FUTURE DEVELOPMENT OF TRANSPORTATION CORRIDORS
ALTERNATIVE DESIGN FOR I-45, HOUSTON, TEXAS

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It is amazing to realize that, excluding the United States; only 28 countries have a GDP (gross domestic product) larger than Houston metropolitan area's GAP (gross area product). Even though Houstonians live in one of the wealthiest cities in the world, Houston is unable to develop transportation infrastructure that matches or outperforms the engineering and long-term vision developing in many other American, European, Asian, and South American cities. Houston's "can do" spirit must be extended to its infrastructure. Houston must not shy away from thinking in new dimensions that will develop an environmentally friendly metropolitan area with an unparalleled quality of life. Engineering alternatives for reconstructing transportation corridors such as the proposed tunneling of I-45 offer a desirable and sound long-term vision for the region.

As Mr. Gary Trietsch, TxDOT Houston District Director, indicated during a meeting - if the tunnel alternative for I-45 does not have major design flaws and if it is what Houston wants, TxDOT can do it but TxDOT cannot do it alone.

Hopefully this paper provides some incentive to Houstonians and others to think out of the box and explore the 21st Century city Houston could easily and cooperatively become.

Gonzalo E. Camacho, P.E.

BACKGROUND

The construction of I-45 north of downtown Houston began in the 1950s and it opened to the public in the early 1960s. Its first cross section consisted of: eight lanes, from downtown to Loop 610; six lanes, from Loop 610 to FM-1960; and continued northbound with four lanes. As usually happens when a roadway is constructed within an urban area, the construction of I-45 required the demolition of residential and park areas.

As Houston grew so did traffic and the demand for additional highway capacity. Twenty years later, the 1980s marked the beginning of the reconstruction and widening of I-45, which ended in the mid 1990s. By then I-45 from downtown Houston to Beltway 8 had eight lanes plus one HOV lane, from Beltway 8 to FM 1960 it had ten lanes plus one HOV lane, and from FM 1960 to SH-242 it had 8 lanes.

In 2005 the Metropolitan Transit Authority of Harris County (METRO), Texas Department of Transportation (TxDOT) and Houston-Galveston Area Council (H-GAC) conducted the North-Hardy Corridor Planning Studies composed of two components; the Transit

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Component and the Highway Component. These studies include a corridor that extends generally along the I-45 and Hardy Tollroad for a total of 30 miles, from I-10 north of Downtown Houston to SH-242. See **Figure 1.1, Area map of I-45 with limits of proposed tunnel alternative**, from Beltway 8 in the north to US-59.

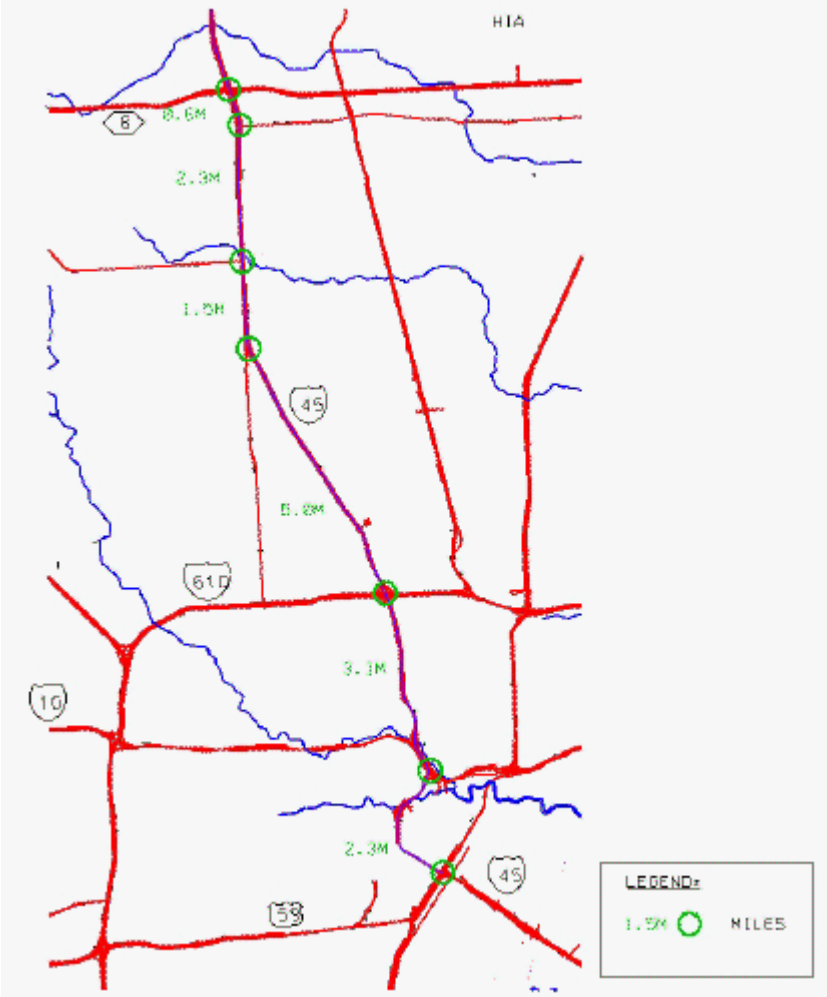

Figure 1.1 – Area map of I-45 limits of proposed tunnel alternative

"Work was progressing on the Gulf Freeway (I-45 from south of downtown to Galveston) in 1951 at a cost of $1,500,000 a mile, and it was being hailed as the outstanding highway engineering development since World War II as well as a model for the nation. Construction had been started in 1946, and about six miles had been completed, with four additional miles under construction. When the first section was opened, it was estimated that the freeway would reach a capacity of 70,000 vehicles by 1957, but by early in 1951, the total use had already surpassed that estimate." (Source: houstonhistory.com)

NORTH-HARDY CORRIDOR PLANNING STUDY – TRANSIT COMPONENT

The Planning Studies Transit Component developed three alternatives. The first alternative follows the I-45 corridor with a spur connecting to the Intercontinental Airport. The second alternative follows the Hardy railroad corridor connecting to I-45 at The Woodlands and with an east west spur connecting to Greenspoint and Intercontinental Airport. The third alternative follows city arterials located east of I-45 from downtown to Beltway 8 continuing along the I-45 corridor north of Beltway 8. A spur connects the third alternative to the Intercontinental Airport. **Table 1.1, Alignment Characteristics for Transit Alternatives**, shows the various alignment characteristics used in determining a Locally Preferred Investment Strategy or LPIS. The LPIS identified by the study is based on the third alternative starting at the University of Houston Downtown.

Table 1.1 – Alignment Characteristics for Transit Alternatives
Source: Exhibit ES.13: Summary of Alignment Characteristics (Draft Report)

	First Alternative	Second Alternative	Third Alternative
Length of Alignment	40.63 miles	42.45 miles	24.08 miles (44.59 miles)*
Number of Stations	26	24	21 (24)*
Length of Aerial Sections	17.96 miles	10.24 miles	11.98 miles
Estimated ROW Requirements	185.7 acres	219.2 acres	86.7 acres (TBD)*
Capital Cost of Index	1.83/1.37	1.47/1.00	1/30/1.01*
Estimated Average Speed	31 mph	33 mph	25 mph (34 mph)*
Demand Potential Index	85	49	100
Estimated Elevated Segment**	18 miles	10 miles	12 miles
Cost Estimates for LRT in millions (per mile)**	$2,141 ($50.08)	$1,813 ($42.56)	$1,474 ($61.43)
Cost Estimates for BRT in millions (per mile)**	$1,606 ($39.82)	$1,238 ($29.07)	$1,111 ($46.30)

*With 2-way HOV Facility. **Information from Executive Report added to the Table 1.2 for clarification.

Per the Final Environmental Impact Statement (Transit Component) the Locally Preferred Alternative or LPA is 5.49 miles long extending from the existing light rail station at UH-Downtown to Northline Mall. The alignment of this alternative follows the right-of-way of existing arterial streets. The cost estimates for the LPA range from $237.7 million to $353.1 million, which is equivalent to $41.8 million to $65.5 million per mile (Source: Table ES-1 of Final Environmental Impact Statement).

NORTH-HARDY CORRIDOR PLANNING STUDY – HIGHWAY COMPONENT

Per the Planning Studies, during peak hours I-45, from I-10 to Beltway 8, has an existing level of service (LOS) "E" or a peak period speed between 36 and 31 MPH; see **Table 1.2, I-45 Existing Traffic Volumes**.

According to the North-Hardy Corridor Planning Studies, the transportation goals and objectives were to seek transportation options that will:

- Maximize the use of transit in the Corridor;
- Maximize the use of the Hardy Toll Road by commuter and truck traffic; and
- Improve freeway operating conditions on IH-45 with no or minimal need for additional right of way.

The Planning Studies also lists specific corridor problems that are to be compounded by expected population growth. These are:

- The Single reversible HOV lane may not be adequate to serve inbound and outbound suburban markets;
- Freeway pavement, about 7 miles north of I-10, needs rehabilitation and to be brought up to current design standards;
- IH-45 by N. Main Street floods during heavy rainfall;
- Lack of local roadway network forces local traffic onto congested I-45;
- Lack of alternatives for auto trips to suburban destinations like Intercontinental Airport, Greenspoint area and The Woodlands; and
- Transit service is heavily focused on work hours demand for Downtown Houston.

The North-Hardy Corridor Highway Alternative Analysis developed a short list of alternatives that included a no-build and six build alternatives. These alternatives assumed that high-capacity transit in the North-Hardy Corridor and improvements to the Hardy Toll Road were in place, namely:

- North Corridor LRT from UH-Downtown to Intercontinental Airport;
- Two-way express bus service in I-45;
- First phase of LRT from UH Downtown to Northline Mall;
- Hardy Toll Road Extension from Loop 610 to Downtown Houston; and
- Hardy Toll Road is widened to 6 lanes from Beltway 8 to I-45 in Montgomery County.

Table 1.2 - I-45 Existing Traffic Volumes
Source: Exhibit ES.3: IH-45 Traffic Volumes Planning Studies (Highway Component)

Section	2000 Daily Traffic Volume	Volume to Capacity Ration (V/C)	Level of Service (LOS)	Peak Period Speed
IH-10 to IH-610	224,000	1.11	E	36 MPH
IH-610 to Beltway 8	262,000	1.30	E	31 MPH
Beltway 8 to FM 1960	234,000	0.93	D	40 MPH
FM 1960 to SH 242	158,000	0.88	D	42 MPH
Reversible HOV Lane	7,322	0.43	B	55+ MPH

Because of public concerns regarding widening of I-45, build alternatives were limited to no more than 12 lanes. Six build alternatives were considered.

