INTEGRATING UNDERGROUND FREIGHT TRANSPORTATION INTO EXISTING INTERMODAL SYSTEMS

Project 0-6870
August 31, 2016

Center for Underground Infrastructure Research and Education (CUIRE)
Department of Civil Engineering
College of Engineering
The University of Texas at Arlington
Arlington, Texas 76019

Principal Investigator:
Dr. Mohammad Najafi, Ph.D. P.E., F.ASCE
Professor and Director, The University of Texas at Arlington, Texas (CUIRE)

Co-Principal Investigators:
Siamak Ardekani, Ph.D. P.E., Professor
Seyed Mohsen Shahandashti, Ph.D. P.E., Assistant Professor
The University of Texas at Arlington, Texas (CUIRE)

1. Report No. 0-6870-1	**2. Government Accession No.**	**3. Recipient Catalog No.**

4 Title and Subtitle **Integrating Underground Freight Transportation into Existing Intermodal Systems**	**5 Report Date** July 31, 2016 **6 Performing Organization Code**
7. Author(s) Mohammad Najafi, Siamak Ardekani, Seyed Mohsen Shahandashti	**8 Performing Organization Report No.**
9 Performing Organization Name and Address Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington (UTA) The University of Texas at Arlington 701 S. Nedderman Drive Arlington, Texas 76019	**10 Work Unit No.** **11 Contract or Grant No.** 0-6870
12 Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080	**13 Type of Report and Period Covered** Final Report April 2015 through August 2016 **14 Sponsoring Agency Code**

15 Supplementary Notes

16 Abstract

The Texas transportation system is critical to the United States economy. According to a report prepared for TxDOT, NAFTA tonnage on Texas highways and railroads is expected to increase by nearly 207 percent from 2003 to 2030. Truck tonnage will grow by 251 percent while rail tonnage is forecasted to increase 118 percent. The number of trucks carrying NAFTA goods will increase by 263 percent and the number of rail units will grow by 195 percent. This will have a profound impact on the Texas highway and rail systems. Additionally, larger ships will arrive in the Port of Houston due to Panama Canal expansion. Therefore, increasing the capacity of the freight transportation system in Texas is a must, but increased land development and population growth make the possibility of building new roads, widening existing roads, and building new railroad tracks very difficult if not impossible. Underground freight transportation (UFT) is a class of automated transportation systems in which vehicles carry freight through pipelines and tunnels between terminals Being able to use a part of the underground space of the existing highways, will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs. By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the stakeholder committee input, this project examines the use of UFT in three proposed routes in Texas, specifically, the Port of Houston to City of Lancaster (near Dallas), Port of Houston to a distribution center within 15 miles of the Port's point of origin, and the border crossing with Mexico in Laredo. This project has shown that underground freight transportation is financially viable, feasible, greener, cost-effective, and can become an important part of intermodal freight mobility in Texas.

17 Key Word Underground Freight Transportation, Underground Pipelines, Tunneling, Construction Methods, Sustainability, Cost Benefit Analysis, Linear Induction Motors	**18 Distribution Statement**

19 Security Classification (of this report) None	**20 Security Classification (of this page) None**	**21 No. of pages** 261	**22 Price** $247,049

This Page is Intentionally Left Blank

Final Report

Integrating Underground Freight Transportation into Existing Intermodal Systems

Project No.: 0-6870

Prepared for:
Texas Department of Transportation (TxDOT)

Prepared by:
Center for Underground Infrastructure Research and Education (CUIRE)

Principal Investigator:
Dr. Mohammad Najafi

Co-Principal Investigators:
Dr. Siamak Ardekani
Dr. Seyed Mohsen Shahandashti

The University of Texas at Arlington

August 31, 2016

This Page is Intentionally Left Blank

EXECUTIVE SUMMARY

INTRODUCTION

According to a TxDOT white paper prepared by the Texas Freight Advisory Committee (TxDOT 2013), “the number of northbound truck crossings at Texas’s land ports more than doubled between 1994 and 2011 – i.e., from 1,623,816 in 1994 to 3,332,899 in 2011”. Texas, more than any other nation, will have to find a way to accommodate such drastic growth simply because of the NAFTA-induced trucking and railroad boom. A report by Cambridge Systematics (2007) states that between 1994 and 2004, rail movements between the U.S. and Mexico increased by 164 percent. According to the Cambridge Systematics, Inc., 2007 final report on the Texas relationship with NAFTA, “An estimated 83 percent of all NAFTA truck freight through all ports of entry—representing more than 3 million truck units per year—uses Texas highways during some part of their journey to reach Mexico” (Cambridge Systematics 2007). According to a 2013 report entitled “North American Free Trade Agreement: Is it Important for Texas?” by the Texas Freight Advisory Committee of the TxDOT: “In 2007, Cambridge Systematics reported that Global Insight TRANSEARCH projected an increase of nearly 207% in NAFTA tonnage on Texas highways and railroads through 2030. Truck tonnage is projected to increase by 251% and rail tonnage is projected to increase by 118% by 2030.”

OBJECTIVES

The purpose of this project is to investigate the feasibility of underground freight transportation which allows for optimized use of existing transportation capacity. Underground freight transportation (UFT) is a class of automated transportation systems in which vehicles carry freight through tunnels or pipelines between intermodal terminals. Being able to use a part of the underground space of the existing highways, will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs. By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the leadership of the Stakeholder Committee, the objectives of this project are to evaluate using UFT in three proposed routes in Texas: specifically, the Port of Houston to City of Lancaster (near Dallas), the Port of Houston to a distribution center within 15 miles of the Port’s point of origin (Baytown), and the border crossing with Mexico in Laredo. For the pilot study and implementation project, some members of the Stakeholder Committee suggested an intra-city freight transportation route across a metropolitan area, such as using UFT to connect railroad or highway freight hubs in Fort Worth and Dallas.

METHODOLOGY

The planning and design objective (Task 1) is to develop schematic designs for *Standard Shipping Containers* (8.0 ft by 9.5 ft by 40 ft), *Crates* (5 ft by 5.3 ft by 10.4 ft) and *Pallets* (3.3 ft by 3.3 ft by 4 ft). The design components include the conduit system, the vehicles (capsules), the conveyance system (tracks), access shafts, and the terminal design and intermodal load transfer systems. This task also covers the UFT operational parameters. Equations were developed to estimate the required headways, number of vehicles, and loading/unloading handlers/forklifts as a function of the freight transportation demand. For the propulsion system, the linear induction motors (LIMs) and automation technologies provide effective means of transporting all freight sizes including standard shipping containers.

The purpose of the *construction method* (Task 2) is to consider options for the conduit system and its components, such as shafts. Cut-and-cover (open-cut or trenching) and tunneling using TBM can be used for *two single-track tunnels* and *one twin-track tunnel* respectively. Cut-and-cover construction is potentially possible and less expensive as an alternate for pipeline installations at rural areas where there is surface availability with minimal disturbances to the traffic, public and the existing roads. While cut-and-cover method is discussed in this report, its use may not be possible along the select routes due to existence of frontage and crossing roads, bridges and foundations. Additionally, the cut-and-cover method has high social and environmental impacts.

For *cost estimating* (Task 3), the capital and operation/maintenance costs for the tunnel, vehicles, the LIM system, controls, and terminals are provided. The tunneling cost is estimated for building one twin-track tunnel, and for comparison, cut-and-cover costs are estimated for two single track tunnels.

Environmental impacts and social costs (Task 4) are important to conserve energy and protect the environment and the quality of life. The UFT system will increase the freight transportation capacity and decrease the social and environmental impacts of the conventional transportation methods. A quantification of UFT benefits, such as, decreasing air pollution, reducing noise, reducing traffic congestion and accident rates, as well as reducing damage to highway infrastructure is included.

Task 5 evaluates the *financial aspects* of this project. Major funding sources, including federal, state, TIFIA and senior bank loans, revenue bonds and equity participation are identified. The project delivery methods considered are design-bid-build (DBB), design-build (DB), and design build-finance-operate-maintain (DBFOM), among other options. Benefit-cost analysis of UFT for the standard shipping containers shows that the net present value (NPV) of UFT is $60 billion (in 2016 dollars) and benefit-cost ratio of the system is estimated to be 3.77. The internal rate of return (IRR) is 12.44%, which indicates that UFT is certainly economically viable. Similar results are obtained for crate and pallet freight transportation.

A *stakeholder committee* (Task 6) was formed to guide the researchers in all aspects of this project. The stakeholder committee is in support of the project and has recognized the necessity of UFT as an intermodal freight transportation in Texas.

CONCLUSIONS

By conducting this project, TxDOT is leading the effort in innovation and this research supports this effort to develop an optimal option which complements and integrates into other innovative systems being considered. Similar efforts in the U.S. include the Hyperloop http://www.hyperloop.global/ (for human transportation inside the tunnel), freight shuttle https://www.freightshuttle.com/ (for moving freight over elevated guideways), and a similar UFT system designed for shipping standard containers in a 137-mile freight pipeline from the San Pedro Bay (SPB) Port Complex (in Los Angeles) to the inland regions of California by the Green Rail

Intelligent Development (GRID) system http://laincubator.org/portfolio-companies/grid-logistics-inc/.

A second phase of this project was proposed to evaluate all aspects of tunnel and vehicle design, the propulsion system, automation, and cost in a laboratory setting, while a third phase was proposed to implement a pilot project for a segment limited to just a few miles.

By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the stakeholder committee input, this project has shown that underground freight transportation is financially viable, feasible, greener, cost-effective, and an important part of intermodal freight mobility in Texas.

This Page is Intentionally Left Blank

DISCLAIMER

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

This report is not intended for construction, bidding, or permit purposes. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This Page is Intentionally Left Blank

ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to **Mr. Chris Glancy, MBA, CTCM**, **PMP**, TxDOT Project Manager at the Research and Technology Implementation Office, and the following TxDOT technical committee subject expert review members for their valuable and constructive comments, feedback, and suggestions.

- **Heath Bozeman**
- **Susana Ceballos**
- **Kale Driemeier**
- **Ryan Eaves**
- **Steve Linhart**
- **Bonnie Longley**
- **David Morley**
- **Justin Thomey**
- **Richard Williammee, Jr.**

The authors acknowledge help and support by TxDOT personnel, **James Kern** and **Al Aramoon**, and DART personnel, **Timothy H. McKay** and **Jerelyn Arbuckle** for providing geotechnical information. This report was copyedited by **Carla Roberts** of Preferred Copy Editing.

