

PROJECT DESCRIPTION

Project Abstract

The United States and Texas in particular have a transportation challenge which requires the simultaneous solution of four problems. Traffic congestion has resulted from road capacity additions not keeping pace with population growth. Vehicles continue to be a major source of air pollution which clouds the air in urban population centers. Safety is a concern with traffic accidents annually claiming over 42,000 lives, causing nearly 3 million injuries, and producing over 4 million property damage claims nationally. And finally energy security is an issue with the transportation sector 97% dependent on oil with over 56% imported from foreign sources.

Dual mode vehicles and infrastructure designs are one alternative which offers a potential answer. This technology can impact both freight and passenger transportation on both new construction and existing routes by adding significant capacity at a fraction of the cost for conventional capacity additions.

This study will survey the dual mode technology currently under development and identify the three to five technology leaders for more detailed study. Specific deployment opportunities will be identified and a comparative analysis of two alternative designs will be completed. Finally, a method will be developed to monitor future progress as technologies mature.

Background and Significance of Work

In 2004 Texas A&M University began researching energy issues specifically to investigate the possibility of achieving energy independence for the nation. This effort quickly differentiated between primary fuels used for mobile applications and stationary applications. Dependence on foreign sources is currently primarily due to mobile consumption – transportation demand. Strategies to eliminate this dependence identified electrification of the transportation sector as an alternative. This led to an investigation of the challenges to electric vehicle technology adoption and dual mode vehicles were revealed as one of the solutions to address the key limitation which is battery capacity or vehicle range between charges.

The Center for Energy, Environment, and Transportation Innovation (CEETI) was formed in early 2005 with start-up funds from a philanthropic foundation. This has enabled a study of the issues related to electrification of transportation and dual mode technologies in particular. A center website has been established (www.ceeti.org) as a communication tool to link to documents and resources useful in this research.

CEETI has hosted and will continue hosting virtual workshops on subjects relevant to understanding the full challenge of introducing such a new mode of transportation. These workshops include sessions on personal mobility, driverless freight, off-guideway technologies, guideway designs, guideway entry and exit ramp design, system performance and reliability issues, energy supply systems, human factors, policy issues, and financial/funding challenges. These workshops are held over the internet with all participants hearing a common audio and viewing a common desktop on which presentations, video, a whiteboard, and ad-hoc lists are displayed or created. This is a low cost method of engaging world class experts on a subject without travel downtime and it creates a multimedia record of the meeting that can be played back for reference. We have included participants in our virtual meetings from Denmark, Japan, UK, France, and across the United States. Our past experience in this specific knowledge area of dual mode technology and the tools for virtual meetings will both be leveraged into this project to deliver a superior product to TxDOT.

Texas Has A Transportation Challenge

As noted in TxDOT literature, Texas has a challenge keeping transportation capacity growing at a pace adequate to meet the demand which is being driven by population increases. The Texas population is expected to grow 64% over the next 25 years and vehicle miles traveled is expected to grow 214% over the same period. At the same time road capacity is forecast to grow only 6% with a major problem being the sourcing of funds for infrastructure construction (1). This mismatch between the growth in demand and capacity results in increasing traffic congestion causing non-productive use of time and fuel while reducing economic competitiveness. (2)

Texas also needs to improve air quality. As shown in Figure 1, the major metropolitan areas of Texas are in non-attainment or near non-attainment status regarding air quality. (3) A major contributor to the air quality problem is mobile emissions due to the internal combustion engine and a dependence on hydrocarbon primary fuels which are currently the most cost effective energy source for transportation. Cleaner alternatives do not have access to the transportation market.

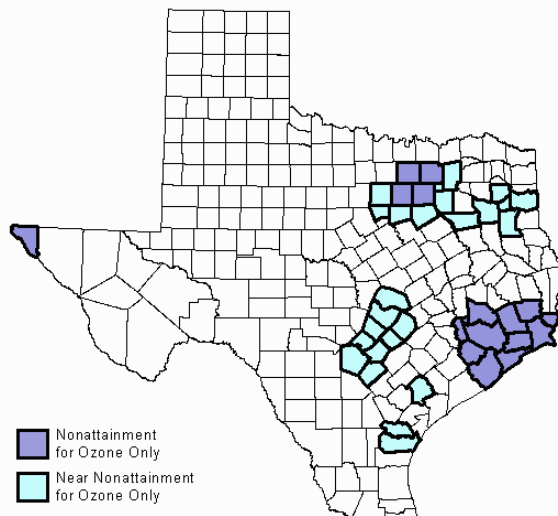


Figure 1: Texas non-attainment and near non-attainment areas for ozone (Source TCEQ)

On the safety front, Texas has the second highest number of traffic fatalities among the 50 states with 3,675 deaths in 2003. (4) In 2000 there were 1450 fatalities involving high blood alcohol levels in Texas (38% of all fatalities) and the Department of Public Safety issued over a half million speeding violations. (5) Clearly driver behavior is a major factor in both fatalities and accidents causing only injuries or property damage.

These combined challenges represent an opportunity for innovation. Solutions which hold the promise of reduced infrastructure cost, reduced traffic crashes due to driver error and other causes, and reduced mobile emissions

with primary fuel flexibility should be of high interest. Dual mode vehicles are potentially such a solution and TxDOT is wise to investigate this opportunity on behalf of the citizens of the state of Texas.

The Dual Mode Transportation System

There are many different embodiments of the dual mode transportation concept, but all should fit within the definition used in the proceedings of a 1974 Transportation Research Board conference on dual mode systems as follows: (6)

Dual-mode transportation is that broad category of systems wherein vehicles may be operated in both of two modes: (a) manually controlled and self propelled on ordinary streets and roadways and (b) automatically controlled or externally propelled (or both) or powered on special guideways. In general dual-mode transportation systems can include both common carrier and private vehicles and provide for the transport of both persons and freight over a common guideway facility.