Build Alternative 1

- From I-10 to FM 1960: 10 general purpose lanes, 2 reversible special purpose lanes

- From FM 1960 to SH-242: 8 general purpose lanes

Build Alternative 2

- From I-10 to Beltway 8: 8 general purpose lanes, 4 separated managed lanes
- From Beltway 8 to FM 1960: 10 general purpose lanes, 2 HOV lanes
- From FM 1960 to SH-242: 8 general purpose lanes

Build Alternative 3

- From I-10 to FM 1960: 10 general purpose lanes, 2 barrier separated HOV lanes
- From FM 1960 to SH 242: 8 general purpose lanes, 2 barrier separated HOV lanes

Build Alternative 4

- From I-10 to FM 1960: 10 general purpose lanes, 2 non-barrier separated HOV lanes
- From FM 1960 to SH 242: 8 general purpose lanes, 2 non-barrier separated HOV lanes

Build Alternative 5

- From I-10 to Beltway 8: 8 general purpose lanes, 2 barrier separated HOV lanes
- From Beltway 8 to FM 1960: 10 general purpose lanes, 2 barrier separated HOV lanes
- From FM 1960 to SH 242: 8 general purpose lanes, 2 barrier separated HOV lanes

Build Alternative 6

- From I-10 to Beltway 8: 8 general purpose lanes, 2 non-barrier separated HOV lanes
- From Beltway 8 to FM 1960: 10 general purpose lanes, 2 non-barrier separated HOV lanes
- From FM 1960 to SH 242: 8 general purpose lanes, 2 non-barrier separated HOV lanes

The six build alternatives and "no build" alternative were evaluated and graded for environmental impacts. This resulted in a grade of B given to the "no build" alternative and C for the other six alternatives. The study also shows that the "no build" alternative is the best option in terms of environmental and community impacts.

The analyzed alternatives were also evaluated based on a travel demand model comparing existing (2003) conditions with "no build" and six build (2025) conditions. The results are shown in **Table 1.3, Travel Demand Modeling Results for Peak Conditions**. These indicate that peak speeds on the general purpose lanes for the 2003 and 2005 "no build" conditions decrease between 0 and 3 MPH. Similarly between the 2025 "no build" and build alternatives the peak speed improves from -1 to 7 MPH. Although the build alternatives are shown to have some operational improvements, the overall level of service (LOS) between 2003 and 2025 remains at LOS "E." A level of service "E" is considered to represent a state of unstable traffic flow based on an "A" through "F" rating where "A" represents free flow and "F" forced or breakdown flow. Generally, LOS of "E" and "F" are not acceptable for traffic operations.

Per the study, and based on 2004 per mile costs, the cost estimates for the six alternatives range from $2.095 and $2.209 billion. The study does indicate, "These conceptual costs are preliminary, planning-level estimates developed to allow comparisons between the

alternatives and not to serve as final engineered cost for any of the alternatives." It also indicates "The majority of each estimate can be attributed to the approximately 11.5 miles between IH 10 and Beltway 8." Between Beltway 8 and FM 1960 it is anticipated that construction will only consist of reconfiguring existing available lanes into two HOV/HOT lanes, and between FM 1960 and SH 242 restriping of existing pavement to include two HOV/HOT lanes.

Table 1.3 – Travel Demand Modeling Results for Peak Conditions
Source: Exhibit ES.8 of North-Hardy Corridor, Highway Alternative Analysis

	Exist 2003 v/c - mph	**No-build 2025 v/c - mph**	**Alt. 1 2025 v/c - mph**	**Alt. 2 2025 v/c - mph**	**Alt. 3 2025 v/c - mph**	**Alt. 4 2025 v/c - mph**	**Alt. 5 2025 v/c - mph**	**Alt. 6 2025 v/c - mph**
I-10 to 610	1.18 – 34	1.24 – 32	1.03 – 38	1.15 – 35	0.98 – 39	0.98 – 39	1.24 – 32	1.24 – 32
610 to Belt. 8	1.46 – 27	1.45 – 27	1.20 – 33	1.36 – 30	1.16 – 34	1.16 – 34	1.45 – 27	1.45 – 27
Belt. 8 to FM 1960	1.10 – 36	1.10 – 33	1.27 – 32	1.20 – 33	1.22 – 33	1.22 – 33	1.10 – 33	1.10 – 33
FM 1960 to SH 242	1.13 – 35	1.13 – 33	1.25 – 32	1.23 – 33	1.23 – 33	1.23 – 33	1.13 – 33	1.13 – 33
HOV	0.48 – 55+	1.03 – 38	0.59 – 55+	0.74 - 55	0.50 – 55+	0.50 – 55+	0.50 – 55+	0.50 – 55+

Of the various alternatives considered, Alternative 2 is the recommended highway alternative. **Figure 1.2, North-Hardy Planning Studies Recommended Alternative 2,** shows a proposed cross section of I-45 at North Main Street, which is currently depressed.

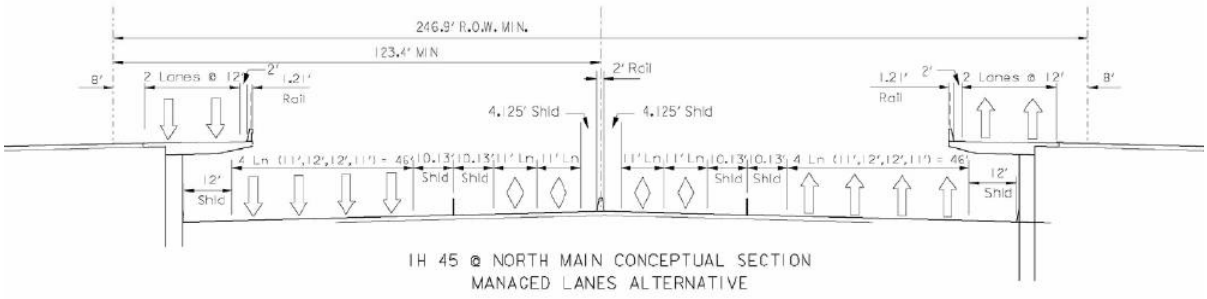

Figure 1.2 – North-Hardy Planning Studies Recommended Alternative 2
Source: North-Hardy Planning Studies

It consists of the following:

- From I-10 to Beltway 8, 8 general purpose lanes and 4 managed lanes
- From Beltway 8 to FM 1960, 10 general purpose lanes and 2 HOV lanes
- From FM 1960 to SH 242, 8 general purpose lanes and 2 HOV lanes

The study also indicates that due to "significant concern from Inner-Corridor residents" the recommended alternative was modified as follows:

- From I-10 to Beltway 8, add 4 managed lanes to the I-45/Hardy Toll Road corridor
- From Beltway 8 to FM 1960, add 2 HOV/HOT lanes to I-45
- From I-10 to FM 1960, remove existing one-way reversible HOV lane

NORTH-HARDY CORRIDOR PLANNING STUDY – SUMMARY

The studies conducted for the North-Hardy corridor by H-GAC, TxDOT, and METRO consisted of two components, a transit study and a highway study. The transit study identified a transit corridor with an initial implementation phase of about 5.4 miles. The proposed transit improvements are to extend the existing downtown light rail system northbound through city arterials located one quarter of a mile or more east of I-45. The highway study identified the reconstruction of I-45 from I-10 to Beltway 8 from its current configuration to 8 general-purpose lanes and the addition of 4 managed lanes that could be located either within the I-45 or Hardy Toll Road corridors. The highway study also recommends reconfiguring the existing I-45 between Beltway 8 and FM 1960 to total of 10 general-purpose lanes and 2 HOV lanes and between FM 1960 and SH 242 to total of 8 general-purpose lanes and 2 HOV lanes. I-45 north of Beltway 8 will not require reconstruction or addition of highway lanes.

The estimated costs for the first phase of the preferred transit improvements range from $237.7 million to $353.1 million, and for the highway Alternative 2 cost is $2.113 billion. Most of these costs are attributed to the reconstruction of I-45 from I-10 to Beltway 8.

PUBLIC PARTICIPATION IN DESIGN ALTERNATIVES

During the fall of 2004 City Council Member Adrian Garcia, who represents stakeholders along the I-45 corridor, called for a public meeting. At this public meeting the Houston Downtown Management District and Hines Corporation presented two independent design alternatives for I-45.

Hines Alternative - Hines proposed to relocate I-45 from north of I-10 to south of Buffalo Bayou (west of Downtown Houston). The proposed alignment would follow the existing north-south Houston Avenue that has about 100 feet of right-of-way and traverses a residential/historic neighborhood. It called for I-45 to be depressed.

The proposed Hines plan also included the relocation of I-10 away from the downtown area to the Near Northside; therefore, vacating existing highway right-of-way that was proposed to be converted into a new urban lake.

The public did not accept and was unreceptive to the Hines alternative.

Downtown Management District Alternative - The Downtown Management District proposed to relocate the I-45 alignment away from the downtown area. This alternative included the depression and capping of the highway segment closest to the downtown area thus developing a green space over the highway.

The highway component of the North-Hardy Planning Studies included the I-45 corridor north of I-10 thus both the Hines and Downtown Management District alternatives were basically outside the studied corridor. However, it was clear that both Hines and Downtown

Management District were interested in developing an I-45 corridor in the downtown area that is more aesthetically pleasing while reducing environmental impacts.

Consequently, Gonzalo Camacho, P.E., who had participated in the public meeting and was familiar with the corridor studies, formulated the question of whether there was an alternative design for I-45 (other than the ones proposed by TxDOT) that could provide better aesthetics and reduce environmental impacts.