This Page is Intentionally Left Blank

STUDENT AUTHORS

Chapter 1, Planning and Design:

- Sirwan Shahooei
- Hamid Dehghan
- Fatemeh Rezaeifar

Chapter 2, Construction Methods:

- Taha Ashoori
- Seyedmohammadsadegh Jalalediny Korky
- Mohammadreza Malekmohammadi
- Ramtin Serajiantehrani

Chapter 3, Cost Analysis:

- Saeed Janbaz
- Razieh Tavakoli

Chapter 4, Environmental Impact Assessment:

- Amir Tabesh

Chapter 5, Financing Means:

- Ehsan Zahed

Chapter 6, Stakeholder Committee:

- Niloofar Rezaei

This Page is Intentionally Left Blank

CONSULTANTS

The following consultants have contributed sections on propulsion methods, linear induction motor (LIM) technology, and geotechnical information:

- Jalal Feghhi, M.S., LIM Consultant, Founder and CEO, Jumbula, Redwood City, CA.
- Robert M. O'Connell, Ph.D., P.E., Professor, Electrical and Computer Engineering, University of Missouri, Columbia, MO.
- Mark Wilkerson, Geotechnical Consultant, Dallas, TX.

This Page is Intentionally Left Blank

TABLE OF CONTENTS

This Page is Intentionally Left Blank

LIST OF FIGURES

LIST OF TABLES

This Page is Intentionally Left Blank

LIST OF ABBREVIATIONS AND ACRONYMS

$\frac{ft}{s^2}$	Acceleration of Gravity
AADTT	Average Annual Daily Truck Traffic
AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
ATA	American Trucking Associations
BANs	Bond Anticipation Notes
BBO	Buy-Build-Operate
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BCY	Bank Cubic Yards
Blvd	Boulevard
BOO	Build-Own-Operate
BOOT	Build-Own-Operate-Transfer
BOT	Build-Operate-Transfer
BTO	Build-Transfer-Operate
BTU	British Thermal Unit
CCFRPM	Glass-Fiber-Reinforced Polymer Mortar
c_d	Coefficient of Air Drag
CDAs	Comprehensive Development Agreements
CH	Clay of High Plasticity, Fat Clay
CLSM	Controlled Low-strength Material
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CTTS	Central Texas Turnpike System
CUIRE	Center for Underground Infrastructure Research and Education
CY	Cubic Yard
DART	Dallas Area Rapid Transit
DB	Design-Build
dB	Decibels
dBA	A-weighted decibels
DBB	Design-Bid-Build
DBF	Design-Build- Finance
DBFOM	Design-Build-Finance-Operate-Maintain
DBOM	Design-Build-Operate-Maintain
DFO	Distance from Origin
DFW	Dallas-Fort Worth
DOT	U.S. Department of Transportation
Ea.	Each
EDC	Economic Development Commission
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency

Eq.	Equation
FAST	Fixing America's Surface Transportation
FBI	Federal Bureau of Investigation
F_d	Air Resistance
FHWA	Federal Highway Administration
FOB	Factory on Board
ft	Foot
F_t	Total Frictional Forces
ft^2	Square Foot
F_w	Frictional Force
Fwy	Freeway
GIS	Geographic Information System
GVW	Gross Vehicle Weight
H	Height
HAP	Hazardous Air Pollutants
HB	House Research Organization Bill
HFC	Hydro Fluorocarbon
HP	Horse-Power
hr.	Hour
HSE	Health, Safety and Environment
HTF	Federal Highway Trust Fund
IAIA	International Association for Impact Assessment
IATA	International Air Transport Association
ICTs	Information Communication Technologies
ID	Inside Diameter
IH	Interstate Highway
IH-45	Interstate Highway 45
in.	inch
IPD	Innovative Program Delivery
IRR	Internal rate of return
KWh	Kilo Watt Hour
L	Length
LBO	Lease-Build-Operate
LCY	Loose Cubic Yard
LIM	Linear Induction Motor
LLC	Limited Liability Company
MAP-21	The Moving Ahead for Progress in the 21st Century Act
MINNOISE	Minnesota Stamina Noise Prediction Computer Model
mph	Mile per Hour
N	North
NAFTA	North American Free Trade Agreement
NCTCOG	North Central Texas Council of Governments
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
NH_3	Ammonia
No.	Number

NOI	Notice of Intent
NO_x	Nitrogen Oxides
NPV	Net Present Value
NTE	North Tarrant Express
O&M	Operations & Maintenance
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
PAB	Private Activity Bonds
PHA	Port of Houston Authority
PPP	Public-Private Partnerships
psi	Pound per Square inch
PSOO	Private Sector Owns and Operates
PTRA	Port Terminal Railroad Association
R^2	Coefficient of Correlation
RCC	Roller Compacted Concrete
RCP	Reinforced Concrete Pipe
ROD	Record of Decision
ROW	Right-of-Way
RPP	Round Particle Pollution
s^2	Square Second
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act-A Lagacy for Users
$SC\text{-}CO_2$	Social Cost of Carbon Dioxide
sec.	Second
SH	State Highway
SO_x	Sulfur Oxides
sq. yds.	Square Yard
STEAM	Surface Transportation Efficiency Analysis Model
TAC	Texas Administrative Code
TBM	Tunnel Boring Machine
TCEQ	The Texas Commission on Environmental Quality
TEA-21	Transportation Equity Act for the 21st Century
TEU	Twenty-Foot Equivalent Unit
THC	Tetrahydrocannabinol
TIFIA	Transportation Infrastructure Finance and Innovation Act
TLCC	Total Life Cycle Cost
tsf	Tons per Square Foot
TTI	Texas Transportation Institute
TX	Texas
TxDOT	Texas Department of Transportation
U.S.	United States
U.S.C.	United States Code
UFT	Underground Freight Transportation
USCS	Unified Soil Classification System
USDOT	United States Department of Transportation
USOMB	U.S. Office of Management and Budget

UTA	The University of Texas at Arlington
UTP	Unified Transportation Program
VOC	Volatile Organic Compounds
VTM	Vehicle-Miles Traveled
W	Width
W	West
P	Power
n	The Normal Force Acting on the Tracks
u	Coefficient of Friction between Wheels and Tracks
v	Operating Speed
ρ	Air Density

DEFINITIONS

Acid Rain: Most rainfall is generally slightly acidic due to the carbonic acid from carbon dioxide in atmosphere. But 'acid rain' is caused when sulfur dioxide and nitrogen oxides (from automobile exhausts and industrial emissions) are washed out from the atmosphere by rain as weak sulfuric and nitric acid. Acid rain can cause serious damage to crops, and leaches calcium ions from soil and plant leaves causing an ionic imbalance.

Appropriations Bills: Bills that outline the amount of funds to be appropriated to each agency and state.

Apron: Distance from the outside shoulder of the main lanes to the inside shoulder of the frontage road.

Authorization Bills: This bills establish the terms and conditions under which a federal agency operates.

Benefit-Cost Analysis (BCA): Is a systematic method of comparing benefits and costs of a project.

Benefit-Cost Ratio: A ratio of present value of benefits divided by the sum of the discounted costs.

Bypass Shunt: A short lane for diverting the vehicles to the platforms for loading/unloading.

Capacity: The capacity of a UFT system in terms of containers flow per day should be sufficiently high to justify the construction and operation of the system.

Cut-and-cover: Open trenching and installing a pipeline on a suitable bedding material and then embedding and backfilling.

Discount Rate: A rate that is used to discount future costs or benefits to the present value.

Emissions: Pollution (including noise, heat, and radiation) discharged into the atmosphere by residential, commercial, and industrial facilities.

Environmental Impact Assessment (EIA): EIA is the required process to predict the positive and negative environmental consequences prior to the decision to move forward with the proposed action.

Environmental Impact Statement (EIS): An environmental impact statement (EIS), under United States environmental law, is a document required by the National Environmental Policy Act (NEPA) for certain actions significantly affecting the quality of the human environment. An EIS is a tool for decision making. It describes the positive and negative environmental effects of a proposed action, and it usually also lists one or more alternative actions that may be chosen instead of the action described in the EIS.

leet Size: The number of vehicles in use when the system is operating at capacity.

Flow: Is defined as the number of freight containers transported in a day.

Forklifts: Forklifts are used for loading/ unloading the crates and pallets to trucks and UFT vehicles.

Greenhouse Gases: Greenhouse gases are components of the atmosphere that contribute to the greenhouse effect. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities such as burning of fossil fuels such as coal. Greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Ground Freezing: Ground freezing is a construction technique used in circumstances where soil needs to be stabilized so it will not collapse next to excavations, or to prevent contaminates spilled into soil from being leached away.

Handlers: Handlers are used for loading/ unloading the shipping containers to trucks and UFT vehicles.

Headway: The time gap between launching two successive UFT vehicles.

Internal Rate of Return (IRR): Represents the discount rate which equates NPV to zero.

Linear Induction Motors (LIM): A linear induction motor (LIM) is an alternating current (AC), asynchronous linear motor that works by the same general principles as other induction motors but is typically designed to directly produce motion in a straight line.

Major Obstructions: Main construction barriers in the highway, including bridges and columns.

Minor Obstructions: Main construction limitations in the highway, including highway and railroad crossings.

Net Present Value (NPV): The difference between the present value of benefits (cash inflows) and the present value of actual costs (cash outflows).

Open-cut: See cut-and-cover.

Operating Speed: The average speed of the vehicles in UFT system excluding stops in terminals.

Platform: The area in UFT terminals which vehicles stop for loading/unloading the freight.

Public Private Partnership (P3): P3 is a contractual agreement formed between public and private sector partners, which allows more private sector participation than is traditional. The agreements usually involve a government agency contracting with a private company to renovate, construct, operate, maintain, and/or manage a facility or system.

Public-Public Partnership: Public-Public Partnership combines various forms of cooperation and integration between public sector entities to finance investment in public infrastructure and/or to carry out joint tasks.

Secant Pile Walls: Secant pile walls are formed by constructing intersecting reinforced concrete piles. The secant piles are reinforced with either steel rebar or with steel beams and are constructed by either drilling under mud or auguring.

Sheet Piling: Interlocking rolled-steel sections driven vertically into the ground to serve as sheeting in an excavation or to cut off the flow of groundwater.

Sideslope: The distance from the outer edge of frontage shoulder to the limits of right of way.

Single Track: A UFT system which accommodates only one line in the tunnel.

Social Benefit: The increase in the welfare of the society that is derived from a particular course of action.

Social Costs: The expense to an entire society resulting from particular course of action.

Soil Nailing: Soil nailing is a technique used to reinforce and strengthen existing ground. Soil nailing consists of installing closely spaced bars into a slope or excavation as construction proceeds from top down.

Soldier Piles and Lagging: Secant pile walls are formed by constructing a series of overlapping concrete-filled drill holes to form a continuous, relatively watertight walls.

Tax Revenue: Tax revenue is defined as the revenues collected from taxes on income and profits, social security contributions, taxes levied on goods and services, payroll taxes, taxes on the ownership and transfer of property, and other taxes.

Traffic Congestion: Traffic congestion is a condition on transport networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queueing. The most common example is the physical use of roads by vehicles.

Trenchless Technology: Trenchless technology consists of a variety of methods, materials, and equipment for inspection, stabilization, rehabilitation, renewal, and replacement of existing pipelines and installation of new pipelines with minimum surface and subsurface excavation.

Tunneling: Tunneling techniques can be used for installation of pipelines and conduits underground with minimum amount of surface and subsurface excavation.

Twin Track: A UFT system tunnel with two lines in the same tunnel or pipeline in opposite directions.

