forecasted cost, their impact on the transportation system will not be experienced for a long time.

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