DEVELOPING DESIGN ALTERNATIVES FOR I-45

From past history, it is common for highways to be expanded and reconstructed every 20 years. This is the case of I-45 which was first constructed in the 1960s, reconstructed in the 1980s, and is currently in the planning process for a third reconstruction. Although reconstruction and adding lanes to I-45 is the preferred alternative, it has some important elements that cannot be ignored:

- Urban growth generates vehicular traffic causing highways to reach capacity. Adding lanes provides temporary capacity but it is not a long-term solution. This is demonstrated by the North-Hardy Planning Study which shows that by 2025 under any of the proposed build alternatives the maximum LOS is "E" or less than 40 MPH for peak traffic conditions;
- Expansion of highways generally requires acquisition of right-of-way. Within urban areas, right-of-way costs are high thus favoring a more compact design or limiting right-of-way;
- Evaluation of highway expansion does not take into consideration the long-term losses of tax revenue due to right-of-way acquisitions, nor losses incurred by businesses and drivers caused by highway construction;
- Traditional highway construction can take many years. Current reconstruction of I-10 in Houston is expected to take 8 years. This is a cyclical process that virtually keeps highways under constant construction reducing their efficiency and safety;
- Cost of highway projects are increasing to billions of dollars and take many years to design and build. These mega projects must be evaluated based on life-cycle costs to have a clear value of the project's present and future costs;
- Environmental studies demonstrate the negative impacts that highways have on the environment, in particular human health. Air, noise and visual pollution are critical factors for quality of life and attracting businesses to urban areas;
- Under current conditions, the cost of operating, maintaining and expanding highways is unsustainable. It is necessary to identify new sources of funding and transportation alternatives;
- Air pollution levels in the Houston region are classified as "moderate" with about 50% of air pollution generated by mobile sources such as vehicles. Improving travel speeds on highways is assumed to reduce some pollutants, but roadway construction and congestion also increase pollution. In fact, the Texas Commission on Environmental Quality (TCEQ) has indicated that the Houston region will not be able to achieve the federally mandated air quality standards;

- I-45 is designated as an emergency evacuation route. Any reduction of capacity or impairment of operations, as occurs during years of construction, is likely to cause unexpected delays and congestion. Evacuating the threatened region under such conditions has potentially catastrophic consequences; and
- The Houston region is prone to flooding. Current segments of I-45 north of I-10 flood with heavy rains.

In formulating alternative designs for the I-45 corridor, many aspects have to be evaluated. The most common alternative is adding highway lanes to the existing pavement in a "pancake" or flat shape. Depressed and elevated or "double decker" are the other design alternatives used in Texas. Considering the limited amount of available right-of-way, the cost of acquiring right-of-way could easily add more than 25% to the cost of the highway. A segment of I-45 at North Main Street is already depressed. Although depressed highways reduce noise and visual pollution, in Houston these are not favored due to flooding concerns and design constraints. Elevating or double decking I-45 may not require additional right-of-way, but it may present significant vertical design challenges and accessibility. Additionally, elevated highways increase noise and visual pollution and extend the area affected by air pollution.

Whether the alternative for expansion is the traditional "pancake" shape, depressed or "double decker," the fact is that all three alternatives impose an immense amount of traffic delay and increase in cost due to construction phasing. This factor is of significant concern in preparation for emergency evacuations since I-45 is a designated emergency evacuation route.

Roadway tunnels, the objective of this paper, are an alternative not evaluated by the North-Hardy Planning Studies. Although roadway tunnels have been used for over 200 years, construction complexity has limited their implementation. However, in recent years, tunnel construction technology has advanced tremendously thus making roadway tunnels an option used in many cities.

ROADWAY TUNNELS CAN BE CONSTRUCTED IN HOUSTON

Why shouldn't TxDOT consider roadway tunnels as a valid alternative for reconstructing and expanding highways? The most obvious answer is because there are very few tunnel experts in the US and most of them are in the northeast. Therefore, when the North-Hardy Planning Studies was conducted roadway tunnels were not considered as a design alternative. In fact, there are few tunnel engineers in the world who are experts in new tunneling technologies. However, Dr. Gerhard Sauer from the Dr. Sauer Group, an international expert in tunneling with worldwide projects, was consulted regarding the use of roadway tunnels as an alternative for reconstructing I-45.

During one of his visits to Houston, Dr. Sauer met with Michael Hasen, P.E. from HVJ Associates, Inc. to discuss soil conditions. Mr. Hasen is an expert in geotechnical engineering and very familiar with the geology of the Houston region. The discussion between these two experts resulted in the conclusion that soil conditions in Houston do not present any challenges that would exclude tunnels as a design alternative. Dr. Sauer indicated that in many aspects Houston soils are favorable to tunneling with tunnel-boring machines.

Considering the North-Hardy Planning Study recommendation of Alternative 2 with a total of 12 highway lanes, Dr. Sauer recommended a roadway tunnel system of two 50-foot diameter tunnels, one tunnel for southbound traffic and the other for northbound traffic. Each tunnel would provide six highway lanes in a double-stacked three-lane configuration. Also the proposed two 50-foot diameter tunnels can be constructed under the existing I-45 and within the existing right-of-way; therefore eliminating the need for additional right-of-way acquisition and dramatically reducing the need for disrupting existing traffic since most of the tunnel work is done below ground and independent of the existing highway lanes.

Figure 1.3, I-45 Alternative Design, Roadway Tunnel Cross Section, and **Appendix B** show various alternatives developed by Dr. Sauer during his analysis of the I-45 corridor.

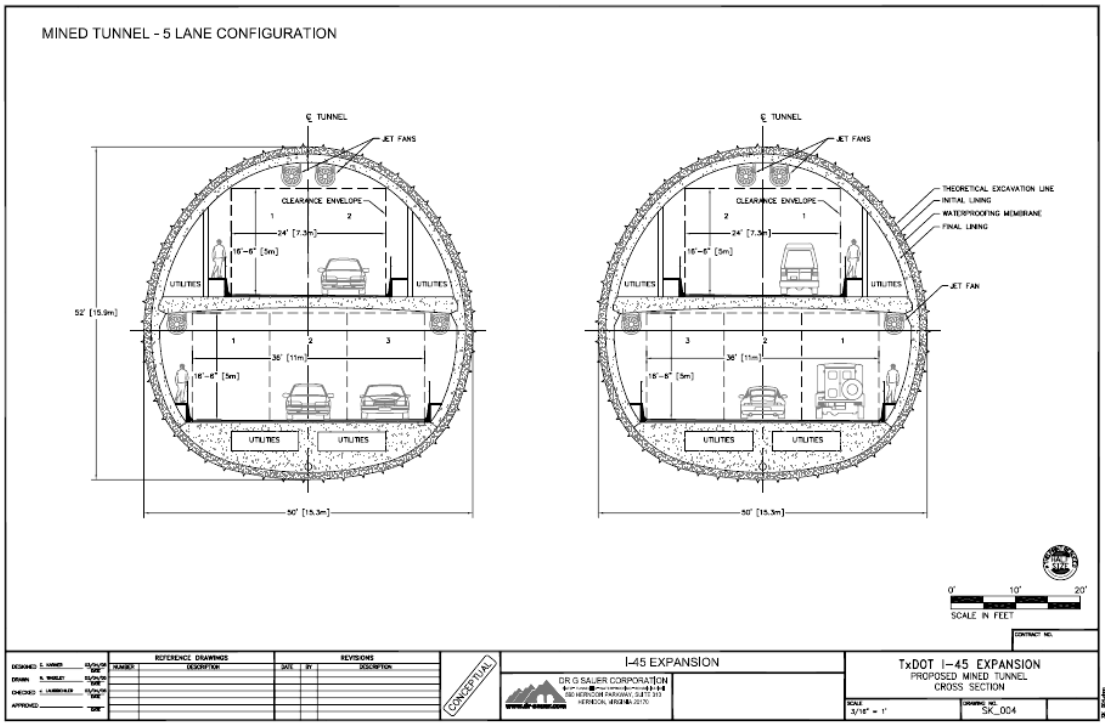

Figure 1.3 – I-45 Alternative Design, Roadway Tunnel Cross Section

Source: Dr. G Sauer Corporation

Dr. Sauer investigated several tunnel configuration alternatives for the I-45 corridor. ***Figure 1.2, I-45 Alternative Design, Roadway Tunnel Cross Section*** *and those shown in* ***Appendix B*** *are some of them. Dr. Sauer final proposed design for I-45, of a 50-foot diameter 6-lane tunnel, is not new. There are two similar50-foot diameter tunnels under construction. These are located in Shanghai, China and Madrid, Spain.*

Another unique characteristic of tunneling is that work can be conducted with minimal interruptions because it is mostly isolated from weather and traffic conditions. Construction of tunnels can be expedited by increasing the number of tunnel boring machines used for

construction. Compared to traditional highway construction, tunnel construction takes a fraction of the time but can vary depending on soil conditions.

PIERCE ELEVATED

The North-Hardy Planning Studies does not address reconstruction and expansion of I-45 south of I-10. I-45 as it crosses downtown Houston becomes the Pierce Elevated. The Pierce Elevated is an elevated highway structure with four lanes in each direction. As it continues south the Pierce Elevated connects to I-45, US-59 and SH 288. Because there are several high-rise buildings adjacent to the Pierce Elevated, it is unlikely that it can be expanded horizontally. The only options for expanding the Pierce Elevated are adding a second level or tunneling. See **Photo 1.1, Pierce Elevated in downtown Houston**.

Photo 1.1 – Photos of Pierce Elevated in downtown Houston

Evaluation of the I-45 corridor determined that the proposed twin tunnel system should extend from Beltway 8 to I-10 and extend south of I-10 to US-59. Access to the twin tunnels would be limited, but allow ramp connections to Beltway 8, Loop 610, I-10, Downtown Houston and US-59. This alternative doubles the I-45 corridor capacity including the Pierce Elevated segment and provides express route options to access downtown, to bypass the CBD, or connect to other major highways.

The proposed twin tunnel alternative is not designed for local access, but local traffic may continue to use the existing I-45 surface lanes. By maintaining the existing at-grade I-45 and adding the twin tunnels, the capacity of the I-45 corridor is virtually doubled.

FLOODING AND STORM WATER DETENTION

Since Houston was built in a bayou watershed environment, a significant concern in the Houston region is the propensity for the area, including roadways, to flood. Although highways are designed for some rain frequencies, highways are not designed for extreme events; however, some parts of Houston highways often flood during heavy storms.

Two basic design strategies are used to prevent flooding of roadway tunnels. First, entrance and exit approaches are elevated well above the expected flood elevations. This prevents

surface water from entering the tunnels. Second, tunnels can be fitted with storm gates or portals used to seal them from any storm surges and floodwaters. Standard drainage and pumping systems are also installed outside and inside the tunnels to collect storm water and dispose of it.