Underground Freight Transportation (UFT): An unmanned, automated, and intermodal form of freight transportation utilizing pipelines and tunnels to transport container, crate and pallet freight between terminals. An automated technology to carry individual freight capsules through underground pipelines with minimum impact on the surface. This system can be built on available right-of-way (row) or under the highways.

Vehicle Mile Traveled: Vehicle miles of travel or vehicle miles traveled (VMT) is defined by the U.S. government as a measurement of miles traveled by vehicles within a specified region for a specified time period. The United States Federal Highway Administration (FHWA) compiles monthly and yearly VMT statistics nationally and by state.

Vehicle: Equipment used for carrying the freight including but not limited to: Capsule, gondola and flatbed trailer.

Volatile Organic Compounds (VOC): VOCs are organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air, a trait known as volatility.

CHAPTER 1-OPERATIONAL PLANNING AND DESIGN

This task is divided into two parts: Part 1, UFT Schematic Designs and Operational Parameters, and Part 2, UFT Propulsion System (LIM).

PART 1-UFT Schematic Designs and Operational Parameters

1.1 INTRODUCTION

This chapter describes schematic designs and operational parameters for an underground freight transportation (UFT) system for three types of loads: standard shipping containers, crates, and pallets. The design components include the tunnel system, the vehicles, the conveyance system (tracks and power systems), the access and ventilation shafts, and the terminal design and intermodal load transfer systems. Separate conveyance systems are proposed for each load type. The freight lines are proposed to be located under the existing roadway right-of-way (ROW), including the space below the highway cross-section, namely, below medians, shoulders, aprons, and frontage roads when applicable. Potential long-haul and short-haul routes for UFT systems are also proposed.

1.1.1 Objectives

The objective of this chapter is to present a schematic design for three types of UFT lines. These include a UFT line for standard shipping containers, a UFT line for standard crate size, and a third line for a standard pallet size. The overall design includes subcomponents including vehicles, tunnels, terminal layouts, and loading/unloading systems. In addition, operational components such as operating speeds, headways, line capacities and associated fleet sizes, number of forklifts and handlers, maximum vehicle loads, and power system requirements are addressed. Finally, three potential routes are proposed. These include a line between the Port of Houston and the City of Dallas near Lancaster, a line from the World Trade Bridge at Laredo, TX, crossing the border to an inland terminal north of the border, and a third line between the Port of Houston and an inland satellite distribution center.

1.2 THE SYSTEM COMPONENTS

To gain a better understanding of system components and feasible design alternatives, literature on previous tubular freight lines either proposed as a concept or constructed as a demonstration project or operational on a limited basis were examined... Federal Highway Administration (FHWA) conducted a study with assistance from Volpe, Volpe's National Transportation Systems Center, and others (Vance, 1999; Zandi, 1976). Attention to major innovations in transportation was taken into consideration. These include the Sydney Freight Circle for container transport from the Port of Sydney to seven distribution warehouses (Fiars, 2009) and the container port expansion project in Shanghai (Guo et al., 2008), and any currently operating systems in the mining industry (Liu and Lenau, 2005; Kosugi, 1999). In addition, proposed systems such as a New York Port Authority UFT line proposed by Liu et al. (2004) and the Freight Shuttle System proposed by Roop et al., (2000) were also examined. These studies, along with input from project stakeholders, formed the basis for schematic designs of various elements of the UFT system. This includes the vehicle and tunnel design, the track design, the propulsion and power system design, and the terminal design as well as the short- and long-haul potential routes. The following sections provide more details.

1.3 DESIGN OF TUNNELS AND VEHICLES

1.3.1 Freight Sizes and Dimensions

In the design of the tunnels and vehicles, three freight sizes were considered. The largest freight size was the standard shipping container (ISO 668:2013 standard container), which is, 8 ft wide, 9.5 ft high and 40 ft long (8 ft W × 9.5 ft H × 40 ft L), with a maximum gross weight of 68,000 lbs. For the sake of consistency, this reports retains the width, height and length order of dimensions throughout. Note that the United Parcel Service (UPS) and Federal Express (FedEx) use length, width, and height in that order to calculate the weight and cubic size of all of their package. An intermediate freight size considered was an International Air Transport Association (IATA), Type 6 standard crate (LD-11 crate), which is 5 ft W × 5.3 ft H × 10.4 ft L with a maximum gross weight of 7,000 lbs. Finally, the smallest size freight considered was a standard U.S. pallet size: 3.3 ft W × 3.3 ft H × 4 ft L, with a maximum gross weight of 4,600 lbs.

1.3.2 Tunnel Types and Dimensions

For each freight size, two types of tunnels, cylindrical and rectangular, were envisioned. Cylindrical tunnels (pneumatic tubes or concrete pipes) are more suitable where tunnel boring machines (TBMs) are used, such as in urban/suburban areas. For this application, tunnels can be as deep as 50–150 ft depending on soil conditions and the presence of other underground installations such as buried utility lines.

The internal diameters of the cylindrical tunnels for a single-track system are 14 ft for shipping containers, 10 ft for crates, and 7 ft for pallets. The tunnel wall thicknesses are 1.0 ft, 0.9 ft and 0.7 ft, respectively, making the tunnel external diameters 19 ft, 11.8 ft, and 8.4 ft, respectively. In twin-track tunnels, considerably larger diameters are required, namely internal tunnel diameters of 23 ft, 15 ft, and 11 ft for containers, crates, and pallets, respectively. The tunnel wall thicknesses would be 1.5 ft, 1.2 ft, and 1 ft, respectively.

Rectangular tunnels (box culverts) and precast circular concrete pipes are most suited for cut-and-cover applications. Within the highway right-of-way, cut-and-cover applications are practical when adequate space is available under medians or side aprons or where infrequent roadways cross under the right-of-way. This ideal situation is typically found only in very rural areas.

Typical construction entails digging a trench, placing the box culvert or precast circular concrete pipe, and covering to a minimum depth of 5 ft from the top of the box culvert to the ground. Stronger materials than locally-excavated soils such as flowable fills or controlled low-strength materials (CLSMs) are typically used. For more information, refer to Chapter 2, Construction Methods.

The external dimensions for rectangular tunnels are 6.2 ft W × 6.5 ft H × 12 ft L for pallets and 7.6 ft W × 8.6 ft H × 25 ft L for crates. The standard shipping containers would require external tunnel dimensions of 10 ft W × 11.5 ft H × 42 ft L. The tunnel dimensions are independent of the construction material and local geology.

Although typical dimensions for rectangular tunnels are discussed, it is anticipated that tunnels for UFT system are cylindrical. This is to accommodate the tunnel boring machines, which will be utilized in the majority of projects to minimize disruption to overland traffic and to communities near the right of way and to avoid adverse environmental impact. This tunneling method minimizes space requirements and soil excavation.

1.3.3 Vehicle Types and Dimensions

Metal vehicles are designed for easy placement or retrieval of freight. Closed vehicles are recommended for crates and pallets to prevent load spillage as well as to provide climate control in cases where such provisions are needed (e.g., transport of medicines or perishable foods).

Since linear induction motors (LIMs) are proposed in this project to propel the vehicles, an aluminum exterior (good conductor) and steel interior (ferromagnetic) are recommended. These vehicles are rectangular and their dimensions for pallet loads and crate loads are 4.2 ft W × 4.5 ft H × 10 ft L and 5.6 ft W × 6.8 ft H × 22 ft L, respectively.

Covered vehicles are not recommended for the standard shipping containers as there is little chance of load spillage in closed shipping containers. Also containers themselves can be climate-controlled if needed. Therefore, an open flat-bed vehicle design with a rectangular cross-section is recommended for shipping containers. Extra space in the tunnel is required for utilities, walkways, maintenance and aerodynamics of moving vehicles. The suggested vehicle dimensions are 9 ft wide, 10.5 ft deep and 49 ft long, with 3-ft high walls. Containers are placed or retrieved from the top. As in the case of crate and pallet vehicles, an aluminum exterior and steel interior are recommended for these vehicles as well. The aluminum exterior is required for LIM installation and operation.

Table 1-1 summarizes the types of loads (pallets, crates, and shipping containers), their typical dimensions, and the corresponding tunnel and vehicle types and dimensions. For the reasons discussed above, only circular (single-track and twin-track) tunnels are considered for each load type. This results in six types of design combinations. Schematic drawings for each of these six designs along with the corresponding dimensions are provided in Figures 1-1 through 1-6. These figures show other details such as location of catwalks and utilities, dimensions of wheels and tracks, and the location of linear induction motor’s primary and secondary power lines.

Table 1-1 Dimensions of Freight Types and Their Respective Tunnels and Vehicles

Freight Type	Tunnel	Vehicle
Pallets (3.3 ft W × 3.3 ft H × 4 ft L)	Two Single-track Tunnels Internal Diameter: 7 ft Wall Thickness: 0.7 ft External Diameter: 8.4 ft	Rectangular External Dimensions: 4.2 ft W × 4.5 ft H ×10 ft L
	One Twin-track Tunnel Internal Diameter: 11 ft Wall Thickness: 1 ft External Diameter: 13 ft	
Crates (5 ft W× 5.3 ft H × 10.4 ft L)	Two Single-track Tunnels Internal Diameter: 10 ft Wall Thickness: 0.9 ft External Diameter: 11.8 ft	Rectangular External Dimensions: 5.6 ft W × 6.8 ft H × 22 ft L
	One Twin-track Tunnel Internal Diameter: 15 ft Wall Thickness: 1.2 ft External Diameter: 17.4 ft	
Shipping Containers (8 ft W × 9.5 ft H × 40 ft L)	Two Single-track Tunnels Internal Diameter: 14 ft Wall Thickness: 1.0 ft External Diameter: 16.0 ft	Rectangular External Dimensions: 9 ft W × 10.5 ft H × 49 ft L
	One Twin-track Tunnel Internal Diameter: 22 ft Wall Thickness: 1.5 ft External Diameter: 25 ft	