The concept illustrated in Figure 2a proposes a new vehicle designed to be lightweight and an optimum aerodynamic shape for high speed guideway operation and maximum energy efficiency while operating on ordinary neighborhood or feeder roads using low speed and electric propulsion. Figure 2b shows a conceptual dual mode car designed to allow it to access a special guideway infrastructure. Other concepts propose use of a pallet or 'bogie' compatible with the guideway as a transporter vehicle to carry a car or a freight container over the guideway infrastructure with the pallet vehicle operating in a single automated mode and never actually leaving the guideway. This is the case in Figure 2c where the car on the right is pinned to the bogie which interfaces with the guideway. The car's wheels are retracted to reduce aerodynamic resistance and therefore are not shown.

Personal Rapid Transit (PRT) systems, as illustrated in Figure 2f, offer small vehicles similar to a car. The PRT vehicle is routed on the guideway automatically and directly to your desired destination without intermediate stops at other stations as required for buses or mass transit systems. It is a form of mass transit that enables the personal space, privacy and direct routing of a car. PRT vehicles are captive to the guideway and thus are by definition not dual mode since their vehicles cannot be manually controlled and self propelled on ordinary roads. PRT advocates do however define dual mode as a special case extension of PRT concepts since the guideway mode uses similar automated externally powered control of lightweight vehicles. Since PRT systems can be evolved to full dual mode

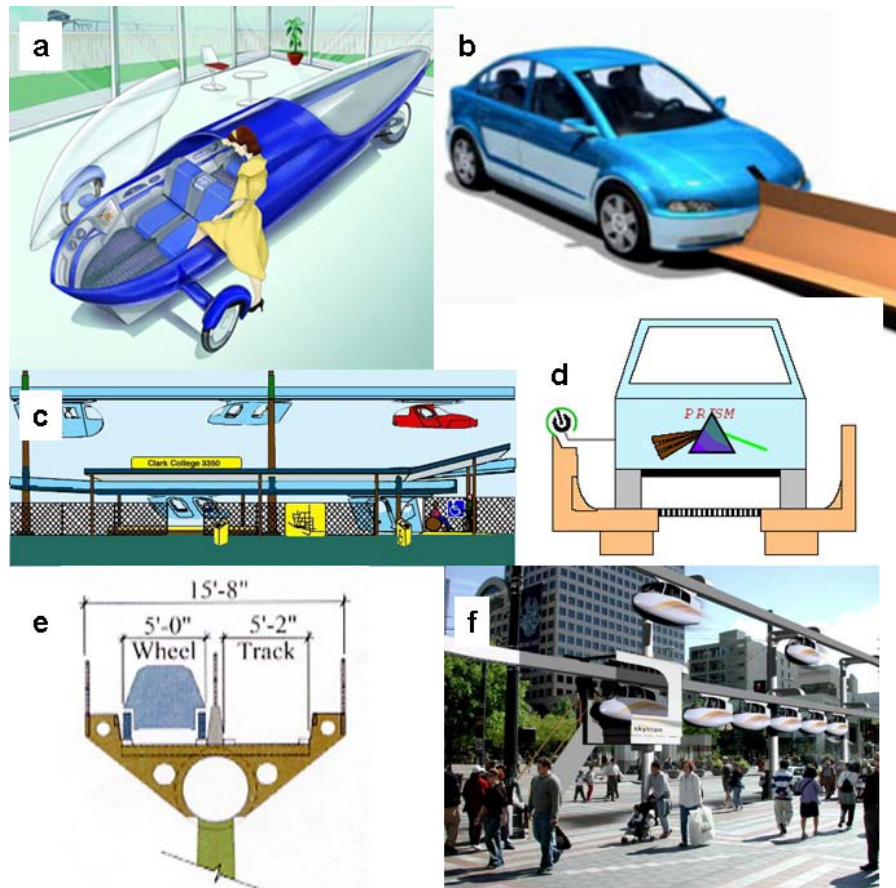


Figure 2: Automated vehicle concepts – (a) TriTrack , (b) Ruf International , (c) Highway , (d) Ford Prism, (e) Personal Transportation System, and (f) Unimodal Ref 7,8,9,10,11,12

systems, the concepts and features of these systems should be weighed in this study provided the system can feasibly evolve into a full dual mode system. The system illustrated in Figure 2c carries both PRT vehicles and dual mode vehicles.

Concepts include versions which place the vehicle on top of a guideway structure and others suspend the vehicle below the guideway. The definition is also broad enough that it would include the Automated Highway Systems (AHS) developed in the 1990s. In that case the guideway was a special separated highway lane outfitted to enable automatic control of the vehicle. Concepts illustrating this vehicle and infrastructure configuration are shown in Figures 2d and 2e.

Dual-mode proponents claim three advantages over other transportation alternatives. The first is the ability of a dual mode vehicle to gather riders essentially at their doorstep using the existing roadway and then delivering them over the guideway network to their destination without requiring any modal transfer. The second advantage is automation or driverless guideway travel which enables smaller economic shipment sizes for goods and more direct point to point travel for people without the intermediate stops experienced in most mass transit alternatives. The third claim involves reduced fuel consumption, mobile emissions, travel times, traffic congestion, and monetary costs.

Freight Considerations

The commercial attractiveness of a completely automated freight system includes:

(1) eliminating issues related to driver hours of service rules for long haul routes, (2) improving safety, (3) reducing insurance costs, (4) ensuring travel time reliability, (5) decreasing transit times, (6) reducing emissions, (7) reducing energy cost variability, (8) maintaining reasonable rolling stock capital cost, and (9) reducing maintenance cost.

The potential exists for increased velocity without a corresponding increase in operating cost. This is shown in Fig. 3, which is based on a model developed at CEETI addressing energy consumption. This figure shows that the cost per 100 weight-mile using \$2 per gal diesel at 65 mph would be comparable to the cost of using 16 cent per kW-h electricity at 130 mph. In other words, the transport speed could be doubled without an increase in operating cost. This includes a significant toll since the national average electricity price is 8.3 cents per kWh. (13)

In contrast, Fig. 4 shows historical freight operating costs since 1965. Two important trend reversals are seen in this figure. Until about 1978, energy efficiency was steadily decreasing, perhaps because trucks were steadily increasing the velocity of freight transport as more and more freight was transferred from railroads to the new interstate highway system. During the period of the imposed 55 mph speed limit, engine technologies were steadily improving, and both may have contributed to the increase in energy efficiency. Once the 55 mph speed limit was revoked at the federal level, states gradually removed this provision over the next few years. The increase in velocity explains the observed decrease in energy efficiency. (14) Even today additional energy consumed with increased freight velocity is offset by the commercial value in reducing delivery time, and in the future, much higher velocities requiring less energy should offer considerable value to the freight industry, particularly considering the impact of NAFTA and the increased import of finished goods from Asia.