Unlike at-grade or depressed highways that are exposed to flooding along their entire length, only the entrance and exit approaches of tunnels are exposed to storm waters or flooding. By limiting the areas of exposure, elevating the entry/exit approaches, and adding drainage strategies, tunnels are easily designed not to flood even during extreme events.

Another obvious benefit of tunnels is the elimination of required storm water detention. Because highway expansion increases impermeable surface areas the addition of storm water drainage, storm water detention facilities, and dewatering pumping systems are required. This adds to the cost of construction and to the long-term operation and maintenance cost.

In the 1950s two roadway tunnels were constructed under the Houston Ship Channel. One of them, the Washburn Tunnel is still in use today and has never flooded.

The characteristic of a roadway corridor designed not to flood and protected from weather conditions is a significant benefit for the Houston region that is susceptible to flooding and hurricanes. This is particularly sensitive for the I-45 corridor since it is a necessary emergency evacuation route.

HIGHWAY DESIGN - STORM WATER

When a highway is expanded it is necessary to provide storm water detention due to the increase of impermeable surfaces. The requirement for storm water detention is very prevalent in Houston because the climate is humid subtropical with frequent storms and often, during heavy rains, segments of highway are water logged. This is the case of the depressed segment of I-45 by North Main Street where storm water collects preventing traffic flow.

Future reconstruction of I-45, in particular if surface lanes are added, must take storm water and flooding into consideration. The simple alternative to drain highways into existing storm water channels may not be an option. Also the development of detention facilities could require the purchase of additional right-of-way and/or investment in extensive storm water drainage systems. In either case, mitigating storm water impacts will increase the cost of highway construction.

The option to tunnel I-45 practically eliminates the need to provide storm water detention or drainage systems since the increase of impermeable surface area is minimal. In addition, the long-term alternative to redevelop the existing I-45 into a parkway has the potential to further reduce impermeable surfaces.

Storms are one of the most common weather conditions that impair traffic flow and safety in Houston. The ability of roadway tunnels to provide drivers a roadway environment that is dry and protected from weather conditions greatly improves traffic flow and safety both during day-to-day operations and during emergency events like hurricane evacuations.

TUNNEL SAFETY

Safety is of significant consideration in the design of tunnels. At the 2005 Houston Transportation and Mobility Conference various tunnel safety experts gave presentations on the many tunnel safety elements that have contributed to the successful construction, operation and safety of roadway tunnels across the world.

Paul Miclea and Kirk McDaniel, tunnel ventilation experts from EarthTech, indicated that design of tunnels with safety in mind involves: good ventilation systems for all conditions, fire detection and alarm systems, a suitable evacuation plans and alternative options, effective fire suppression capabilities, continuous training and evacuation exercises, consideration of the "Worst-case Scenario", recognize that fire departments have limited capabilities, continually educate people how to behave in tunnels (particularly in emergencies, since people do not always behave as engineers would like them to). Also the design of tunnels is regulated by agencies such as: US DOT, Volpe National Transportation Systems Center, US Department of Energy, National Fire Protection Association, American Public Transportation Association, National Research Council Transportation Research Board, and the National Institute of Standards and Technology.

Rudolph Koller from Hopferwieser Consult ZT GmbH indicated that safety aspects in roadway tunnels include: parking bays, cross passages for pedestrians and vehicles, tunnel ventilation, fire fighting equipment, redundant power supply, tunnel and emergency lighting, emergency telephone system, traffic control, CCTV system, fire protection system, tunnel radio system, public address system, air quality measurements, data transmission system, and tunnel operations.

Because roadway tunnels are built with cross passages for vehicles and have limited access, roadway tunnels are better designed for emergency evacuation and for implementing emergency counter or contra flow lanes.

The roadway tunnels also provide a safer driving environment because tunnels are protected from weather conditions such as storms and intense solar heat. Houston is characterized by storms and uncomfortable solar heat. Both of these weather conditions affect drivers, pavement characteristics, visibility and overall traffic safety of highways. These types of weather conditions do not affect roadway tunnels. In fact, tunnels offer drivers an environment that is dry, with little temperature fluctuation, and visually undisturbed.

ENVIRONMENTAL IMPACTS AND PROXIMITY OF SCHOOLS TO I-45

The quality of life in urban areas is significantly affected by the expansion of highways and subsequent increased traffic congestion. In fact, Andres Duany, an international urban planning expert, has stated that cities are competing world wide for economic development based on their quality of life.

In terms of the I-45 corridor and its expansion, quality of life is characterized by the negative impacts I-45 has on: air quality, noise levels, visual aesthetics, and both neighborhoods and businesses.

There are many examples of neighborhoods in urban areas being divided by highway development. The construction of I-45 is not an exception. When I-45 was first constructed it required the demolition of historic neighborhoods like German Town and the demolition of green spaces such as Woodland Park. The periodic expansion of I-45 and other highways has continued the trend of removing green spaces, residential areas and businesses in favor of

wider highways. The long-term effect of this trend has not been considered in the planning of highway expansion.

Although one of the objectives for expanding I-45 is to limit right-of-way purchases the environmental impacts will be negative and detrimental to the quality of life along the corridor. For example, between downtown Houston and Beltway 8 there are over a dozen schools within a half-mile of I-45, many of them are elementary schools. There are a number of studies that demonstrate the negative impacts of highways on human health. Based on these studies the American Lung Association indicates the following:

- "Air pollution may limit the capacity of the lungs in 10 to 18 years olds who live within about one third of a mile of a freeway. Such changes to lung function can reduce the capacity to breathe for the rest of their lives and increase their risk of serious lung diseases."
- "Children who live near freeways have a higher risk of being diagnosed with asthma."
- "Studies have found increased risk of premature death to those who live near a major highway or an urban road."

Since the North-Hardy Planning Studies only consider horizontal expansion of I-45 it is understandable that in the area of environmental and community impacts the evaluation of the six alternatives receive the same ranking of "C" while the no-build alternative is evaluated as having a rank of "B." However, if a roadway tunnel is evaluated against the no-build and six build alternatives it is obvious that the tunnel alternative would rank even higher than the no-build alternative for the following reasons:

- During underground construction of the tunnels impact on existing traffic conditions is limited and most pollution generating construction traffic is eliminated;
- Roadway tunnels must be designed with air circulation systems due to the concentration of toxic exhaust coming from vehicles. It is a standard practice in most roadway tunnels having air circulation systems to include air filtration. Air filtration systems commonly used in tunnels include electro static precipitation, which has the ability to remove over 90 percent of toxic particulate matter;
- Because tunnels are underground they eliminate noise and visual pollution;
- By eliminating the need to expand the existing I-45, the tunnel alternative will further reduce negative environmental impacts and will decrease the volume of traffic using the existing I-45 surface lanes; and
- Reducing traffic demand on the existing I-45 allows for redevelopment of the at-grade I-45 corridor into a more parkway-like transportation corridor with the potential to develop green areas and reduce storm water impacts.

LOCAL ACCESS VS. THROUGH TRIPS

It should be noted that because of the deficient roadway grid in Houston many local vehicular trips access highways like I-45. This reduces highway capacity that should be used for through or longer trips. While through vehicle trips require few lane changes and maintain a relatively constant speed, local trips tend to weave in and out of traffic at various rates of speed. Many vehicle crashes and "phantom bottle necks" are attributed to changing

lanes and speed variations. Reducing traffic weaving and variable speeds improve safety and traffic flow efficiency.

Although TxDOT's current highway standards permit the elimination of traffic weave for on/of ramps using grade separation, Houston highways continue to provide significant access to local trips. The proposed tunneling of I-45 provides a more efficient and safer alternative to the proposed six build alternatives since it would be used for long or through vehicle trips while the existing at-grade I-45 could still be used for both local and through vehicle trips.

COST OF ROADWAY TUNNELS

Many roadway planners, engineers and public officials have a "knee jerk" reaction assuming that tunnels are expensive propositions. Many of them make this assumption because of improperly executed projects that include tunnels, or reports conducted by individuals who are not familiar with the latest tunnel engineering design and construction methods.

Boston's Big Dig - The most quoted project used to demonstrate that roadway tunnels are prohibitively expensive is Boston's Big Dig. It should be noted that government agencies have and are continuing to conduct investigations on the cost overruns that increased the cost of the project by about 500% of its original estimate. Although analysis of cost overruns of Boston's Big Dig is beyond this paper, the following facts about it must be considered:

- It "Is the largest and most complex urban infrastructure project ever undertaken;"
- Less than eight lane miles of the 161 lane miles built are in tunnels, the rest are viaducts, bridges and surface roads;
- The Charles River Bridge is the world's widest cable-stayed suspension bridge;
- One third of the Big Dig costs, about $5 billion, were to keep sidewalks, streets, and highways open;
- Because of the Big Dig project, over 170 acres of prime downtown real estate were converted from city dump, industrial use, and highway to open spaces and parks; and
- The tunnel construction method used in the Big Dig was cut and cover. Tunnel mining or boring is a more efficient and less expensive method used in constructing tunnels and it is the one recommended for Houston.

In effect, the Big Dig is more than a roadway tunnel project with long term benefits that have not yet been evaluated. Therefore, for cost evaluation purposes, to compare other roadway tunnels to the Big Dig is inappropriate.

Estimated Construction Costs vs. Time Value - Based on extensive experience in other tunnel projects located in Asia, Europe and the Americas, as well as soil conditions in the Houston area; Dr. Gerhard Sauer has estimated that the cost of a 50-foot diameter two-level tunnel costs approximately $20,000 per linear foot. Considering that the proposed alignment for the twin-tunnel I-45 corridor is about 14.8 miles in length, the estimated cost for tunneling I-45 is $3.126 billion.

The North-Hardy Planning Studies estimates the recommended Alternative 2 to cost $2.113 billion. Assuming the estimated costs are in 2005 dollars it is necessary to analyze both alternatives based on their "time value." For comparison purposes a simple time value calculation was conducted based on the following assumptions:

- Estimated costs for Alternative 2 and tunnel are in 2005 dollars;

- Design and construction start at year 2007 taking a total of 10 and 5 years for design and construction of Alternative 2 and tunneling respectively;
- Equal end-of-period payments for duration of the project was calculated by dividing estimated project costs at year 2007 by the number of design and construction years; and
- Future value for both alternatives was calculated for annual interest rates of 5, 10 and 15 percent. These rates account for annual inflation and increase of design and construction costs.