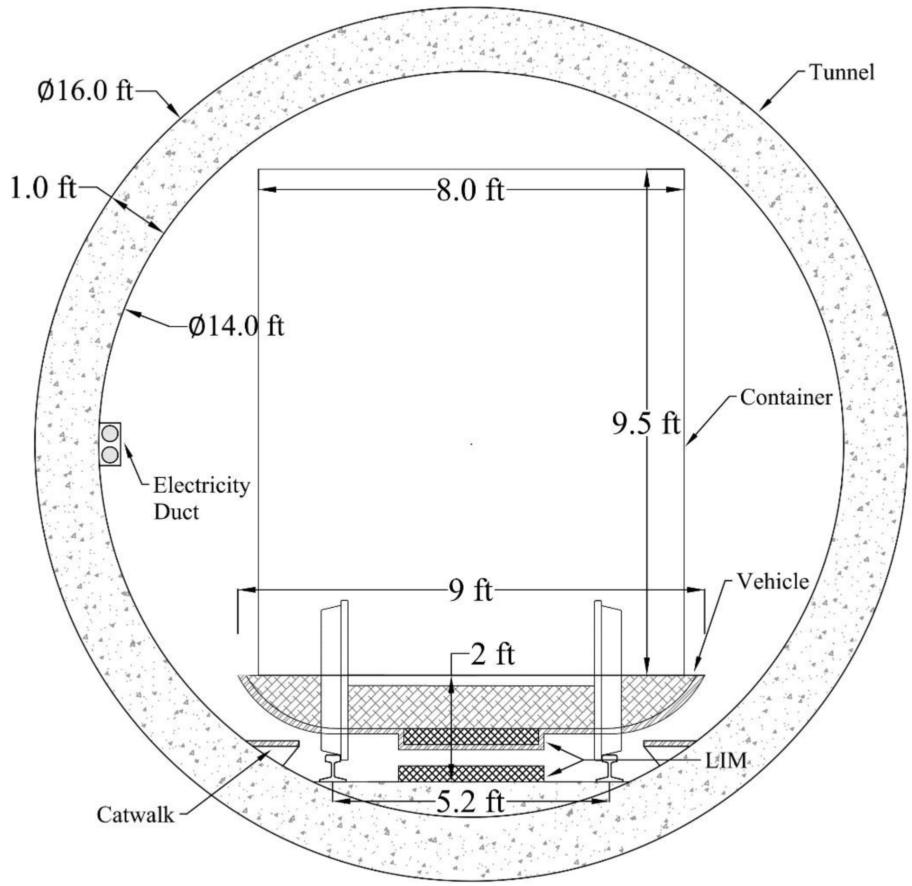


Figure 1-1 A Single-track System for Standard Shipping Containers

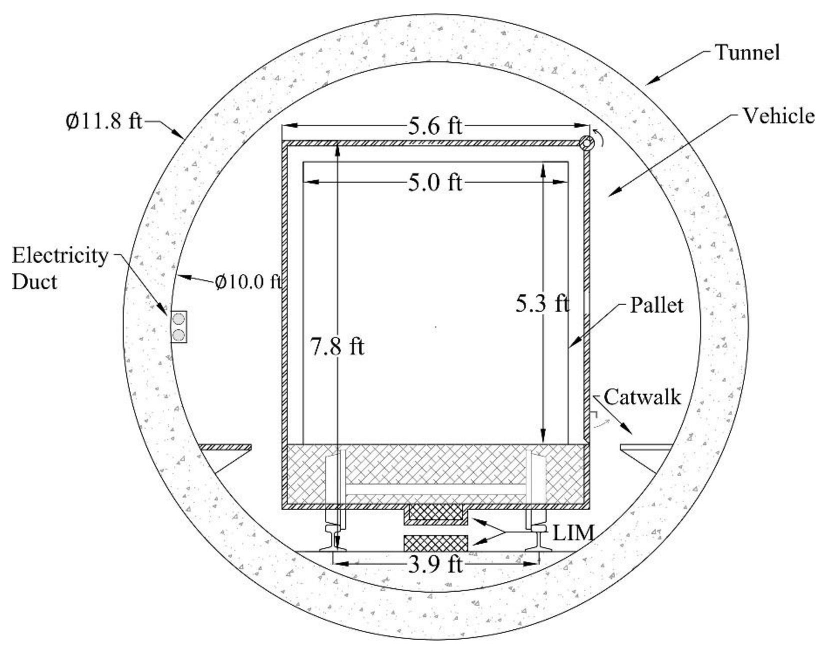


Figure 1-2 A Single-track System for Standard-Size Crates

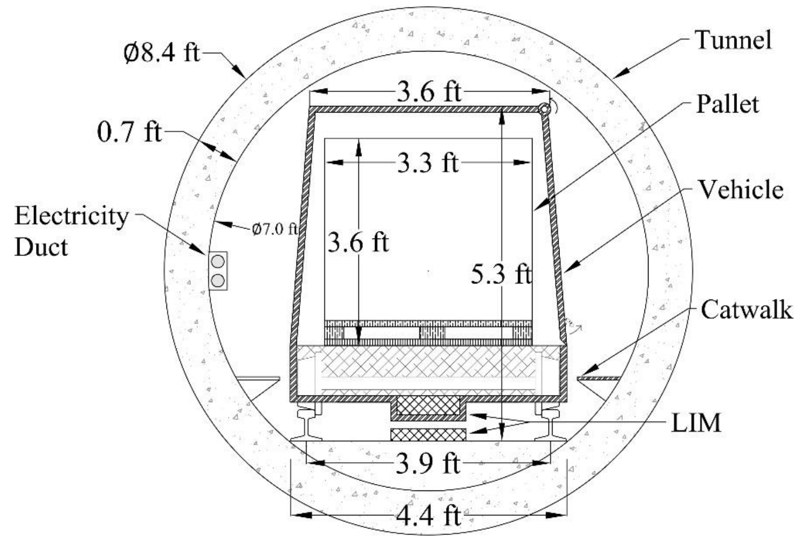


Figure 1-3 A Single-track System for Standard-Size Pallets

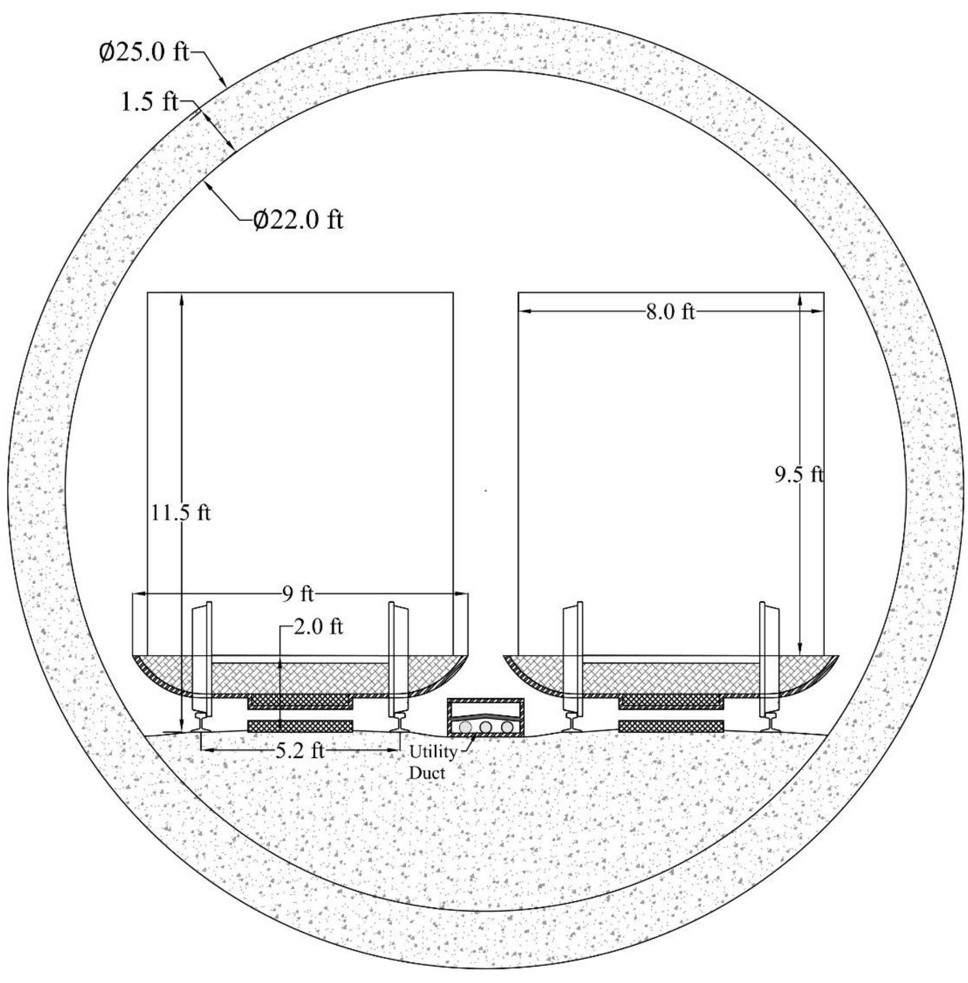


Figure 1-4 One Twin-track System for Standard Shipping Containers

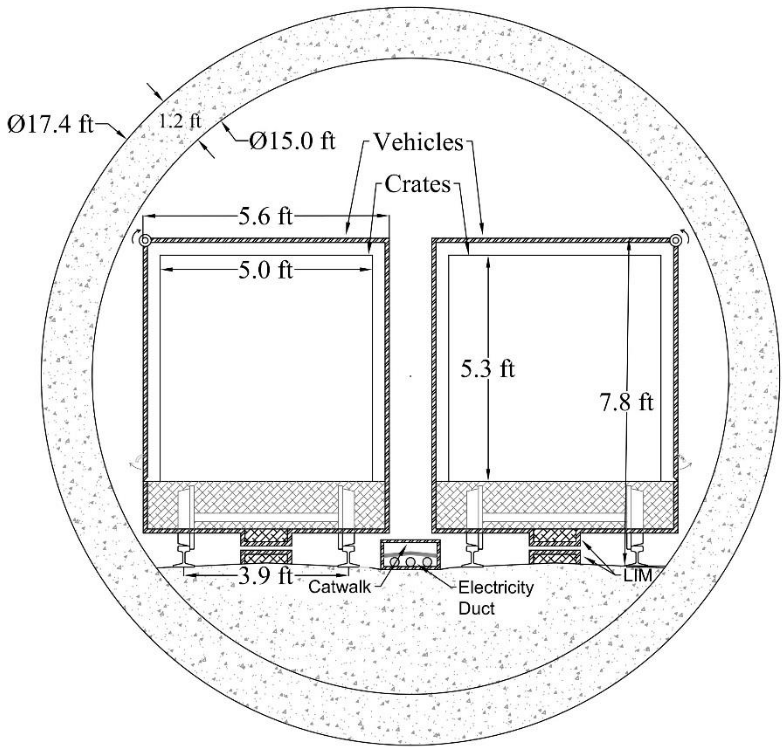


Figure 1-5 One Twin-track System for Standard-Size Crates

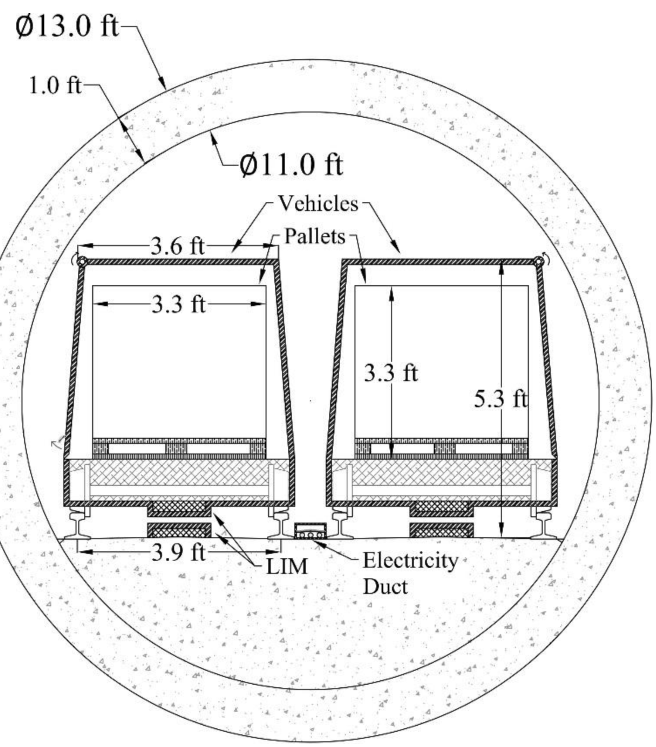


Figure 1-6 One Twin-track System for Standard-Size Pallets

1.4 POTENTIAL PROPOSED ROUTES

Figure 1-7 illustrates the location of three proposed UFT routes.