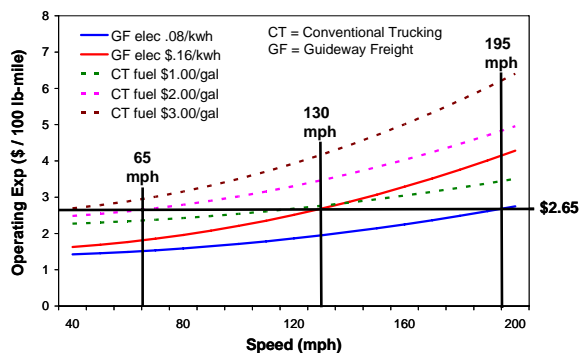


Fig. 3: Cost comparison for electrified driverless freight versus the current highway system

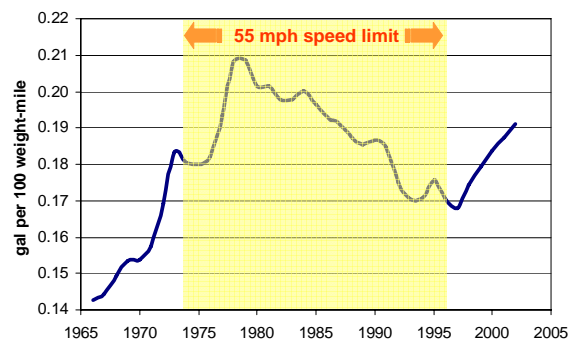


Fig. 4: Historical freight energy consumption

Where trucking can be expected to move goods 500 miles per day in the current system without driver teams, the future system could move goods 4800 miles in a 24 hour day at 200 mph since no driver rest or refueling

stops are required. This would dramatically impact the logistics of goods movement by enabling fewer distribution centers to serve the nation with less than one day service.

Since most dual mode systems are envisioned to be light weight in nature, the freight being considered for this system is not the bulk heavy freight carried by trains or some trucks but rather the lighter high value freight. In Europe it is estimated that over 2/3 of freight value fits within a size shape factor of 1.2m x .8m x 1.5m and less than 900 lbs. (15) If this statistic holds in the US, it will provide guidance regarding the freight pairs which might be shifted to the new architecture.

A final consideration for freight is related to border security. A driverless system with a modern infrastructure could offer customs check-in much like air freight. Once approved, freight could move across the border non-stop to an inland port distribution facility. Since freight movement is automated, tracked, and does not have the freedom to exit at the will of a driver, security and control over international shipments can be enhanced without bottlenecks at the border crossings.

Personal Mobility

In parallel with driverless freight intercity movements, single mode automated mass transit vehicles could be built within urban settings. Like driverless freight, small transit coaches could initially involve vehicles captive to the guideway system. This low to medium population density transit solution offers volume variability appropriate for the application – smaller vehicles than busses or trains delivering individuals or small groups directly to their desired destinations without intermediate stops.

The vehicles in this system promise travel at much higher speeds with smaller headways due to the automated operations of the guideway (no driver error), the captive connection of the vehicle to the guideway, and the reduced degree of freedom regarding paths a vehicle can take relative to highways. Higher speeds of the order of 100 mph in urban areas and 200 mph in intercity corridors could mean a single lane urban guideway has a capacity of more than 20,000 vehicles per hour compared to 2000 vehicles per hour for a single lane highway. For transportation planners, this infrastructure would provide an ideal solution to the ever increasing problem of congestion due to limited funding and space for additional capacity.

Since human error is the cause of most accidents on highways, an automated operation promises to eliminate the human error factor, thereby helping to achieve the zero accidents vision. A congestion free system and a pre-determined fixed speed would ensure travel time reliability. People would be able to work or relax in their vehicles while on the guideway thus increasing their productivity. The benefits of reduced stress, reduced emissions, enhanced safety, lower cost, faster transit time, improved travel time reliability, and productivity in route all provide a new value proposition for consumers. This will be an important factor influencing the adoption rate of the new technology and will impact public health and the economy of the country.

Technical Challenges

An automated highway system (AHS) was designed and demonstrated in 1997 (16, 17, 18), proving that vehicles could be laterally and longitudinally controlled by computer even in a highway environment where the degrees of freedom far exceed the mechanical freedom of vehicles captive to the guideway as used in many dual mode designs. Also in AHS related studies, autonomous vehicle following systems used laser, radar, and machine vision systems to maintain constant time gaps between consecutive vehicles. If in addition the vehicles communicated with other vehicles to augment the sensor data, then the vehicles could operate with a constant distance spacing between vehicles invariant with speed. This latter mode allows electronically coupled strings of vehicles to operate even at high speed with short headway room between vehicles and as such increases the throughput capacity of the infrastructure. (19,20) This is critical because the combination of higher speeds and short headways is the method by which dual mode guideway systems achieve their capacity claims.

AHS highway operation studies showed the capability of reaching lane capacities of 6000 to 7000 vehicles per hour before consideration of merging conflicts and using conventional highway speeds. (21) Other studies allowing vehicles to randomly join and leave vehicle platoons only studied capacities from 3000 to 4500 vehicles per lane per hour. (22) These capacities can be compared to conventional highway capacities of about 2000 vehicles per lane per hour. A review of the operational strategies for maintaining safe distances between vehicles while allowing merge and diverge maneuvers and high speeds where applicable is in order to qualify dual mode capacity claims.