Table 1.4 – Calculated Time Value For Estimated Construction Costs of Alternatives
(Billions of $)

	2005 Cost Estimate	2007 Calculated Cost of Project Based on 2005 Estimates F = P (F/P, i, n)			Calculated Future Cost of Project at End of Construction F = A (F/A, i, n)		
		i = 5%	i = 10%	i = 15%	i = 5%	i = 10%	i = 15%
Alternative 2 (12.5 miles)	$2.113	$2.329	$2.556	$2.794	$2.930	$3.712	$4.729
Tunnel Alternative (14.8 miles)*	$3,126	$3.446	$3.782	$4.134	$3.808	$4.618	$5.574
Calculated % Increase of Estimated Cost of Tunnel vs. Alternative 2					**30.0**	**24.4**	**17.8**
* Includes segment of about 2.5 miles of I-45 between I-10 and US-59 including the Pierce Elevated.							

Table 1.4, Calculated Time Value For Estimates Construction Costs of Alternatives, indicate that the calculated time values based on annual interest rates of 5, 10 and 15 percent vary between 30.0 and 17.8 percent or an average of 25 percent. The additional cost of 25% for the tunnel alternative is not prohibitive considering the many short and long-term benefits that roadway tunnels have over traditional at-grade expansion, specifically:

- Construction time of tunnels takes half or less than traditional at-grade highway reconstruction;
- Roadway tunnels have the potential to generate revenues through tolls;
- The I-45 tunnels would connect to US-59 addressing needed expansion through downtown Houston – specially the Pierce Elevated; and
- Life expectancy for roadway tunnels is 150 years.

From the results of the time value calculations it can be observed that: roadway tunnels are not as expensive as these are perceived, the North-Hardy Corridor Planning Study must include roadway tunnels as part of its alternative analysis, and the short and long-term benefits that roadway tunnels have over the build alternatives should be included in the evaluation.

Potential Revenues - The general public has the perception that once a highway is built and paid it is "free" to drivers forever. What the public does not realize is that generally the life expectancy of a highway is 20 to 30 years, which means that a highway requires periodic maintenance (overlays) or reconstruction during its life cycle. Highways are not "paid for"

after they are constructed but require continuous maintenance, rehabilitation or reconstruction. Nevertheless, current Texas legislation, which prevents the conversion of existing un-tolled lanes or "free" lanes to tolled lanes, may have not taken in consideration the difficulty TxDOT has in funding the operation, maintenance and expansion of the highway system in the state of Texas. For the I-45 corridor this means that after reconstruction a minimum of 8 lanes must remain as general-purpose or "free" lanes. This reduces the potential for TxDOT to collect much needed revenues.

It must be noted that the tunnel alternative would be considered new highway lanes and it can be a tolled facility. This provides TxDOT an alternative not fully explored during the analysis of the proposed six build alternatives as identified by the North-Hardy Planning Studies.

Another alternative for generating additional revenue, which is not very common, is the development of a tax increment (transportation) redevelopment district for the I-45 corridor. This is explained in this paper under the subtitle I-45 Parkway Concept.

Life-Cycle Cost Analysis – Life-cycle cost analysis of highways permits the evaluation of all relevant cost of design alternatives incurred during the expected life of the alternative such as: capital costs, maintenance, rehabilitation, and effects of construction and maintenance.

A transportation project is a long-term investment with a defined performance level. A life-cycle cost analysis is an objective analysis that permits comparing alternative designs based on their engineering merits, operation and maintenance costs, and proper economic analysis techniques. The Federal Highway Administration indicates that life-cycle cost analysis includes five steps: establish design alternatives, determine activity timing, estimate cost incurred by the implementing agency and users, compute life-cycle costs, and analysis of results.

Since the North-Hardy Planning Studies selected six build alternatives that could be considered to have similar life-cycle costs, then to evaluate them based on their capital costs may be appropriate. However, when comparing design alternatives that have significant variances in capital costs, time of construction, and expected life, the life-cycle cost analysis is of significant importance, particularly when agencies must select design alternatives that benefit the public over long periods of time.

For instance, from similar tunnel projects constructed in various parts of the world it is fair to assume that the proposed tunneling of I-45 could be designed and built in five years or less. On the other hand, highway reconstruction projects similar to I-45 currently take about 10 years to design and build.

Although typically highway pavements are typically designed to last 20 to 30 years, over time pavements deteriorate at an increased rate especially without proper maintenance and rehabilitation. Unlike pavement characteristics used in highways, new design and construction methods for tunnels have improved the life expectancy of a roadway tunnel to as much as 150 years. Therefore, it is of utmost importance that agencies like TxDOT conduct proper life-cycle cost analyses when comparing competing designs such as the build Alternative 2 recommended by the North-Hardy Planning Studies and the tunneling of I-45 as proposed by this paper.

Public Private Partnership – Public private partnerships or PPPs have been successfully implemented across the world because they provide much needed:

- Funding for investment in transportation infrastructure;
- Expertise in the design, construction, operation and maintenance; and
- A system of checks and balances that provide more efficient investment over the life cycle of the project.

The alternative of tunneling I-45 permits the development of a toll-only facility allowing TxDOT to obtain toll revenues over the life cycle of the project. The potential of toll revenues enhances the possibility to use a PPP as an alternative for reconstructing the I-45 corridor.

It should be noted that recent state legislation permits toll road authorities, such as the Harris County Toll Road Authority (HCTRA), to engage TxDOT in developing partnerships similar to public private partnerships allowing HCTRA to fully or partially participate in the tunneling of I-45.

CONGESTION MANAGEMENT

Roadway congestion is an ever-increasing urban problem challenging cities and government agencies into developing strategies to reduce traffic congestion. There are not many examples of cities that have successfully reduced traffic congestion except for the City of London. The Transport of London has implemented congestion pricing in central London obtaining a 20 percent reduction in the number of vehicles entering central London and generating millions of pounds of additional annual revenues. London's congestion pricing program has been so successful that it is being expanded.

Toll roads that charge higher prices during peak hours in order to improve vehicular speeds have also successfully implemented congestion pricing. Locally HCTRA is implementing similar congestion pricing strategies to reduce the number of vehicles using the Westpark Toll Road thus increasing operating speeds.

Whether congestion pricing is applied in a business district or a highway, it has proven to be the most effective alternative in managing traffic congestion. By implementing fees to access an area or use a facility it is possible to manage not only the number of vehicles but also the type of vehicles and the routes vehicles use.

The development of a toll-only facility, as proposed by tunneling I-45, offers the potential to implement congestion pricing strategies that can help improve vehicular speeds and routing of heavy vehicles or those carrying hazardous materials.

EMERGENCY EVACUATION ROUTE

Because safety and emergency evacuation is part of the design, operation, and maintenance of roadway tunnels; roadway tunnels are better alternatives for expediting vehicles during emergency evacuations. The Houston region experienced this type of emergency evacuation during Hurricane Rita in September 2005 when millions of vehicles attempted to evacuate the area causing regional traffic congestion that lasted for over 24 hours.

The proposed tunnel design alternative for I-45 would have limited access connecting to Beltway 8, Loop 610, I-10, downtown Houston and US-59/SH-288. This eliminates the need to provide access control to on/off ramps as it was experienced during the Hurricane Rita evacuation. Roadway tunnels are equipped with information technology services (ITS) that

permit efficient and effective routing of traffic and communication with drivers. Also, for safety purposes, the proposed twin-tunnel alternative is required to have cross passages. Limited access, ITS technology, and tunnel cross passages can be incorporated into an emergency evacuation plan that includes counter flow strategies, thus permitting traffic to change direction on all or part of the tunnel vehicular lanes.

Although extensive preparations have been conducted to evacuate areas of the Houston metropolitan area subject to potentially catastrophic events like hurricanes, finding immediate refuge may be the best alternative that many people will have to save their lives. As are many roadway tunnels in Europe, the proposed I-45 tunnel can be designed to carry traffic and provide emergency evacuation shelter during extreme events like hurricanes or flooding. The entire proposed 14.8-mile corridor, with about 180 miles of highway lanes, could be used to shelter people and emergency rescue vehicles.

In the aftermath of a potentially catastrophic event, it is critical to the continued survival of citizens that emergency vehicles are in operation and have immediate access to the region. In this regard, the proposed tunneling of I-45 provides both vehicular protection and critical access.

It must be noted that during Ted Koppel's Nightline program in October 28, 2005 "Town Hall Meeting – Ready or Not" televised live from Houston, it was indicated that the federal government has billions of dollars for funding emergency evacuation that were not being fully used. Considering that I-45 is a designated emergency evacuation route in the fourth largest city in the country and the I-45 tunnel could provide emergency evacuation shelter, local transportation agencies like TxDOT must explore this potential source of funding as part of the alternative analysis.

I-45 PARKWAY CONCEPT

When roadway tunnels are constructed under I-45, from Beltway 8 to US-59 south of Downtown Houston as the tunnel alternative proposes, it is likely that the added capacity to the I-45 corridor will reduce traffic demand for the existing I-45 surface lanes. The decrease in traffic demand due to the construction of the tunnels gives TxDOT the opportunity to: implement needed pavement rehabilitation, re-stripe the surface to fewer lanes thus improving lane and shoulder widths, and close or modify on/off ramps.

Currently the Harris Country Metropolitan Transit Authority (METRO) has a one-way reversible HOV lane located in the center of I-45 with the expectation that future reconstruction of I-45 will provide a total of two HOV lanes, one lane for each direction. The proposed tunneling of I-45 gives METRO the alternative to use the roadway tunnels without restrictions and potentially implement a high capacity transit alternative like light rail in the median of I-45, where the HOV lane is currently located. Denver Southeast Corridor has a similar configuration where light rail is located in the highway median.

Therefore, instead of expanding I-45 horizontally, the alternative to tunnel I-45 provides a number of alternatives that will improve the corridor in many aspects such as: increasing highway capacity, the reduction and potential improvement of environmental impacts, and the enhancement or use of alternative modes of transportation. More importantly the tunnel alternative creates a long-term vision for what the I-45 corridor could become, a world-class transportation corridor and point of pride for Houston.