Figure 1-7 Locations of Three Proposed UFT Routes

A potential route considered for shipping containers is a 250-mile UFT route from Port of Houston (Barbour's Cut Terminal) to the Dallas Logistic Hub south of Dallas in the suburban town of Lancaster (see Figure 1-8). This UFT route can be constructed under the existing right-of-ways of SH-225 and IH-610 in Houston and IH-45 from Houston to Dallas.

Another suggested route being considered for shipping containers is a short-haul UFT line at the border between the U.S. and Mexico in Laredo, TX. This route is approximately four miles from the Mexican side of the World Trade Bridge in Nuevo Laredo to the interchange of TX-20 Loop and IH-35 near the Union Pacific Railroad Port in Webb County near Laredo (see Figure 1-9).

The World Trade Bridge, one of the four international crossings in Laredo, is the one which handles most of the truck traffic at the Laredo border between the U.S. and Mexico. There is considerable truck congestion at this border crossing, mostly due to customs inspection. While a UFT line across the border would not necessarily reduce the customs inspection delays, trucks could unload their containers into the UFT line and containers could be picked up on the other side. This would mitigate the problem of fully-loaded trucks idling for hours in queue for customs inspections. In addition, if trucks from Mexico unload their containers into the UFT line to be picked up at the other end by U.S. licensed trucks, it could reduce the instances of heavy Mexican trucks with potential safety issues traveling on U.S. highways. New customs facilities would need to be constructed to inspect the containers placed onto or coming out of the UFT line before transferring the containers to trucks and rail. These facilities could be placed away from the mainstream traffic line with truck parking available. Existing customs facilities would remain operational to handle non-commercial traffic as well as commercial trucks which either opt out of or are not allowed to use the UFT system due to a particular payload they might be carrying or for any other reasons.

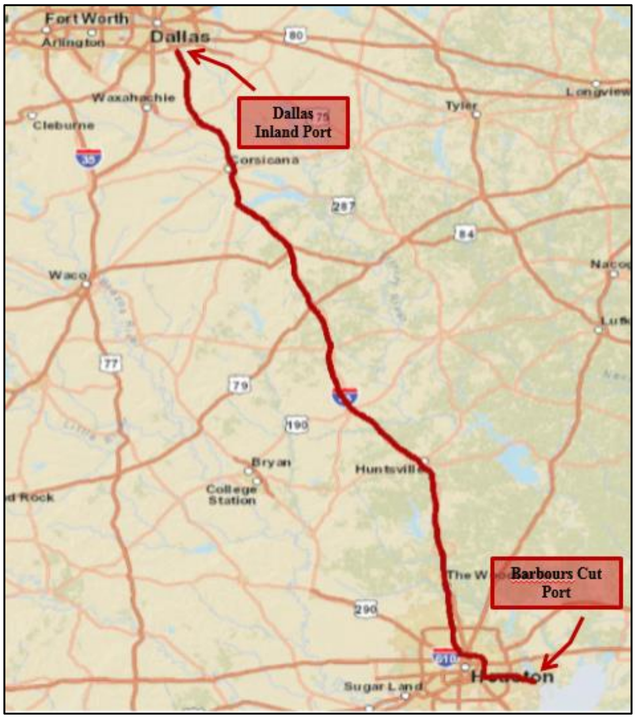


Figure 1-8 Proposed Houston-Dallas UFT Route

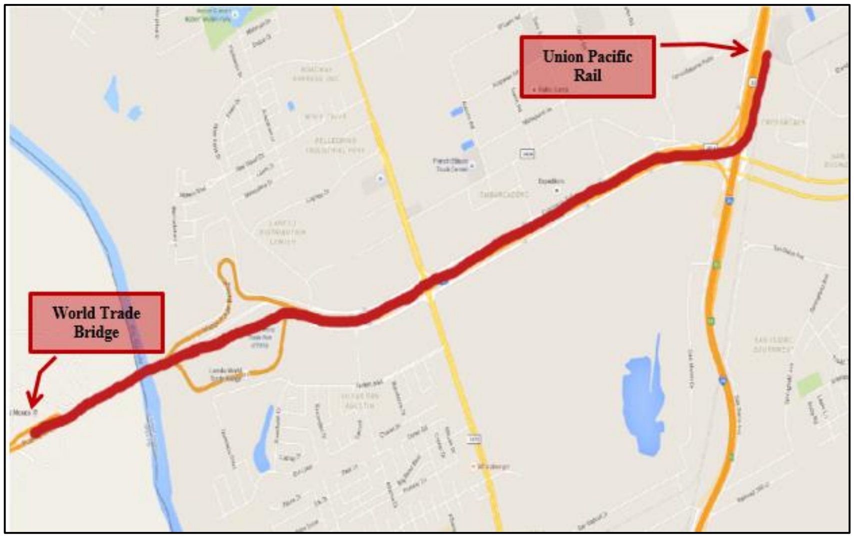


Figure 1-9 Proposed UFT Route at the World Trade Bridge (Laredo) Border Crossing

Another short-haul UFT route is considered from Port of Houston (Barbour's Cut Terminal) to an inland satellite port immediately outside the Houston metropolitan area. One possible inland port location would be in Baytown, TX where IH-10 crosses SH-146. This location is approximately 15 miles northeast of the Barbour's Cut Port, with a large existing truck terminal on IH-10. It is also near a major Chevron petrochemical facility (see Figure 1-10).

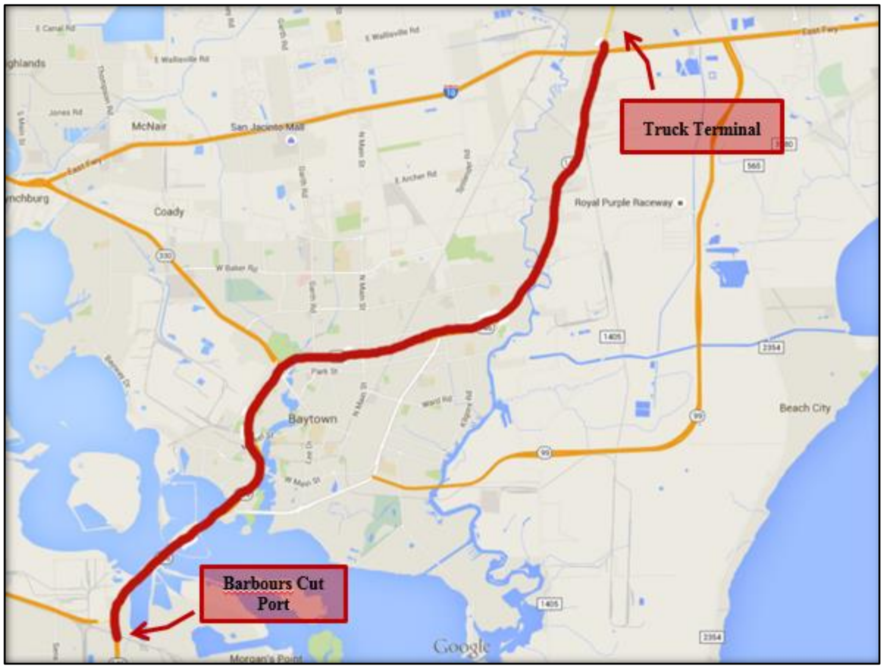


Figure 1-10 Proposed UFT Route Connecting Port of Houston to an Inland Satellite Distribution Center

The above UFT route could handle certain types of freight such as perishable foods that should not undergo excessive delays or hazardous freight that should not be carried in densely-populated areas. This route was initially designed to handle shipping containers but, if need be, the system can be downsized to accommodate crates or pallets as well. This system would also have the benefits of reducing truck congestion at the port as well as truck traffic on city streets and highways. If this route proves to be feasible, several such inland satellite distribution centers could be established under major freeway corridors on the eastern, western, and northern boundaries of the city. Table 1-2 presents all three routes with freight types and lengths.

Table 1-2 Route Information with Freight Types and Lengths

No	Route	Freight Type	Origin	Destination	Length (mile)
1	Dallas-Houston	Shipping Container	West side of Barbour's Cut Port, Houston	Dallas Logistic Hub, North of Union Pacific Intermodal Terminal, Lancaster	250
2	Laredo Border	Shipping Container	Southwest of the World Trade Bridge, Nuevo Laredo, Mexico	Intersection of IH-35 and US 59, North side of Union Pacific Intermodal Terminal, Laredo	4
3a	Houston Port – Satellite Dist. Center	Shipping Container	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15
3b	Houston Port – Satellite Dist. Center	Crate	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15
3c	Houston Port – Satellite Dist. Center	Pallet	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15

1.5 Typical Highway Cross Section

The main idea in using an underground system for transferring goods is to use the current technology to bore tunnels under existing highway right of ways in order to enhance corridor capacity, reduce traffic congestion, improve safety, and mitigate the environmental impact. To design such a UFT system, it is necessary to identify various cross-sectional elements and dimensions to determine unused or available spaces within existing right of ways which could be utilized to construct such systems. All three proposed UFT lines are beneath major highways owned by TxDOT with by-and-large similar cross-sectional elements and geometric characteristics. Route 1 (the Port of Houston to City of Lancaster) is proposed to be located below the IH-45 right-of-way, Route 2 (the Laredo Border route), which is partially below the TX-20 Loop, and IH-35 to Route 3 (the Port of Houston to inland satellite port) is below the TX-201 Loop.

The highway elements in each corridor include medians, main lanes (including shoulders), aprons (area between main lanes and frontage roads), frontage roads (including shoulders), and side slopes (area from the frontage road boundary to the right-of-way limit). At times in urban areas, the median may be very narrow or even non-existent due to a limited right of way. In some other areas, there may be no frontage roads, in which case the side slopes will start from the outside edges of the main lanes to the right-of-way limits. The various cross-sectional elements are schematically depicted in Figure 1-11. A short description of each highway element is also available in Table 1-3, along with other GIS database information.