The means for switching to direct one vehicle in one direction and perhaps the next vehicle in another direction at high speed presents a challenge. One can envision the mechanical switches used to direct trains for instance either straight or to a separate track. Mechanically switching may be problematic but other approaches using non-mechanical switches or strategies which force direction changes to occur off-guideway at slower speeds are incorporated in some systems. The strategy for addressing this function will be a differentiator between system designs.

A closely related issue is the coordination of guideway traffic with feeder or frontage roads. Coordination of guideway traffic with the off-guideway traffic at exits would be required to ensure side street congestion does not back up onto the guideway. Schemes might include automated parking, more distributed exits, cooperation of traffic signals with guideway control systems, or sufficient buffer space at off-ramps to absorb peak traffic. Some of these solutions will add complexity to implementation or may add to the footprint of a system. Guideway traffic operation does have one advantage in that each vehicle is not a free agent but instead has a declared destination and known routing and speed from the time it enters the guideway. This will allow control of volumes exiting at any given ramp with overflow directed to previous or next exits. Strategies for addressing the ingress and egress points of guideways will need to be investigated.

Regarding safety, the current vehicle and roadway architecture has a mean time between injury causing crashes of at least 50,000 vehicle hours and a mean time between fatality crashes of at least 2.5 million vehicle hours. (23) Automated systems clearly do not have this level of experience with operation in realistic traffic conditions and highway speeds. There is considerable experience and research and demonstration effort ongoing however in low speed operations. The requirements and achievements with regard to safety certification of designs should be explored.

Even when safe operation can be demonstrated in normal operation, there still needs to be an ability to handle abnormal events. These abnormal events might include a fallen tree, power outage, terrorist events, earthquakes, high winds, ice, lightning, debris, or other situations which have cascading effects. Schemes for fault detection, identification and control system reconfiguration to address single or multiple faults are required and should be investigated in the new systems.

Fault tolerance and robust design are closely related to system reliability. While dual mode systems may be designed with few moving parts in guideway mode, not all systems will have addressed this issue equally. One of the arguments for example to limit guideway use to captive vehicles operating only in guideway mode is due to the concern that vehicles entering from off-guideway mode may be exposed to unpredictable environments, tampering, or improper maintenance, and the inability to detect or diagnose the vehicle condition during check-in to the guideway. Faults may also include sensor malfunctions, controller software or hardware failure, in-vehicle failures, wireless communication failures, or numerous other abnormalities. Overall reliability of designs will need to be evaluated as a part of the survey and alternatives analysis tasks.

The guideways themselves are generally proposed to be lightweight structures with varying span lengths if elevated. This raises the issue of how deflections due to vehicle load and guideway expansion will be addressed. Traveling at the high speeds proposed in some systems might introduce an uncomfortable bounce due to pre-cambered spans or a clacking due to expansion joints. (24) More complex means of addressing these challenges using dynamic schemes or levitation will most likely introduce additional cost and possibly reliability concerns. Alternatively a rigid structure which renders deflections under load negligible may be massive and cost prohibitive. Vehicle and load limits, minimum operational vehicle spacing, any propulsion means built into the guideway, methods of addressing all-weather operation, and right-of-way capacity for cabling will all affect the structural design, cost and footprint.

Institutional Issues

Institutional barriers to development of a new architecture are perhaps more severe than the technical challenges and include technological uncertainty, financial risk, and institutional inertia.

Technological Uncertainty

The AHS studies included evaluation of alternative propulsion and road powered AHS solutions, reliability studies, check-in and check-out systems, cost/benefit analyses, safety and maintenance studies, studies of legal, institutional and societal issues, malfunction management, AHS system health management, vehicle operational analysis, automated system construction analysis, a system evolution study, a roadway deployment analysis, a comparison of rural and urban considerations, a comparative systems analysis, an evaluation of impacts on surrounding non-AHS roadways, and a commercial and transit analysis (16). These studies did advance the

understanding of issues related to check-in, check-out, automated vehicle control, system impact, etc. and have begun to address the technology uncertainty but more remains to be done as discussed previously. Access to the literature including these studies and to transportation professionals will aid in development of a screening process to be used to rank current dual mode technologies.

Computing and sensor capabilities have also advanced immensely since the early work in the 1970s and the whole arena of intelligent transportation systems (ITS) has been pursued with interest by political decision makers, automakers, and transportation professionals. ITS includes smart cars, freight movement, infrastructure management, electronic payment systems, situational awareness, etc., but its primary implementation focus has been the integration of communications and traffic operations. ITS has established a system architecture for communications and information standards that has also begun to reduce the technological uncertainty.

Figure 5 diagrams the potential that integrating fuel, electricity, communication, and transportation

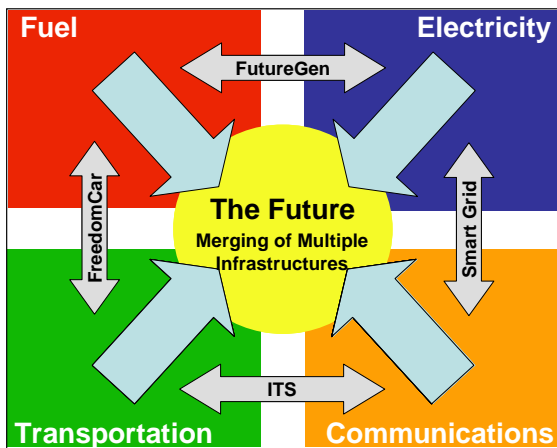


Fig. 5: Diagram showing potential for integrating multiple infrastructures

infrastructures could bring. Each of these has its own industry, government, and disciplinary constituencies. Shown in the diagram are notable collaborations between adjacent silos: the intersection between fuels and transportation with the current focus on hydrogen as an energy carrier (FreedomCar program), methods of generating electricity with minimal or zero emissions (FutureGen), merging of communications and electric transmission technologies to create a reliable electric grid (Smart Grid), and the intersection of transportation and communications with a federal focus for over a decade through the intelligent transportation systems (ITS) program.