TURNING A HIGHWAY INTO A PARKWAY

Houston has two very unique express roadway corridors, Memorial Drive and Allen Parkway. Both of these corridors have limited access and are tree-shaded green spaces with posted speeds between 35 and 50 MPH that carry traffic efficiently. Unlike standard highways, Memorial Drive and Allen Parkway have smaller footprints; their paved width consists of the travel lanes without shoulders while highways are required to have 10 to 12-foot wide shoulders. The smaller roadway footprint allows unused right-of-way to be green space. See **Photo 1.2, Memorial Drive, limited access parkway.**

Photo 1.2 – Memorial Drive, limited access parkway

Since the proposed I-45 tunnel alternative will carry most of the through traffic, the demand for capacity on the existing I-45 lanes will be expected to decrease allowing surface traffic to be primarily local. Over time, while existing service roads continue to provide access to adjacent properties it is possible that: the overall footprint of paved lanes can be reduced, the I-45 main lanes can be redeveloped into an express parkway, and the existing HOV facility can be modified for high capacity transit or light rail use. Conceptual renderings of the I-45 parkway with a high capacity transit corridor in the median of the parkway are shown in **Appendix C and D** of this paper.

The long-term vision for the I-45 corridor is to:

- Create an underground roadway tunnel system for long or through vehicle trips;
- Develop an at-grade parkway primarily for local access but available for through traffic;

- Include a high capacity high-speed transit corridor located in the center of the parkway with potential extensions to The Woodlands, Intercontinental Airport, the University of Houston Main Campus, and Hobby Airport;
- Benefit from market forces and Houston's unique "no zoning" ordinances to develop a transit oriented pedestrian friendly urban transportation corridor;
- Create long term funding strategies, such as a Tax Increment Reinvestment Zone (TIRZ) to ensure development of a transit-oriented corridor; and
- Reverse the negative impacts of existing highway infrastructure by adding linear green spaces, reducing impermeable surfaces, creating more storm water detention strategies, and potentially incorporate into the corridor the creation of park nodes at bayou crossings (Buffalo Bayou, White Oak Bayou, Little White Oak Bayou, and Halls Bayou).

DALLAS NORTH CENTRAL EXPRESSWAY CORRIDOR

The development of North Central Expressway in Dallas has been very similar to I-45 in Houston. Both highways were first constructed then reconstructed in nearly parallel time periods. However, during its third reconstruction, the North Central Expressway was reconfigured into a depressed highway with local streets crossing over it, and the redesign included elements that increased green areas and improved the corridor aesthetics. In addition, the Dallas Area Rapid Transit (DART) developed on the east highway frontage a light rail corridor that extends from Downtown Dallas to the City of Plano located about 20 miles north - the Red Line. According to DART the Red Line carries the equivalent of two freeway lanes of traffic. More importantly, the unique characteristics of the North Central Expressway corridor have contributed to the Red Line becoming one of the most successful light rail corridors in the nation because:

- Residents from suburbs like Plano and Garland can ride the light rail or park and ride to access downtown Dallas;
- Successful transit oriented development opportunities were created adjacent to areas like Mockingbird Station and downtown Plano;
- Accessibility has been improved by linking the Red Line to shopping centers like the NorthPark Center Shuttle connecting the Park Lane Station to NorthPark Center; and
- Public private partnerships allow the use of private parking facilities to park and ride DART's Red Line.

Similar to the North Central Expressway corridor, the I-45 corridor offers significant opportunities to develop a high capacity high-speed transit infrastructure that in many instances offers greater opportunities than those encountered along the North Central Expressway corridor. These are:

- Directly connecting business districts such as downtown Houston and Greenspoint which are considered two of the largest central business districts in the nation;
- Accessing adjacent shopping centers such as Northline Mall and Greenspoint Mall.
- Developing park and ride facilities at crossings of major highway corridors like Beltway 8 and Loop 610;

- Providing pedestrian access to many businesses located along the I-45 corridor including Gallery Furniture - considered the largest furniture store in the nation and owned by Jim "Mattress Mack" McIngvale a respected and admired member of the Houston community; and
- Future opportunities for connecting to The Woodlands, Intercontinental Airport, University of Houston Main Campus/TSU area, and Hobby Airport.

By developing an alternative highway system through tunneling, the I-45 corridor will benefit from the reduction of environmental impacts due to vehicular emissions, traffic congestion, and visual and noise pollution. It allows redevelopment into a more aesthetically pleasing parkway that has the ability to offer a safer roadway environment. And by implementing a high capacity transit system, I-45 evolves into a multi modal transportation corridor with the potential to develop into an urban corridor with an improved quality of life.

TIRZ FUNDING OPPORTUNITIES FOR TOD

As the nation's transportation infrastructure increases in size and complexity, funding for its maintenance, operation and expansion become depleted or are insufficient. Toll roads, congestion pricing strategies, and public private partnerships are relatively new tools that public agencies and cities are using to meet the ever-increasing demand for mobility within and between urban areas.

The proposed alternative of tunneling I-45 benefits from the development of a toll-only roadway tunnel system that has the potential to generate revenue in perpetuity. On the other hand, expanding the existing I-45, per legislation, must provide "free" access even though the infrastructure is not free and requires continuous investment of funds. It is sensible then to look for alternative sources of funding operating, maintaining, and rehabilitating the existing I-45 surface highway.

It must be noted that agencies like TxDOT, owning acres of prime real estate within central business districts, such as downtown Houston where TxDOT owns right-of-way for I-10, US-59, and I-45, gain no financial benefit from the potential revenue that could be generated if this real estate was developed into a mix of transportation and business enterprises. Some roadway tunnel projects as well, as transit-oriented development, have enhanced the revenue potential of adjacent properties for both government agencies and private entities, by increasing the value (tax revenue) and marketability of private properties respectively. Nevertheless, highway and transit agencies generally do not fully benefit from the services they provide.

Real estate market studies indicate that location, accessibility, and quality of life characteristics such as green spaces, enhance the demand and value of properties. Also the type of transportation services available and its benefits are reflected in the cost of real estate. For example, the value of real estate adjacent to subway stations in London is much higher than real estate located further away. An article published by Tunnel & Tunneling Magazine shows how property values along transportation corridors vary depending on the type of transportation infrastructure. It compares property values between established: urban streets, elevated urban highways with local access, and pedestrian friendly urban streets with urban highway tunnels. It is not surprising that elevated urban highways have a negative effect on property values while a more pleasant pedestrian friendly urban street with access to high-speed mobility like roadway tunnels increase property values.

Therefore, when considering alternative designs for the I-45 corridor, the proposed twin-tunnel roadway option is not only a superior short term solution for providing mobility, but also facilitates the long-term proposal to develop the I-45 corridor into a multi-modal transportation corridor with an at-grade parkway and a high speed transit system.

The tunnel option provides the alternative to develop a toll-only facility with potential long-term revenues; but more importantly, it allows the long-term development of a transit oriented urban corridor with increased property values and improved quality of life.

Ultimately the proposed tunneling of I-45 and long-term development of a transit oriented urban corridor suggests the potential for development of a tax increment (transportation) reinvestment zone (TIRZ) or tax increment financing for the I-45 corridor. This will allow the allocation of tax increment toward the redevelopment of the proposed multi modal surface transportation infrastructure while providing TxDOT the opportunity to ultimately leverage its valuable highway right-of-way for development of commercial and recreational uses.

PUBLIC SUPPORT

The I-45 tunnel and parkway alternative has been presented to dozens of organizations and it has received unparalleled support. Additional information about the proposed tunnel alternative, graphics, public involvement, and letters of support can be found at www.i45parkway.com.

EVALUATION OF PROPOSED BUILD ALTERNATIVES

Exhibit 52 of the North-Hardy Planning Studies outlines the evaluation of the no build and six build alternatives. See **Table 1.5 Evaluation of Proposed Build Alternatives**.

Table 1.5 – Evaluation of Proposed Build Alternatives
(Source: North-Hardy Planning Studies)

Criteria	No Build	Build 1	Build 2	Build 3	Build 4	Build 5	Build 6
Mobility Impacts	F 148,650 hr	C 131,992 hr	B 131,011 hr	A 120,967 hr	A 120,967 hr	D 146,992 hr	D 146,992 hr
Conceptual Capital Costs	N/A	F $2.191 B	B $2.113 B	F $2.209 B	D $2.174 B	C $2.137 B	A $2.095 B
Regional Connectivity	F 148,650 hr	C 131,992 hr	B 131,011 hr	A 120,967 hr	A 120,967 hr	D 146,992 hr	D 146,992 hr
Ease of Implementation	N/A	D	B	D	D	D	D
Environmental & Community Impacts	B	C	C	C	C	C	C
Final Grade	D	D+	B-	C	C+	D+	C-
Ranking	**7**	**5**	**1**	**3**	**2**	**5**	**4**

According to the North-Hardy Planning Studies the criteria used in developing **Table 1-5, Evaluation of Proposed Build Alternatives**, consist of the following:

- Mobility criteria – It measures in vehicle hours of delay per day considering 55 mph as a base average speed resulting on hours of delay as shown on **Table 1-5**.
- Conceptual capital costs – It should be noted that the conceptual costs as indicated by the North-Hardy Planning Studies "are preliminary, planning-level estimates developed to allow comparisons between the alternatives and not to serve as final engineered costs."
- Regional connectivity – It is to measure "the ability to reach activity centers and neighborhoods" within the I-45 travel corridor. The evaluation used is the same as the one used for mobility criteria.
- Ease of implementation – Per the North-Hardy Planning Studies, ease of implementation evaluates the "ability to secure funding for each alternative." Since Build Alternative 2 is the only one with that incorporates managed lanes with tolling strategies it is given a higher ranking while a rank of D was given to the others.
- Environmental and community impacts – This criterion evaluates three areas as outlined by the North-Hardy Planning Studies: urban or quality of life elements, natural environment elements, and cultural elements. The planning studies indicate that the no-build alternative will not have a negative impact and the build alternatives will have similar but more negative impact.

While the proposed build alternatives are basically similar, the inclusion of the tunnel alternative, which adds highway capacity to the corridor, is significantly different to the proposed build alternatives. A preliminary evaluation of the tunnel alternative based on the selected criteria follows.