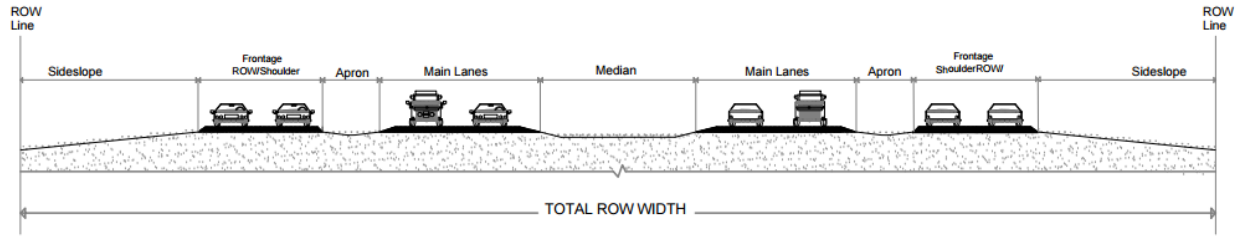


Figure 1-11 Typical Cross Section of a Highway

The UFT project is designed to be constructed beneath the existing right of ways. With the exception of any land required for terminals, there will be no need for right of way purchases. To ensure this, identifying the detailed right of way elements and associated widths for each segment within each corridor is necessary. The width of each highway cross-sectional element is derived from TxDOT GIS databases[1].

1.6 GIS DATABASES AND MAPS

The geographical information system (GIS) provides the capability of editing, storing, analyzing and displaying geospatial data. It can also provide comprehensive information about the project environment and specifications. GIS data may include descriptive information on spatial data and a database that is geographically searchable. For large-scale projects such as UFT, GIS is an efficient tool to manage and analyze data on cross-sectional elements within the right-of-way for each corridor segment.

For the operational planning and design of the system, GIS is utilized to characterize the geometric elements of highways in each of the three UFT corridors. Other physical elements including obstructions (e.g., creeks, rivers, underground structures, etc.), bridges, pipelines, and intersecting roadways are also included in each GIS database. The data are arranged within a one-mile distance from origin (DFO), which is a common method for analysis in long corridors such as those in this project. In this method, the specifications for each one-mile highway segment have been classified in one record and are numbered based on the distance of the segment from the beginning of the project.

For the three main corridors proposed in the UFT project, attempts were made to maintain consistency in building the database for each corridor, despite the differences encountered in availability and format of the data from one corridor to the next. The TxDOT GIS database discussed earlier was the main source of data for this purpose. The GIS database assembled includes the information summarized in Table 1-3.

[1] http://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html (Accessed on Nov. 4, 2015).

Table 1-3 Available Data in GIS Database for Task 1

Median Width	The median width between two opposite main lane directions
Main Lane Width	The total width of the main lanes and shoulders, in both directions
Frontage Width	The total width of frontage roads and shoulders, in both directions
Apron Width	The distance from the outside shoulder of the main lanes to the inside shoulder of the frontage roads
Right-of-Way Width	The total width of the publicly-owned land available, including all road elements and buffers
Major Obstructions	Major construction obstructions in the segment, including underground structures (e.g., bridge piers), creeks, rivers, etc.
Minor Obstructions	Minor construction obstructions in the segment, including highway and railroad crossings
Pipelines Crossing the Route	Number of utility pipelines crossing the route in the segment

1.6.1 Route 1-The Port of Houston to City of Lancaster (near Dallas)

This route is about 250 miles long and starts in Barbour's Cut Port terminal in Houston and ends at the Lancaster Intermodal Terminal south of Dallas. The route is mostly designed to be under the IH-45 corridor, except in the Houston urban area where it is under TX-225 and IH-610. Figure 1-12 shows a segment of the route GIS map. The full database for this route is provided in Appendix A.

A closer examination of the map shows the locations of major obstructions, minor obstructions, railroad crossings, and utility lines buried below the corridor area. The GIS database is also represented in MS Office Excel format (Table 1-4) so that the information can be available for use in other project tasks. As mentioned before, all data are in DFO format with the origin designated as the Barbour's Cut Terminal in the Port of Houston.

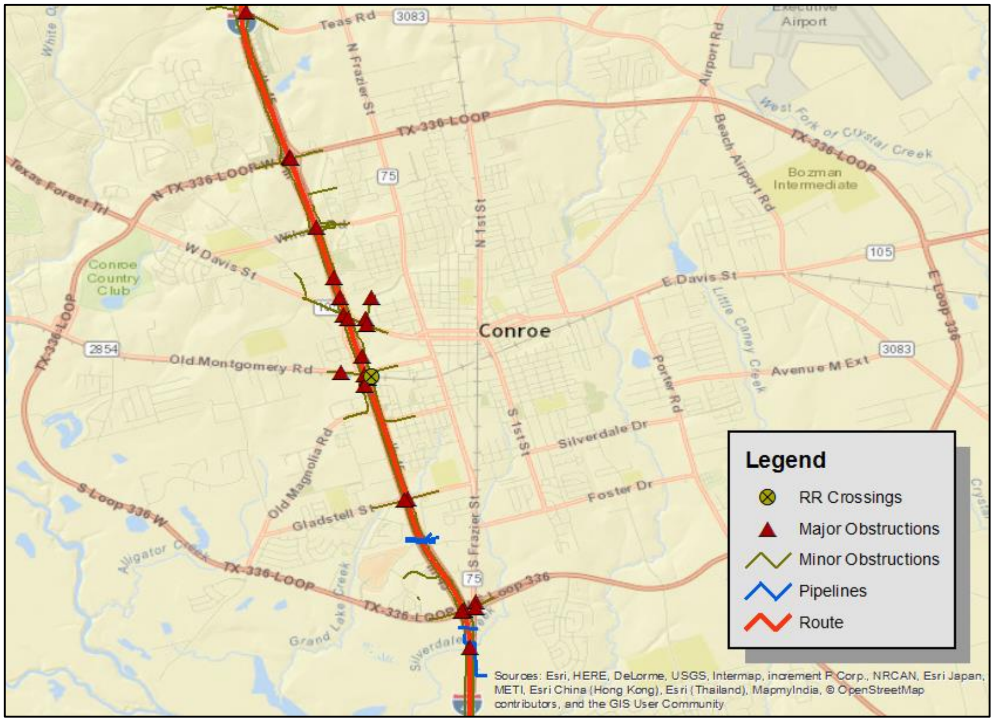


Figure 1-12 An Example of Available Data in GIS Maps

Table 1-4 Route 1-The First 10 Distance from Origins (DFOs) in the GIS Database for the Port of Houston to City of Lancaster (near Dallas)

Item	Distance from Origin (DFO)									
	1	2	3	4	5	6	7	8	9	10
Median Width (ft)	4	4	4	4	6	6	6	4	4	6
Lane Width (ft)	192	140	140	140	196	196	196	144	120	120
Frontage Width (ft)	20	20	20	20	20	20	20	24	24	20
Apron Width Right (ft)	80	40	40	40	60	20	20	40	40	40
Apron Width Left (ft)	40	40	40	40	60	20	0	40	40	40
Total ROW Width (ft)	300	300	300	300	300	300	300	300	300	300
Major Obstructions	7	0	3	2	2	5	1	4	5	3
Minor Obstructions	2	0	2	4	1	2	2	1	2	2
Pipe Xing ROW	0	0	0	0	0	0	0	0	0	0

1.6.2 Route 2-The Laredo Border

As shown schematically in Figure 1-13, the Laredo Border route starts from the southwest end of the World Trade Bridge in Nuevo Laredo, Mexico and terminates at the intersection of IH-

35 and Tx-20 Loop on the north side of the Union Pacific Intermodal Terminal. The route is four miles long, with less than one mile located on the Mexican side of the border.

Table 1-5 shows the database of this route including highway element widths and obstructions for each of the four DFOs along this route.

Figure 1-13 GIS Map of the Route at Laredo Border

Table 1-5 Route 2-GIS Database of Laredo Border

Item	Distance from Origin (DFO)			
	1	**2**	**3**	**4**
Median Width (ft)	700[2]	24	24	38
Lane Width (ft)	96	96	96	78
Frontage Width Right (ft)	0	42	42	20
Frontage Width Left (ft)	0	42	42	20
Apron Width Right (ft)	0	70	70	70
Apron Width Left (ft)	0	70	70	30
Sideslope Width Right (ft)	2	28	28	22
Sideslope Width Left (ft)	2	28	28	22
Total ROW Width (ft)	800	400	400	300
Major Obstructions	2	3	8	1
Minor Obstructions	2	2	3	0
Pipe Xing ROW	0	0	0	0

[2] Current US Customs facilities are located in the median at this DFO

1.6.3 Route 3-the Port of Houston to Inland Satellite Distribution Center in Baytown

To decrease the truck traffic in the port area as well as on more congested urban roads, a UFT route is designed to transfer freight between the Port of Houston and an inland satellite distribution center, which trucks can more easily access to pick up or unload containers. One end of this route is at the west side of the Barbour's Cut Terminal, and the other end is at a truck terminal on the northeast corner of the IH-10 and SH-146 interchange. This route is 15 miles long and is located mostly below the TX-201 Loop. Figure 1-14 shows the GIS map of this route.

The GIS database for the Port of Houston to the inland satellite distribution center in Baytown is shown in Table 1-6. This database has 14 records, one for each 1-mile section, and shows the highway geometry and obstructions along the corridor.

Figure 1-14 GIS Map of Port of Houston to an Inland Satellite Distribution Center

Table 1-6 Route 3-GIS Database of the Port of Houston to the Inland Satellite Distribution Center in Baytown

Item	Distance from Origin (DFO)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Median Width (ft)	4	22	22	2	2	22	20	150	200	24	0	0	0	0	0
Lane Width (ft)	104	112	112	112	112	112	88	110	72	72	78	78	78	78	78
Frontage Width Right (ft)	20	0	0	20	32	24	24	40	0	0	0	0	0	0	0
Frontage Width Left (ft)	32	0	0	32	32	24	24	24	0	0	0	0	0	0	0
Apron Width Right (ft)	0	0	0	36	40	36	80	50	0	0	0	0	0	0	0
Apron Width Left (ft)	0	0	0	40	40	40	80	50	0	0	0	0	0	0	0
Sideslope Width Right (ft)	64	133	33	29	31	31	2	0	14	12	21	21	21	21	21
Sideslope Width Left (ft)	64	133	33	29	31	31	2	0	14	12	21	21	21	21	21
Total ROW Width (ft)	288	400	200	300	320	320	320	424	300	120	120	120	120	120	120
Major Obstructions	5	0	4	4	0	9	2	2	1	0	1	1	1	1	1
Minor Obstructions	1	0	1	2	6	3	3	0	3	2	2	0	0	2	2
Pipe Xing ROW	2	0	0	1	1	1	0	0	0	0	0	1	2	0	0

1.7 ESTIMATING OPERATIONAL PARAMETERS FOR THE SHIPPING CONTAINER SYSTEM

1.7.1 Introduction

A component of the operational design of the system is to develop a relation between headway, flow, and speed for the UFT system. The findings can then be applied to the proposed UFT lines between Houston and Dallas and between the Laredo border and Houston to distribution center routes. The goal is to determine the number of handlers required at the terminus points as well as the desired container flows per day, the number of vehicles needed in the system, the operating speed, and the minimum safe headway.