The dual mode concept offers an opportunity to further integrate these efforts by merging all four quadrants simultaneously. In addition, a new infrastructure could provide a rigid housing for electric power transmission lines, fiber optic communications lines, and fuel lines. Merging these infrastructures could attract additional commercial interests in the infrastructure that could share the financial cost of construction. Figure 6 shows a diagram of this aspect (25).

Financial Considerations

Entrepreneurs have proposed different version of an electrified transportation system from mass transit concepts to dual mode vehicles to personal rapid transit systems. Each solution has its strong and weak points and associated costs. To estimate the cost of a new infrastructure, we can make a first order approximation by reviewing the range of estimates provided by the entrepreneurs. Entrepreneurial firms have offered infrastructure cost estimates of \$0.75 to \$7 million per mile (7,8) for a single rail on-board fueled system, \$10 million per mile (26) for a light rail equivalent with dual mode off guideway capability, and \$4 to \$22 million per mile (12,24) for a magnetic levitation system all excluding right of way costs.

If the new infrastructure were applied to parallel the current 46,500 mile interstate highway system (IHS) with 30% in urban settings at \$40 million/mile and 70% in rural settings at \$15 million/mile, this would result in a cost of \$1.05 trillion. Constructing such an infrastructure and spreading the expenditures over 30 years would result

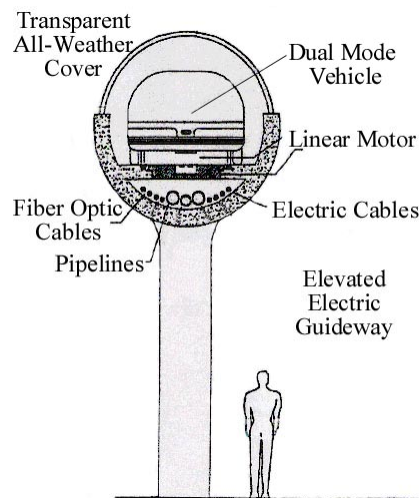


Fig. 6: Diagram of dual mode concept illustrating potential to merge transportation, electricity, communications, and fuel

in an average cost of \$35 billion/year for 30 years to develop the 21st century infrastructure. Costs could be higher or lower depending on the technology chosen and the number of lane miles built. Uncertainty causes financial risk and is driven by the lack of a clear national direction, unknown public adoption timeframes and the unproven nature of an emerging technology..

This is clearly a large infrastructure investment but it is the right order of magnitude for the nation and it assumes high-end costs. FHWA and AASHTO have estimated costs to maintain current highways at \$139 billion to \$155 billion in 2000 growing to \$170 to \$186 billion per year by 2025 respectively. (27) AASHTO estimates the cost to not only maintain but also improve current highways to range from \$189 billion in 2000 to \$220 billion in 2025. Included in these numbers is approximately \$63 billion annually for operations and maintenance non-capital costs.

The interstate highway system (IHS) cost the US \$329 billion in 1996 dollars and it took 40 years to build. The IHS is credited with creating \$6 in benefits for every \$1 invested and with enabling 25% of the productivity gains for the nation in the 40 years from 1956 to 1996 (28). If the new transportation architecture can be credited with creating 25% of the 1.3% annual productivity gain on the US \$12 Trillion GDP by cutting working capital costs for manufacturers, speeding transit times, and expanding competition then benefits would reach \$780 billion per year over 20 years due to this factor alone.

Additional benefits will be derived from:

- reducing congestion which cost the US over \$64 billion per year (2)
- cutting safety related cost by at least 35% - \$80 billion per year (27)
- reducing military costs of protecting the national interest in global energy supplies – a conservative \$33 billion per year expense, (29)
- \$17 billion per year in emissions/environmental impact costs (30)
- multiple revenue stream potential through the use of right-of-way within the infrastructure for communications cables, electric power transmission, etc.
- reduced maintenance costs for conventional roads

Although the capital costs are high, when viewed in perspective with the alternatives, it can be commercially justified. This opens the potential for public-private partnerships in the development of this infrastructure with private parties granted the right to collect tolls for guideway use and electric power consumption. This is a practice becoming more common among growing states such as Texas where the Trans-Texas corridor initiative proposes to develop major new transportation corridors with private financing. State legislative action has been required to establish the contractual right to privately collect tolls on infrastructure built on publicly obtained right-of-way.

To be effective as a new network alternative, the dual mode system must be introduced on a national scale. This differs from current mass transit solutions that are different in each city. On an equipment supply side , the result would be reduced unit costs of both infrastructure and rolling stock. From a technology adoption perspective, as with any networked system, the value of the network increases as the size of the network is expanded. For the present project this will mean a view to the scalability of the system to a national level with national standards.

Many transit systems have very low ridership and consequently low performance compared to promised benefit/cost ratios. Often this is due to attempts to fit a high population density solution into a medium or low density environment. Dual mode solutions have the promise of changing this dynamic by broadening the effective area served by a given infrastructure. Rather than walking a maximum of a half mile to a mass transit station, people drive in their dual mode vehicle perhaps five or ten miles to the dual mode guideway. In addition, the light weight and lower cost nature of the infrastructure should enable more guideways for a given funding volume. Both of these factors work to attack the low population density challenge and the financial risk of slow implementation and adoption.

Institutional Inertia

Together, the reduced costs, productivity gains and economies of scale can help justify the infrastructure investment provided a forward path is chosen which causes individuals acting in their own best interest to make travel and freight shipment mode choices which support maximum utilization of this new infrastructure. This requires a technology roadmap and a careful balance of the benefits of the new mode to ensure a healthy modal growth coalition develops. Self-financing by user fees, emphasis on complimentary nature rather than competition to other modes, a connection to economic growth, and an evolutionary/incremental path toward the transformational

vision must be developed. To this end a stakeholder group should be formed to advise the project of the various perspectives.

The history of innovation shows that new products are successfully launched when all the component technologies have been developed, and the only remaining task is one of integration. In addition, innovation tends to take a path of hybridization rather than wholesale change. The path of hybridization has begun with the introduction of hybrid vehicles that integrate electric motors with the usual internal combustion engine (ICE). The next step is the plug-in hybrid which is intended to rely on battery power for the electric motor and to use the ICE back-up only for extended range. These new propulsion alternatives will be combined with new control features such as adaptive cruise control, lanes keeping assistance, etc. as conventional solutions continue to incrementally evolve. The dual mode vehicle can be envisioned as another hybridization step in which the range of electric vehicles and the automation possibilities are extended by electrified guideways.