- Mobility criteria – The addition of new highway lanes with minimal effect on the existing infrastructure and implementation of traffic management strategies using tolls allows the tunnel alternative to provide vehicular speeds at or higher than the 55 mph average speed used in the criteria.
- Conceptual capital costs – Conceptual cost for the tunnel has been estimated in this paper based on a construction life cycle instead of a present value of capital costs as the other alternatives were evaluated. Based on this construction life cycle cost between the recommended build alternative by the North-Hardy Planning Studies, at a 10% annual rate of interest plus inflation, the tunnel alternative cost is about 5% more per mile.
- Regional connectivity – Based on the North-hardy Planning Studies this criterion is quantitatively the same as the mobility criteria.
- Ease of implementation – Considering that this criteria evaluates the securing of funding for development of the highway, it gives a value of B to the recommended alternative and D to the others based on the ability of alternative B to generate funding through four managed lanes. Since the tunnel alternative is proposed to be a toll only facility and its cost on a per mile basis is 5% higher, it is proper to assume that the tunnel alternative should be evaluated higher than the recommended alternative.

- Environmental and community impacts – When comparing two very different alternatives such as the proposed alternative number two from the planning studies and the tunnel alternative, the three areas considered under this criteria may be best evaluated separately. However, for the purpose of this paper it is appropriate to give the tunnel alternative a higher evaluation than either the proposed or no build alternatives since it has no or minimal environmental and community impacts, and it is the only option that actually reduces air pollution and eliminates noise pollution.

Quantitative vs. Qualitative Analysis – Agencies like TxDOT and Houston METRO have to make decisions on multi-billion dollar transportation infrastructure that affect the region short and long term. In making these very important decisions the evaluation of alternatives based on a quantitative analysis while supplementing the evaluation of alternatives with a qualitative analysis might be a best option.

The North-Hardy Planning Studies mixes both quantitative and qualitative analysis. This might not be best method for comparing alternatives since: it does not weigh the quantitative data equally between the alternatives, such as hours of delay; it weights traffic delay higher by evaluating the same impact data twice, as shown in both mobility and regional connectivity impacts; and reduces the importance of "environmental and community impacts" by evaluating three different areas (urban elements, natural environmental elements, and cultural elements) with the same value.

Evaluation of Proposed Tunnel Alternative – **Table 1-6, Evaluation of Proposed Build and Tunnel Alternatives**, shows criteria given to the no build alternative and the recommended build alternative. Comparing the recommended build alternative against the proposed tunnel, it can be determined that the tunnel alternative has a better evaluation in each of the five selected criteria.

The evaluation shown on **Table 1-6, Evaluation of Proposed Build and Tunnel Alternatives**, is provided to indicate that the roadway tunnel alternative, when properly evaluated, has the potential to out perform the recommended build alternative number two. Therefore, as TxDOT and the Houston community consider the reconstruction of I-45, it is essential that fair and equal consideration be given to the tunneling alternative proposed by this paper. Roadway tunnels offer an alternative that will add traffic capacity to the I-45 corridor while improving the corridor's negative impacts including air and noise pollution. The ultimate development of an I-45 at-grade parkway with high capacity transit represents a vision for the future that far surpasses the North-Hardy Planning Studies recommended I-45 corridor Build 2 alternative.

Table 1.6 – Evaluation of Proposed Build and Tunnel Alternatives (6)					
	North-Hardy Planning Studies		Proposed Evaluation Including Tunnel		
Criteria	**No Build**	**Build 2**	**No Build**	**Build 2**	**Tunnel**
Mobility Impacts	F 148,650 hr	B 131,011 hr	D 148,650 hr	D 131,011 hr	A (1) Free flow
Conceptual Capital Costs	N/A	B $3.712 B 12.5 miles $297.0 M/m	Cost of rehabilitation	B $3.712 B 12.5 miles $297.0 M/miles	A (2) $4.618 B 14.8 miles $312.0 M/miles
Regional Connectivity	F 148,650 hr	B 131,011 hr	D 148,650 hr	D 131,011 hr	A (3) Free flow
Ease of Implementation	N/A	B	N/A	D	A (4)
Environmental & Community Impacts	B	C	B	D	A (5)

(1) LOS of free flow is given a value of A while LOS of "E" is given a value of D

(2) Conceptual costs given a value of A to tunnel because estimated tunnel costs are 5% per mile more than the recommended alternative Build No. 2 and the tunnel is a toll only facility.

(3) LOS of free flow is given a value of A while LOS of "E" is given a value of D

(4) Design and construction of an at-grade facility is estimated to take about 10 years and generate significant traffic construction and environmental impacts due to construction. The tunnel alternative has an estimated time of design and construction of 5 years and has minimal impacts.

(5) Tunnel alternative eliminates noise pollution, reduces air pollution, and has minimal environmental and community impacts.

(6) This evaluation is limited to the construction life cycle of the project. Ideally the analysis should correspond to the life cycle of the project, which for an at-grade highway is generally construction time plus 20 to 30 years and for a roadway tunnel is construction time plus up to 150 years.

Appendix A – Contact list of speakers who presented on the topic of Roadway Tunneling during the 2005 Houston Transportation and Mobility Conference

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Topic: Large diameter tunnel in Madrid, Spain

Paul Miclea & Kirk McDaniel
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Topic: Tunnel ventilation & fire-life safety issues

Gerhard Goisser
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Topic: Herrenknecht tunneling systems, large diameter TBMs

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Topic: European tunnel safety and E/M standards

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Topic: Tunneling Conditions in Houston, Texas