Variables that significantly impact the operation of a UFT system include operating headway, loading/unloading operation, operating speed, and the route length. While a small headway may raise safety concerns, a large headway will decrease the system efficiency. The capacity in a UFT system in terms of containers transported per day or per unit time (container flow) should be sufficiently high to justify the construction and operation of the UFT system.

Speed has a close relation to flow and headway. The overall operating speed should be comparable to those in other modes of freight transportation, such as trucks and trains. Speed is an important factor in energy consumption (power requirements). The above operational characteristics (speed, flow, headway) strongly influence the UFT terminal design system such as the number and performance characteristics of handlers available for loading and unloading, the number of loading/unloading platforms, and the land area required for a terminal. The following sections elaborate the relationship among headway, flow, the number of handlers and vehicles.

1.7.2 Operating Speed in the UFT System

As stated previously, the proposed UFT system will use electric linear induction motors (LIM) for its propulsion system. As is the case with other sources of energy, the energy consumption in LIM systems has a direct relation to the operating speeds and acceleration rates. Keeping the operating speed of the UFT system low will lead to lower power requirements and operating costs. A lower speed also has benefits regarding the wear and tear on rail tracks, vehicles, the overall tunnel system and therefore, system depreciation. Based on the above, an operating speed of 45 mph is considered optimum speed for the Port of Houston-Dallas UFT system. This speed is high enough to be comparable to the overall speeds of trucks and freight trains but low enough to minimize energy consumption. The fact that the route will be unhindered by underground traffic and stop lights will assure a timely delivery.

According to the Federal Highway Administration (FHWA), the average truck speed on IH-45 between Houston and Dallas is about 54 mph[3]. The proposed 45 mph UFT speed, however, can be considered to be competitive with truck speeds considering that the 54 mph speed is the average operating speed for trucks and does not account for refueling stops, driver breaks, being checked at weigh stations, etc. Therefore, the average overall truck speeds are expected to be considerably lower than 54 mph.

Moreover, the freight rail system connecting Houston to the DFW metropolitan area is a part of the Union Pacific Railroad Company. The average speed in this system is 30 to 33 mph[4], which is lower than the designated 45 mph speed of the UFT system. A comparison of these data indicates that the optimum speed for the UFT system is about 45 mph, which is comparable or higher than truck or rail operating speeds; yet low enough for optimum power requirements.

[3] http://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/10factsfigures/table3_8.htm (Accessed on Nov. 4, 2015).
[4] http://www.railroadpm.org/home/RPM/Performance%20Reports/UP.aspx (Accessed on Nov. 16, 2015).

1.7.3 Estimating Minimum Headways

Several factors influence the choice of headways in the UFT system. Two types of UFT headways can be defined: the minimum headway and the operating headway. Safety concerns and propulsion system restrictions provide basis for determining the minimum headway. Operating headway, on the other hand, is defined based on the desired system flow, which could be lower than the system capacity.

The minimum headway (h_{min}) can be determined so that it meets the propulsion system requirements and prevents collisions between successive vehicles. This suggests that the headway between two successive vehicles should be large enough for the first vehicle to reach the highest operating speed while providing enough time for the second vehicle to stop safely. The time required to travel the length of a vehicle can be considered in this computation. The functional relation for the required minimum headway based on the above considerations is as follows:

$$h_{min} = \frac{l}{1.47} + 1.47\left(\frac{v}{a} + \frac{v}{d}\right) \qquad \text{(Eq. 1-1)}$$

where:

h_{min}= minimum headway between vehicles (sec),
l= length of the vehicle (ft),
v = running speed (mph),
a= acceleration rate (ft/sec^2), and
d= deceleration rate (ft/sec^2).
The coefficient 1.47 is to convert the speed from mph to ft/sec.

Regarding the shipping container system, vehicles should be long enough to accommodate the 40-foot standard shipping containers. With additional front and rear overhangs required for operational purposes, a minimum overall vehicle length of 49 ft will result, as shown schematically in Figure 1-15.

Similar to operating speed, the acceleration rate is also an important variable in energy consumption. A high acceleration rate will increase energy consumption, in most cases without a commensurate operational benefit. An acceleration rate of about 10 ft/sec^2 is recommended for the UFT system, as it is small enough to reduce energy consumption and to prevent containers from shifting, yet large enough to minimize headways.

While energy consumption is not a major consideration in the deceleration case, having a high deceleration rate may also result in shifting of containers or excessive shear force on the vehicle chassis and axles. A deceleration rate of about 10 ft/sec^2 is considered to be a reasonable value in this case, comparable to a rate at which a vehicle is normally brought to stop at a traffic signal. Considering an operating speed of 45 mph, acceleration and deceleration values of 10 ft/sec^2, and a vehicle length of 49 ft, Eq. 1-1 yields a minimum safe headway of about 14 seconds.

The LIM system imposes limitations on the design and operations of the UFT. Decreasing the headway between vehicles, for example, could overheat the LIM system. A sufficiently long gap between successive vehicles is needed to give the LIM system time to cool down and to sustain normal operations. Overheating the LIM system is both unsafe and energy consuming. Based on LIM experts consulted, a 30-second headway is an optimum headway for a UFT system for standard shipping containers[5]. By the same token, the optimum headway for both the crate and pallet UFT systems has been set at 20 seconds[5].

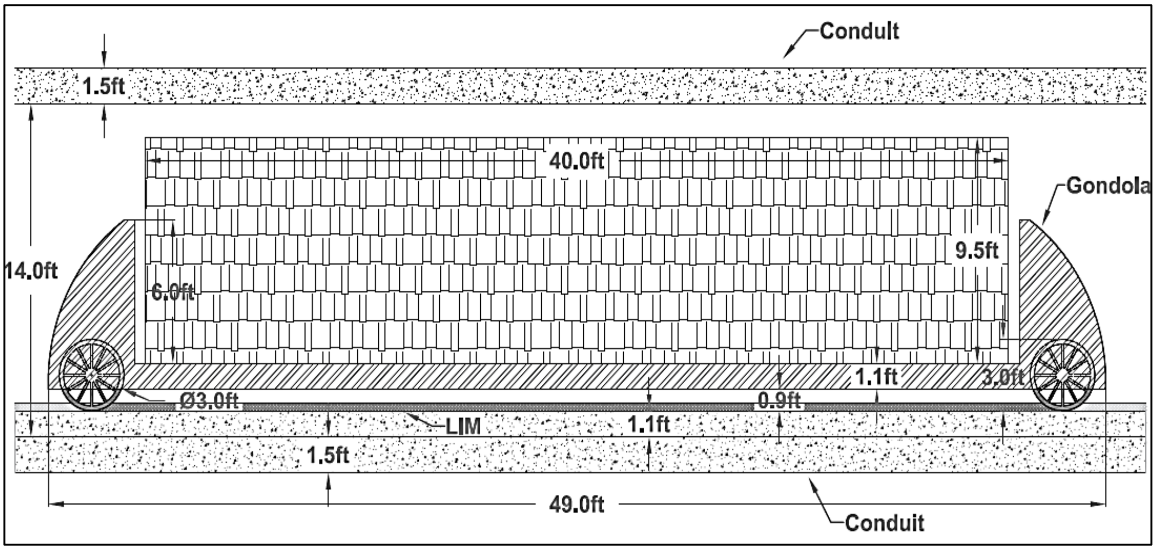


Figure 1-15 Longitudinal Section of a Shipping Container Vehicle

1.7.4 Determination of System Capacity

The system capacity is defined as the maximum number of freight loads the UFT system can deliver in a 24-hour-day. Capacity can also be considered as the maximum flow of vehicles. Based on this definition, the system capacity is directly affected by the minimum headway of the system. A UFT system with a lower headway will naturally have a higher freight transport capacity. Eq. 1-2 shows the relation between the minimum headway, working hours per day, and the system capacity:

$$C = 3{,}600 \frac{T}{h_{min}} \qquad \text{(Eq. 1-2)}$$

where:

h_{min}= minimum design headway (sec),
T= working hours (hrs/day), and
C = system capacity (vehicles/day/direction).

Based on the estimated minimum headway of the shipping container system (30 Sec) and a 24-hour workday the system capacity is estimated to be 2,880 vehicles/day/direction.

[5] Feghhi, Jalal, UFT Project email correspondence, Nov. 18, 2015.

1.7.5 Calculating Operating Headways

The operating headway for the UFT system is primarily influenced by the system flow, the number of containers to be delivered in a day and the working hours per day at the origin and destination. The operating headway can be calculated using Eq. 1-3:

$$h_{opr} = 3{,}600\frac{T}{Q} \qquad \text{(Eq. 1-3)}$$

where:

h_{opr}= operating headway (sec),
T= working hours (hrs/day), and
Q = system flow (vehicles/day).

Since the UFT system is designed to operate 24 hours a day, Table 1-7 and Figure 1-16 show the operating headway versus the container (vehicle) flow in the system.

Table 1-7 The Relation Between Desired Flow Rates (Q) and Operating Headways (h)

Q (Containers/Day)	h (Sec)
1,500	58
2,000	43
2,500	35
3,000	29
3,500	25
4,000	22

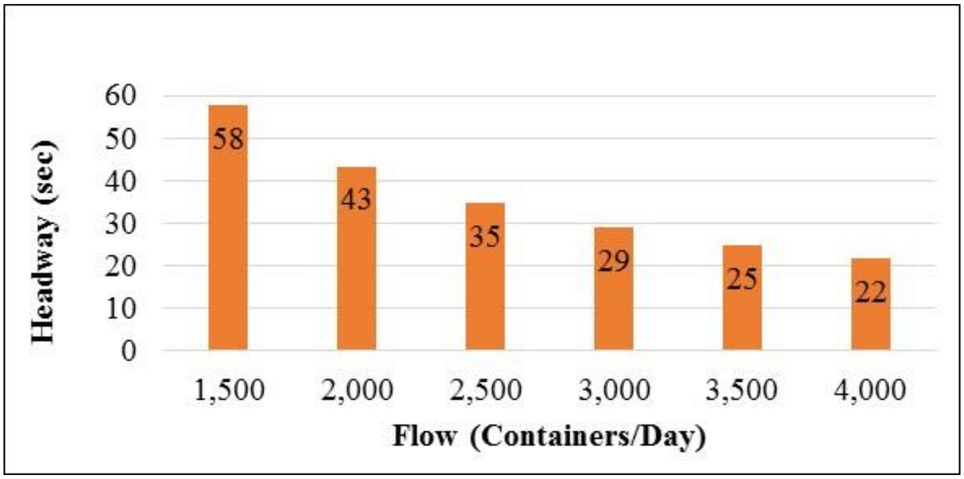


Figure 1-16 UFT System Headway vs. Shipping Container Flow

1.7.6 Estimating Number of Handlers at Terminals

Handlers are one of the most essential and costly components of a UFT terminal. Handlers are used for both loading and unloading the shipping containers as well as for stacking the shipping containers in the stacking yard and for loading/unloading trucks. The operating characteristics of handlers are significantly influenced by the UFT system headways and capacity. The time required for handlers to load or unload a shipping container determines the number of platforms in each loading/unloading section of the terminal. A UFT system with a lower headway requires a higher number of handlers to accommodate freight arriving or departing.