A potential evolutionary step toward this 21st century infrastructure vision would be to introduce the dual mode infrastructure first as a single mode driverless freight system for intercity goods movement and as a mass transit system in urban environments. This would build the network of guideways with designs planned for later interconnection and access by dual mode personal vehicles. Some strategy such as this will need to be developed to solve the chicken and egg problem as it relates to guideways and vehicles – it is hard for one to happen without the other. These transition issues will be critical in the introduction of a new architecture.

A technology roadmap is a tool that can assist in organizing this process and one should exist or be created for dual mode systems. Figure 7 illustrates such a roadmap and represents a Toyota view of the future of transportation vehicles and infrastructure. The upper right corner indicates the introduction of “Smartways” and “Smartcars”. (31) Other similar roadmaps and research plans originating from UC Berkeley, France, Sweden, and Germany are described in “Intelligent Vehicle Technology and Trends” by Richard Bishop. (18)

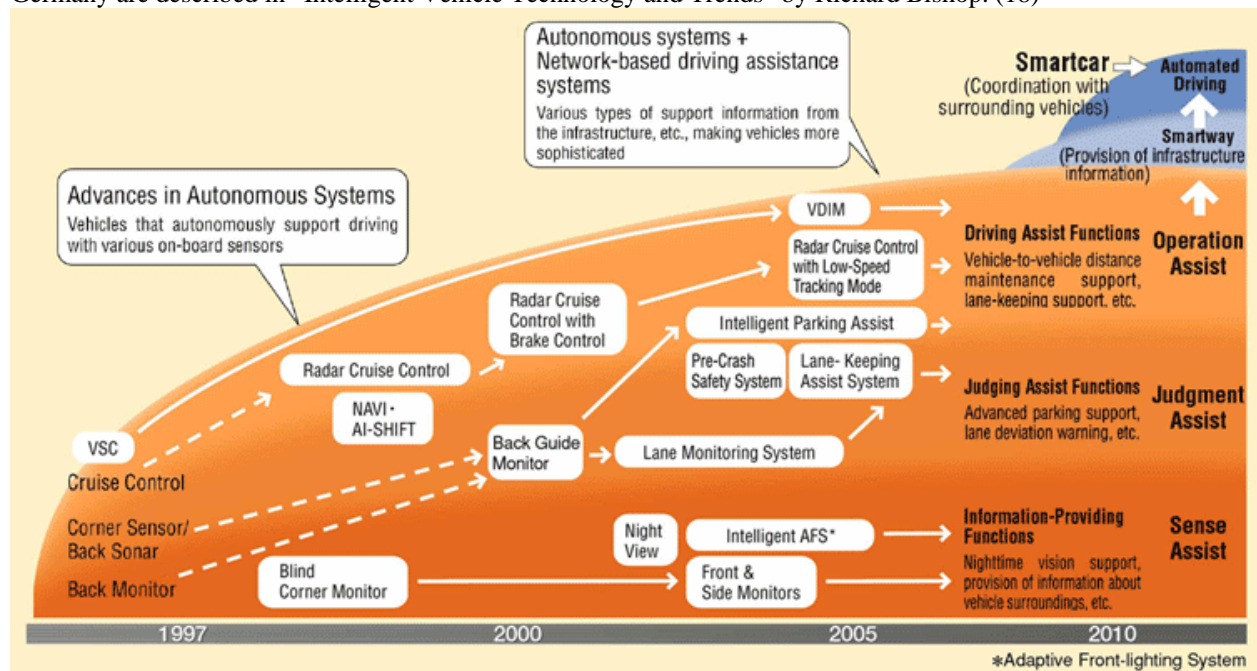


Figure 7: Toyota timeline for intelligent vehicle and infrastructure systems (Source Toyota)

The Center for Energy, Environment, and Transportation Innovation (CEETI) at Texas A&M University has developed a high level technology roadmap that functionally describes the dual mode transportation solution and what would be necessary technological developments to achieve this end. This report (32) is available on our website at http://www.ceeti.org/technology_roadmap.htm.

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Implementation

The research findings from this project will aid in transportation planning of future capacity additions and in the development of national standards for a new mode of transportation provided the claims of significant advancement over conventional modes can be substantiated. Assessment of capabilities will be summarized in a technical paper to be submitted to TRB to raise the debate to a national level and support federal level agencies in the development of necessary programs for development of national standards and programs to support technology innovation in this direction. In order to develop the results, the following steps will be taken:

1. State of the art review of current dual mode technology options
2. Virtual workshops will be used to communicate findings and enable collaboration in technology reviews while minimizing travel.
3. Comparative analysis of two alternative deployment options
4. Qualitative survey of stakeholders to provide contextual perspective beyond the technology challenges
5. Deliver research products

Work Plan

Texas A&M University has developed a high caliber team to execute this research including the principal researchers involved in the Center for Energy, Environment, and Transportation Innovation, professional staff from the Texas Transportation Institute, and other university researchers. The research plan will draw from both transportation professionals and the broader group of stakeholders with an interest in transportation issues.

** For each task with a ** beside the task title, a technical memorandum will be sent to TxDOT upon completion of the task.

Task 1: Conduct Literature Review **

The literature review will use a traditional approach of performing a search of known transportation databases to identify recent articles or papers of interest to this project. The following will be the focus of the literature review:

- Dual mode technologies
- Benchmark modal technologies/costs for adding capacity for transportation services
- Driver behavior and mode/route choice
- Behavior surrounding supply chain logistics choices for goods movement
- Value of travel time savings and reliability for both people and goods movement

Articles, technical papers, presentations and study reports will be listed and the documents linked to on the CEETI website where possible to provide a comprehensive reference library of dual mode information. Jim Longbottom will perform this task.