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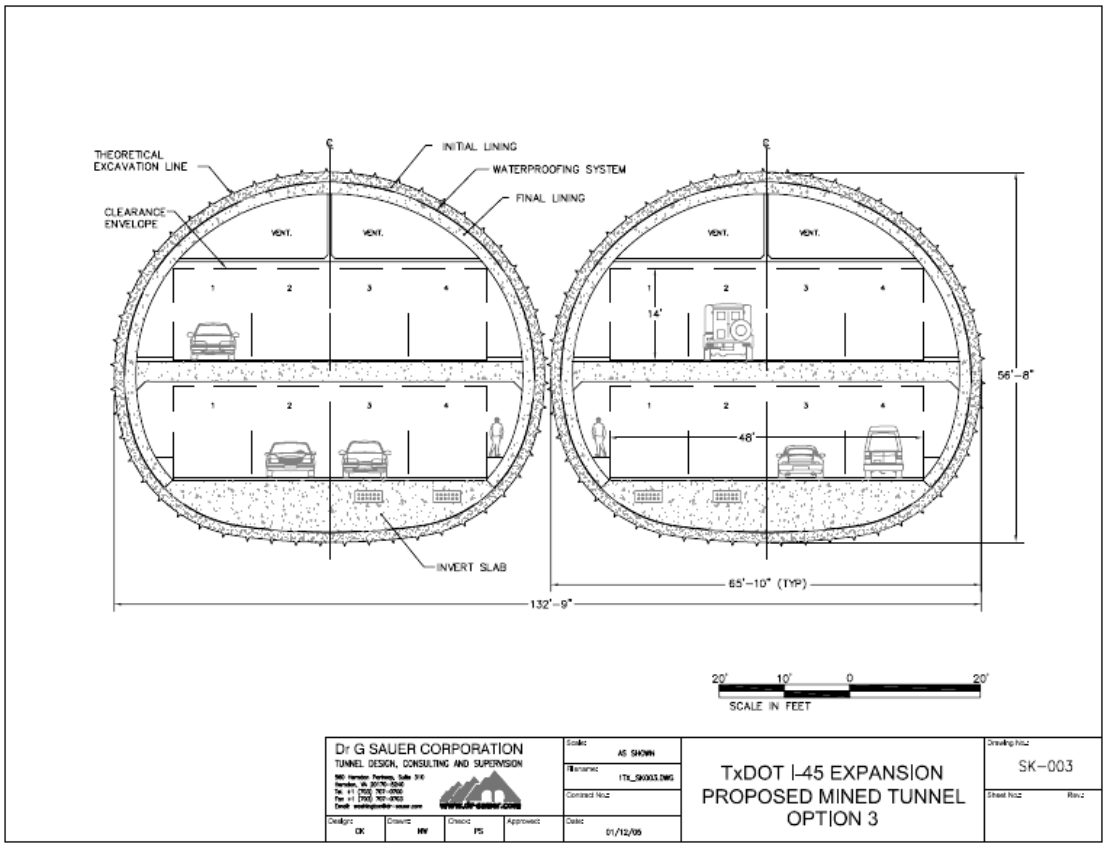
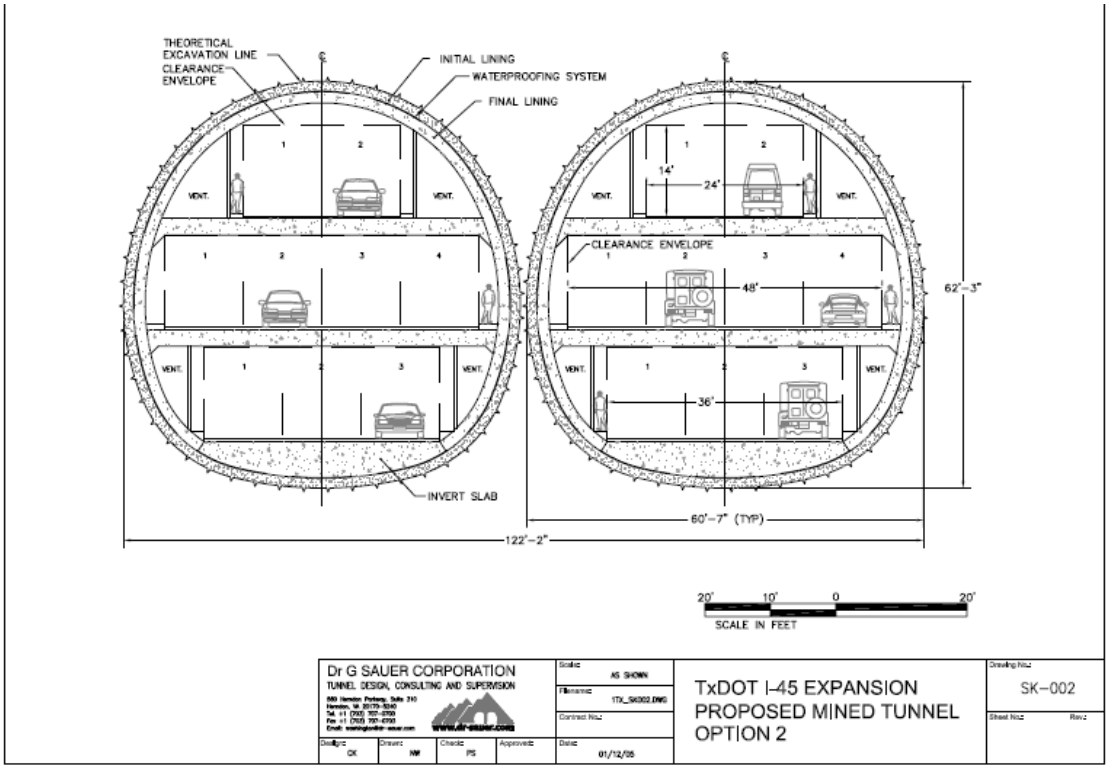
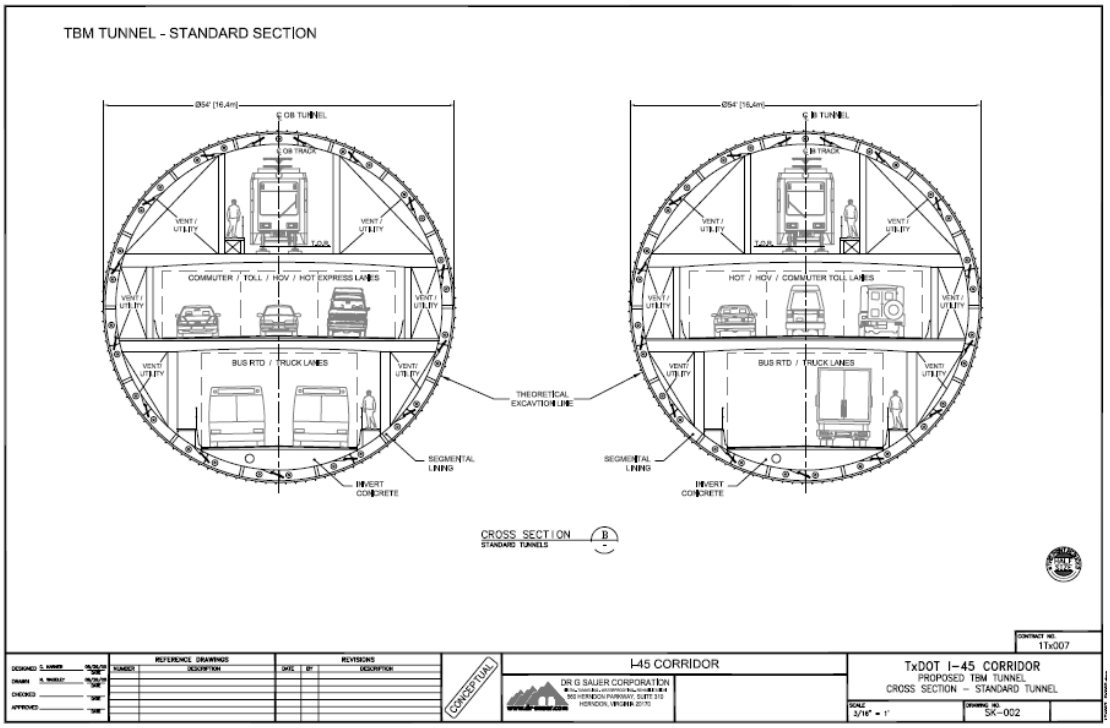
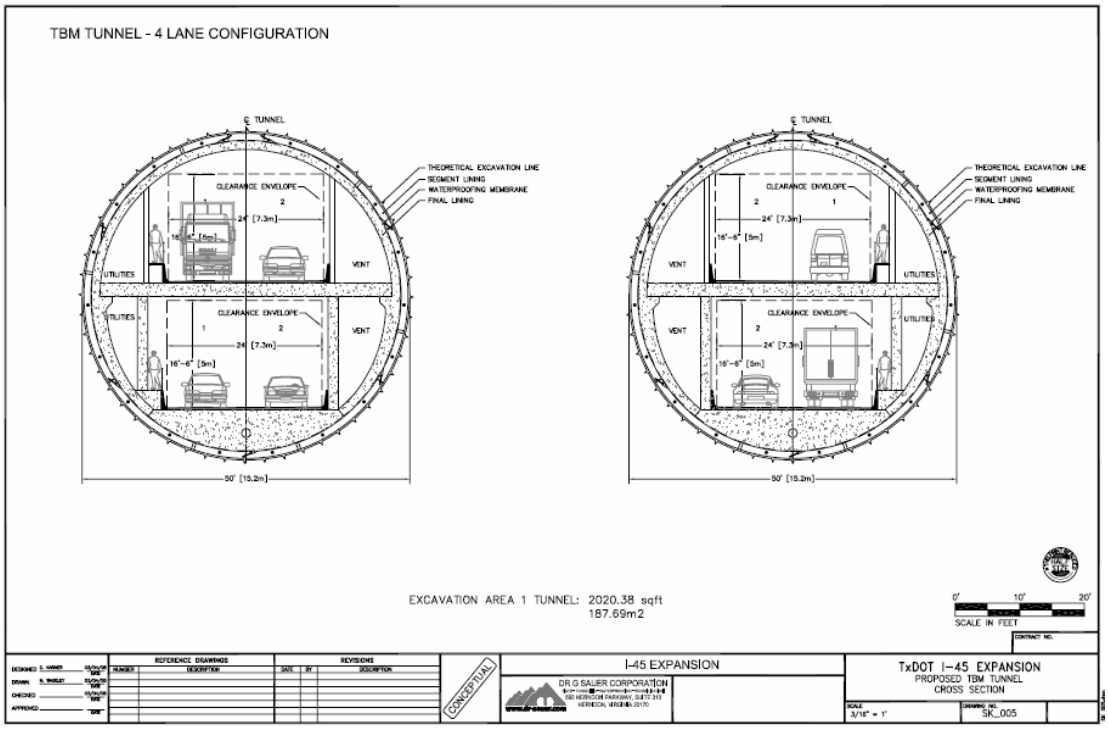
Topic: LBJ roadway tunnels





Appendix B.1 – I-45 Tunnel, Tunnel Cross Sections of Conceptual Design Alternatives

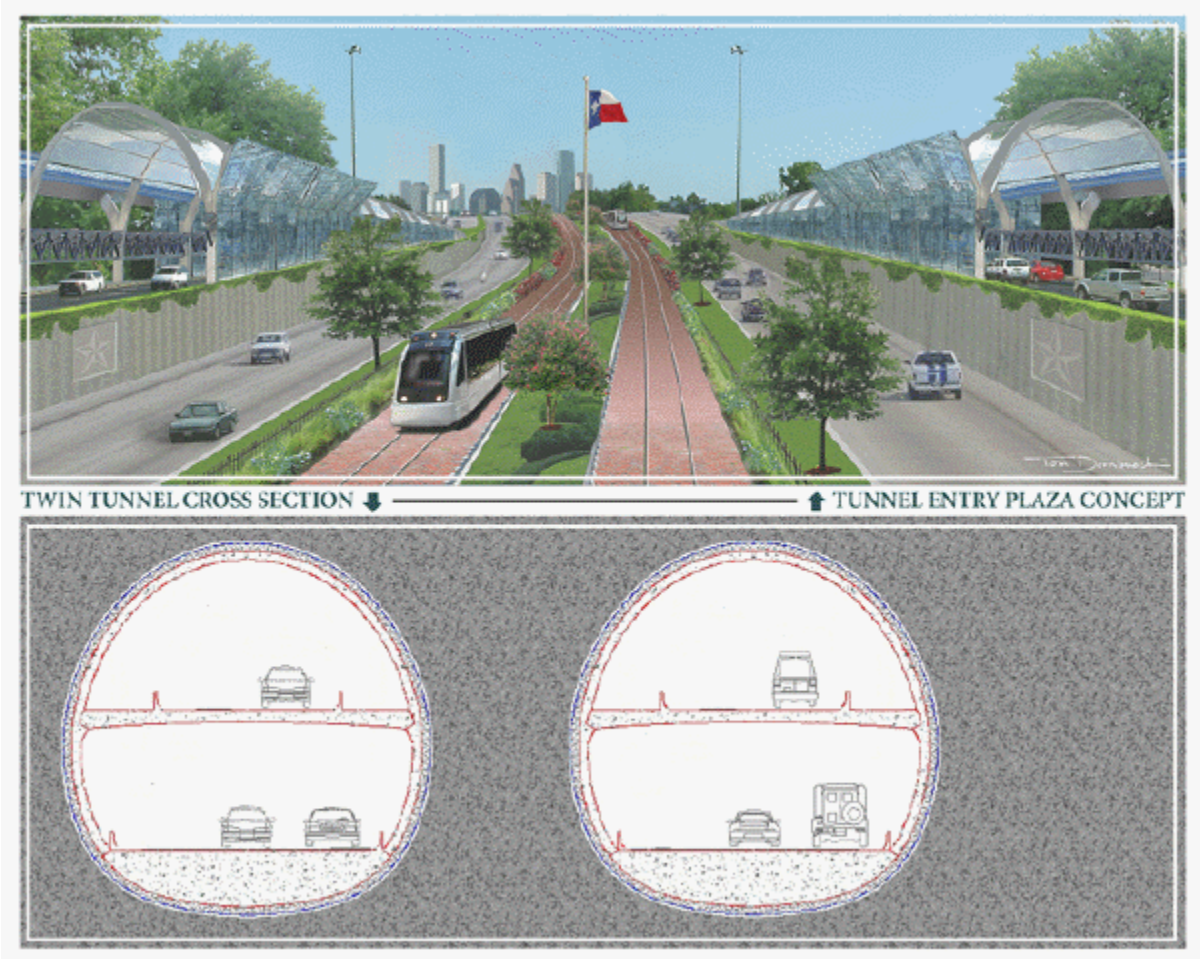




Appendix B.2 – I-45 Tunnel, Tunnel Cross Sections of Conceptual Design Alternatives

(Artistic rendering of the I-45 Parkway created by Tom Dornbusch.)

Appendix C – Top photo shows existing I-45 north of Downtown and bottom is a conceptual rendering of the I-45 parkway with high capacity transit



(Artistic rendering created by Tom Dornbusch. Rendering is only shows as a visual aid and not as an engineering cross section of the proposed roadway tunnels and parkway.)

Appendix D – Conceptual cross section of proposed tunnel alternative with mass transit corridor

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