Task 2: Conduct Technology Developer Screening **

This task will involve telephone, web meeting, and face-to-face interviews with dual mode technology developers. Members of the research team will conduct face-to-face interviews if the interviews can occur within Texas. CEETI and TTI researchers have an extensive network of contacts at the national and international level relevant to dual mode technology and can leverage opportunities for face-to-face interviews without cost to TxDOT through trade association meetings and through the use of web hosted meetings using software available at the university.

There are currently close to 100 dual mode and PRT technology developers in various stages of development. Dual mode developers that will be contacted include but will not be limited to:

- Tri-Track (Austin, TX)
- Mega-Rail (Ft. Worth, TX)
- Ruf International (Denmark)
- Unimodal (Calif / Montana)
- Ford Motor Company - Prism
- Highway (Ohio)
- Toyota Motor Company
- Silvertip Design (UK)
- Skyweb Express (Taxi2000)
- Skycab (Sweden)
- Cybercab (EU / China)
- 2getthere (Netherlands)
- Vectus PRT
- CargoCap (Germany)
- Evacuated Tube Transport
- Owen Transit Group
- Personal Transportation System (Calif)

As a result of the interviews with dual mode technology developers, a presentation summarizing and comparing current technology status and features will be prepared. This presentation will provide the information necessary to identify the developers with sufficient potential to be considered in the later more detailed phases of the study. Jim Longbottom will have primary responsibility for this task.

Task 3 – Workshop to present developer survey and rank technology alternatives **

Results of Task 2 will be provided to the team members ahead of the meeting and presented in the workshop. Specific criteria for ranking the technologies will be developed in the workshop but are anticipated to include: (1) their ability to add capacity per dollar invested, (2) technology readiness, (3) adaptability to existing networks – urban, intercity, people movement, freight movement, (4) environmental impact – emissions, noise, visual (5) estimated construction time, (6) reliability and robustness of design, (7) speed, convenience, and space requirement / footprint, (8) safety features, (9) handicap compatibility, (10) potential for logistics problems, (11) method of coordinating vehicles in operation to manage traffic, (12) potential for public adoption, (13) energy efficiency and primary fuel flexibility, (14) ability to handle some specified minimum freight load and size/shape factor (15) vehicle aerodynamics, and (16) technology risk or dollars to mature technology.

Technology readiness will be evaluated using a scheme similar to that used by NASA as shown below in Table 1.

Table 1: Technology Readiness Levels

<i>Technology Readiness Levels</i>	<i>Stages of Adoption Industry Wide</i>
<i>Basic Technology Research:</i>	
Level 1: Basic principles observed and reported	Awareness: target industry is conscious of an innovation.
<i>Research to Prove Feasibility:</i>	
Level 2: Technology concept and/or application formulated	Awareness: target industry is conscious of an innovation.
Level 3: Analytical and experimental critical function and/or characteristic proof of concept	Awareness: target industry is conscious of an innovation.
<i>Technology Development:</i>	
Level 4: Component and/or breadboard validation in laboratory environment	Interest: industry intrigued with the innovation.
<i>Technology Demonstration:</i>	
Level 5: Component and/or breadboard validation in relevant controlled environment	Interest: industry intrigued with the innovation.
Level 6: System/subsystem model or prototype demonstration in a relevant controlled environment	Trial: industry experimenting with the innovation.
<i>System/Subsystem Development:</i>	
Level 7: System prototype demonstration in a commercial environment	Decision: industry adopters decide to continue, quit, or re-create the innovation.
<i>System Test and Operations:</i>	
Level 8: Actual system completed, qualified, and tested in a commercial environment	Adoption: continuation or integration of the innovation into the industry.
Level 9: Actual system adopted through use in the commercial environment	Adoption: continuation or integration of the innovation into the industry.

Based on technology ranking, three to five technology options will be selected for more detailed study. The full research team will be involved in the technology reviews and ranking process. Expertise of the team includes Gardoni – structural design, Burris – transportation economist, Morgan – freight operations, Parlos – sensors/electric motors, reliability, Swaroop – automated highway systems, Hawkins – traffic flow optimization, Goodin – transportation planning/policy/operational issues of managed lanes, Ford – system dynamics and constructability, Economides – energy issues, Ungemah –market-based transportation planning/outreach/marketing, and Longbottom – networked system innovation and energy issues.

Task 4: Gather Stakeholder Input **

Stakeholder concerns are an important part of eventual project development. The involvement of stakeholder groups early in the process will help to identify issues, concerns, and educational or outreach needs that must be addressed to ensure industry/public acceptance and eventual adoption of the technology.

The stakeholders will be identified early in the project to aid the project team with perspective beyond the academic/technical viewpoint using a focus group approach to capture their input. In addition to TxDOT, it is anticipated that the stakeholder group will have approximately 15 members from traditional transportation partners as well as untraditional partner sectors for TxDOT. The members may represent:

- metropolitan planning organizations (MPOs),
- toll authorities,
- regional mobility authorities (RMAs),

- transit authorities
- economic development council
- economists
- infrastructure construction contractors
- environmental groups
- railroad companies
- electric utilities
- retailer/wholesaler/supply chain professional
- primary fuel suppliers
- automotive manufacturers
- telecommunications providers
- infrastructure financiers
- electrical equipment manufacturers
- law enforcement
- public citizens – school teacher, pastor, business person

Approximately 2 months into the project an initial virtual meeting will be held with the stakeholder group to introduce them to virtual meeting format and dual mode technology. After Task 3, the stakeholder group will be presented with the Task 3 rankings and more detail on dual mode potential technologies in a second virtual meeting. The stakeholder group will be asked for input on (1) concerns to be addressed in subsequent tasks and (2) potential application environments for demonstration of the new technologies. A third virtual meeting will be held following the task 7 workshop. Stakeholders will be asked to comment on the selection of two technology options from the list of five alternatives presented. The stakeholder group input will be provided to the research team for their consideration in Task 8. A fourth and final virtual meeting of the stakeholders will be held upon completion of Task 8. Ginger Goodin, David Ungemah, Christine Economides and Jim Longbottom will be involved in this task at a minimum.

Task 5: Identify Near Term Initial Deployment Opportunities for Dual Mode Demonstration **

Specific areas with capacity or mobility challenges that are potentially suitable to a demonstration scale solution will be identified. These potential deployment opportunities may be related to goods movement, people movement or both.

Goods movement applications will be limited to high value freight which fits within a size/shape/weight/value limit applicable to dual mode type solutions – for example single pallets not exceeding 50in width x 50in depth x 60in height and 2100 pounds and values over \$1200 per ton.

The demonstration opportunities may use a single mode version of a dual mode system if compelling economics will enable this evolutionary path to justify new infrastructure network development and if the system is compatible with eventual dual mode use. Preferred opportunities will enable at least limited demonstration and testing of the full dual mode potential of the proposed systems in a setting realistic enough to build confidence in broader use of the demonstrated technology.

As a part of this task, three to five specific opportunities will be outlined with traffic volume, footprint limitations, right-of-way/easement cost, and current emissions status. This information will be used in task 6 by the technology developers to demonstrate the value and flexibility of their technologies. The research team will select the deployment opportunities to be put forward in task 6.

Task 6: Solicit solutions from dual mode developers for specific deployments **

The opportunities developed in task 5 will be offered to the technology developers as potential applications for dual mode solutions. Technology developers with the highest rankings from the screening process will be given 7 weeks to develop presentations on how their technology is best applied in at least two of these applications. Jim Longbottom will be responsible for administering this task.

Task 7: Conduct Workshop Review **

Task 6 will culminate in a presentation of the developer's solutions to a panel followed by a question and answer session using the a physical or virtual meeting format. Each developer will present their solutions without other competing developers present. The panel will judge the technologies presented using a format similar to the process used in Task 3 but will have more specifics. Based on these evaluations, the top two technology and deployment option combinations will be identified and selected for the alternatives analysis. The full research team will be involved in this workshop review process.

Task 8: Perform Alternatives Analysis on Two Guideway Infrastructure Construction Options **

To understand the infrastructure construction options more completely, an independent analysis will be completed by TAMU engineering and TTI personnel. This comparative analysis will provide detailed comments on the alternatives. It will review developer claims and analyze constructability, modularity, strength, footprint, safety issues, operational features, and maintenance requirements. In addition to the structural analysis, opportunities for private funding, potential legislative barriers, human factors, and environmental issues will also be considered in the alternatives analysis. The end result of this analysis will be a report providing more complete understanding of the strengths and weaknesses of the studied alternatives. Each of the research team members will evaluate the two alternatives from the perspective of their area of expertise and provide written comments.

Task 9: Develop Program to Monitor Future Dual Mode Technology Progress **

Dual mode infrastructure and vehicle technologies are an emerging area of dynamic development. As congestion, energy security, safety, and environmental issues continue pressing transportation professionals for new solutions, continued rapid development of these technologies is expected. Development of industry standards and system test facilities for the new architecture should be expected. A method of continued monitoring of dual mode transportation will be developed and proposed to maintain an evergreen view the maturation of these technologies. This will be a process mimicking tasks 1-4 to update the baseline work completed in this project Jim Longbottom will be responsible for this task.

Task 10: Develop research report & present to TxDOT

A research report will be developed to document the findings, methods, and application value of the completed research. A draft research report will be reviewed by the full project team to provide a final opportunity for input from the community of transportation professionals. This report will be made available both in hard copy and electronic forms and a companion presentation will be prepared for presentation to TxDOT. Jim Longbottom and Christine Economides will be responsible for this task.

Identification of Information Technology (IT) Deliverables to TxDOT

None

Assistance or Involvement by TxDOT

TxDOT will be asked to provide normal project oversight through the project director, project coordinator and project advisors. Access to TxDOT data on benchmark costs for conventional infrastructure construction and traffic flows in congestion corridors will be requested where not already available to TTI and should be provided on an "as available" basis.

Deliverables Table



**RTI
Deliverables Table
Project No. 0-5827**

Form DelTable
(2/2006)
(GSD-EPC)

Note: Deliverables on this Table are not considered received by TxDOT until submitted to RTI.

Products: Research Projects – Include a minimum of one product (e.g., specifications, guidelines, recommendations, design procedures, devices, or software resulting from the project) for implementation within TxDOT operations, delivered as either a stand-alone item, or within a report.

Implementation Projects – Minimum products will be as specified on the IPR.

No.	Stand-Alone Product Description	Due Date (normally due at or before project termination)	Responsible Party for Multi-Agency Agreement	Comments

Reports: Research Projects – Include a minimum of one Report, which documents completely the work performed, methods used, and results achieved, and one Project Summary Report of a maximum of four pages (approximately 1,200 to 1,800 words). If the report will contain one or more of the products listed above, then state under comments which product (by product number) will be included in the report.

Implementation Projects – Minimum reports will be as specified on the IPR.

No.	Report Description (Succinctly describe intended contents of each report.)	Due Date (if no date shown, defaults to 60 days after project termination)	Responsible Party for Multi-Agency Agreement	Comments
R1	Report: Comprehensive and detailed documentation of the research performed.	10/31/2007		
PSR	Summary of work performed, findings and conclusions.	10/31/2007		

Date Updated:



RTI Schedule of Research Activities

Form Schedule
(5/2004)
(GSD-EPC)

Original Schedule		Revision Date:											
Revised Schedule													
Work Completed		FY 2007											
	Est. % of total project budget	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug
Research Activity													
Task 1. Conduct Literature Review	7%												
Task 2. Conduct Technology Developer Screening	11%		SM1										
Task 3. Workshop Review and Ranking of DM Technology Alternatives	11%												
Task 4. Gather Stakeholder Input	13%					SM2							
Task 5. Identify Near Term Deployment Opportunities	8%												
Task 6. Solicit Solutions from DM Developers	7%												
Task 7. Conduct Workshop Review	11%								SM3				
Task 8. Alternatives Analysis of Two Options	11%											SM4	
Task 9. Develop Program to Monitor Future DM Technology	10%												
Task 10. Develop Research Report	11%												
Total	100%												

SM = Stakeholder group meetings