Eq. 1-4 shows the relation between flow, UFT system working hours per day, the loading/unloading time, and the number of loading and unloading pair platforms:

$$N_c = \frac{Q \times t}{3{,}600T} \qquad \text{(Eq. 1-4)}$$

where:

N_c = number of loading/unloading pair platforms,
t = loading/unloading time (sec),
T = working hours (hrs/day), and
Q = system flow (vehicles/day).

This number (N_c) is equal to the number of platforms needed in each loading and unloading section of terminal. If we denote N_t to be the total number of handlers required in the system, then $N_t = 2N_c$. A number of additional (backup) handlers will also be needed in case of emergency or breakdown of the operating handlers. It is reasonable to consider two additional handlers for each section of the terminal (loading and unloading sides) as backups. As a result, the total number of handlers required in the UFT terminal can be calculated as follows:

$$N_t = 2 \times (N_c + 1) \qquad \text{(Eq. 1-5)}$$

where:

N_c = number of loading and unloading paired platforms and
N_t = total number of handlers/forklifts required.

It can be concluded that in a shipping container terminal, assuming 90 seconds as the average loading/unloading time of a handler, a total of 20 handlers will be needed to handle a capacity of 2,880 containers per 24-hour work day. Table 1-8 and Figure 1-17 show how the total number of handlers varies with the desired UFT flow.

Table 1-8 The Relation between Desired Flow Rates and the Total Number of Handlers

Quantity (container loads per day)	N_c Loading/unloading paired platforms)	N_t (handlers & forklifts
1,500	2	6
2,000	3	8
2,500	3	8
3,000	4	10
3,500	4	10
4,000	5	12

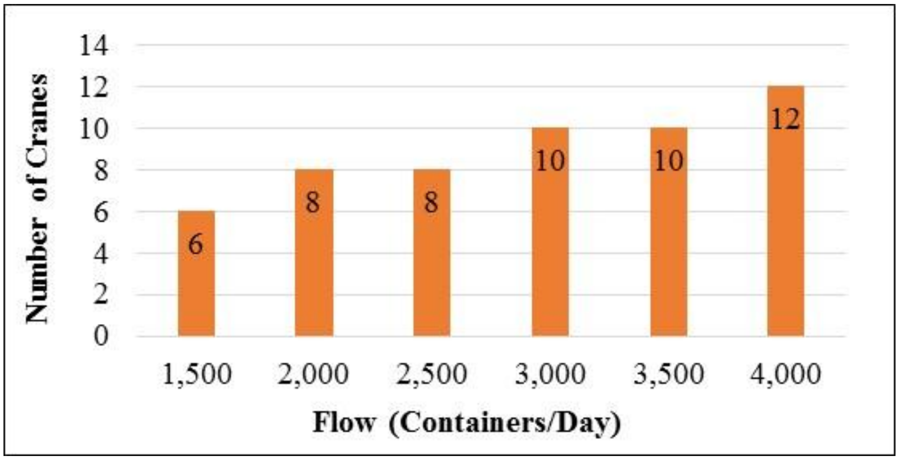


Figure 1-17 Total Number of Handlers in Relation to System Flow

1.7.7 Required Number of Vehicles

In the operation of the UFT system, it is necessary to know the number of vehicles in use when the system is operating at capacity (at minimum headway). When the UFT system is handling flows lower than capacity, then not all vehicles will be in use. The excess vehicles can be either on stand-by in each terminal's layover section or continue to circulate in the line with no payload. The required number of vehicles depends on the system length, speed, and operational headway, as follows:

$$N_g = 7{,}200\left(\frac{L}{v \times h_{opr}}\right) + 1.47\left(\frac{v}{h_{opr}}\right)\left(\frac{1}{a} + \frac{1}{d}\right) \qquad \text{(Eq. 1-6)}$$

where:

N_g = number of vehicles in use,
h_{opr} = operating headway (sec),
L = total length of the line (miles),
v = running speed (mph),
a = acceleration rate (ft/sec^2), and
d = deceleration rate (ft/sec^2).

Table 1-9 and Figure 1-18 show how the number of vehicles required in the UFT system varies with operating headway.

Table 1-9 The Relation Between Operating Headway and Number of Vehicles

h_{opr} (operating headway in seconds)	N_g (number of vehicles in use)
15	2,668
20	2,001
25	1,601
30	1,334
35	1,143

Figure 1-18 Total Number of Vehicles in the Shipping Container System Based on the Operating Headway

Eq. 1-6 yields the required number of vehicles in the UFT system when the flow in both directions is the same. The minimum headway for the Port of Houston-Dallas UFT system is determined to be 30 seconds with a one-way line length of 250 miles; hence, a total of 1,334 vehicles will be needed for this system.

For the Laredo border UFT line with the shipping size container system, the minimum headway remains the same, but its one-way length is only four miles. Thus, the required number of vehicles for this system will be 22. For the line from the Port of Houston to a satellite in-land terminal in Baytown, for a one-way length of 15 miles, a total of 80 vehicles will be required under capacity conditions. Note that this line is being designed for crate- or pallet-load systems. The operating parameters of those systems are analyzed in the next section.

1.7.8 Section Conclusion

The operating parameters for each of the three routes for standard shipping container systems are summarized in Table 1-10. As shown, the operating parameters are based on a 30-

second minimum operating headway or capacity flow of 5,760 containers per day. If the container volume is less than the line capacity, excess vehicles could be stored in the lay-over sections of each end terminal, thus allowing higher than minimum operating headways. Alternatively, as discussed earlier, 30-second headways could continue to be maintained by allowing some vehicles to circulate empty.

Table 1-10 Summary of Operating Parameters for UFT Routes for Shipping Containers

Route	Dallas-Houston	Laredo Border	Houston-Dist. Center
Length (miles)	250	4	14
Speed (mph)	45	45	45
Min Headway (sec)	30	30	30
Capacity (Vehicles/Day)	5,760	5,760	5,760
Handlers (per terminal)	8	8	8
Vehicles Circulating	1,334	22	80
Platforms (per terminal)	6	6	6
Terminal Area (acres)	21.5	21.5	21.5

1.8 ESTIMATING OPERATING PARAMETERS FOR PALLET AND CRATE SYSTEMS

1.8.1 Speed, Headway and Capacity

As previously described, the 45 mph speed is considered an optimum speed for the UFT system; hence, the crate and pallet systems are designed for a speed of 45 mph as well. Considering this speed and the length of each vehicle, the minimum safe headway can be calculated using Eq. 1-1. The acceleration and deceleration rates are considered to be 10 ft/s^2. Calculations show that the minimum safe headway for both systems is about 14 seconds.

Regarding the minimum operating headway, it should be noted that for vehicles carrying crates or pallets, due to lighter gross weights than shipping container vehicles, the minimum headways based on the LIM system requirements are 15 and 10 seconds, respectively.[3] However, due to safety and handler operating constraints at the terminals, a minimum operational headway of 20 seconds is recommended for the latter two UFT systems.

Knowing the minimum headway, Eq. 1-2 determines the system capacity. For the crate and pallet systems with 20-second headways, the capacity will be 4,320 vehicles per day per direction.

1.8.2 Number of Forklifts

Each vehicle with crates or pallets contains two loads. So it is reasonable to consider a loading/unloading time that is greater than that for shipping containers. It should be noted, however, that forklifts can be operated faster than handlers used for shipping containers. But since each vehicle contains two loads, for calculation of capacity, the loading/unloading time for each vehicle is considered to be approximately 1.5 times greater than that for shipping containers, i.e., about 120 seconds per vehicle.

Eq. 1-4 determines the number of platform pairs in a terminal design which is six loading and unloading platforms for pallet and crate size systems with minimum headways of 20 seconds and operating at full capacity.

The total number of forklifts needed in each terminal is twice the number of loading/unloading platform pairs plus two for backup. Hence, a total of 14 forklifts are needed in each terminal for crate/pallet size systems.

1.8.3 Number of Vehicles

The length of the Houston-Satellite distribution center, for which the pallet and crate size systems are designed, is 15 miles. The required number of vehicles in this system using Eq. 1-5 for pallet and crate systems with 20-second headways in Houston-Satellite Port route is 122.

1.8.4 Section Conclusions

The operating parameters of the three systems for the Houston-Satellite distribution center route (one system for each load type) can be summarized as shown in Table 1-11.

Table 1-11 Summary of Operating Parameters for Each UFT Size Load in the Designated Houston-Distribution Center Route

Route	Houston to Satellite Dist. Center	Houston to Satellite Dist. Center	Houston to Satellite Dist. Center
Freight Type	Shipping containers	Crates	Pallets
Length (miles)	14	14	14
Speed (mph)	45	45	45
Min Headway (sec)	30	20	20
Capacity (vehs/day/direction)	2,880	4,320	4,320
No. of Handlers (per terminal)	8	N/A	N/A
No. of Forklifts (per terminal)	N/A	14	14
Vehicles Circulating (at capacity conditions)	80	122	122
Fully-Loaded Veh. Weight (U.S. tons)	39	9.3	5.6
Loading/Unloading Platforms (per terminal)	6	12	12
Terminal Area (acres)	21.5	21.3	8.7

1.9 TERMINAL DESIGN

The objective of this section is to develop a schematic design for the UFT terminals for each of the three load types (shipping containers, crates, and pallets). The terminal design specifications include rail facility design and layout, freight handling, highway access, planning and environmental considerations, and project time scales.[1] The development of individual freight terminals demands a detailed approach for freight flows, handling processes, equipment selection, the role of information communication technologies (ICTs) in freight transport, and the operational and control rules. Therefore, the design and operating analysis of these systems are significant components in providing a state-of-the-art functional design.[2] Based on the import and export items in the Port of Houston and their packaging methods,[3] the need and specifications for various elements at the terminal yard are shown in the Tables 1.12 and 1.13.

1.9.1 Schematic Design of Terminal

A key component of the UFT terminal is the loading and unloading platforms. A total of six platforms (three loading and three unloading) are sufficient for the shipping container UFT system between Houston and Dallas. For the smaller size UFT systems (pallets and crates), due to shorter headways, 12 loading/unloading platforms would be necessary. If more loading/unloading areas are needed, the number of platforms could be increased to handle additional container flows.

---

[1] Network rail (2015), "Move my Freight by Rail" available at: www.networkrail.co.uk/aspx/10442.aspx. (Accessed on Dec. 1, 2015).
[2] Designing Cargo Terminals. (2015), available at: http://www.districon.com/practices/cargo-logistics/designing-cargo-terminals. (Accessed on Dec. 4, 2015).
[3] Port of Houston Authority (PHA), (2015), "Import and Export Items with Packaging Methods in PHA," Available at: http://www.portofhouston.com/. (Accessed on Dec. 4, 2015).

Table 1-12 Export Items with Packaging Methods in Port of Houston (Port of Houston Authority, 2015)

Items	Packaging Methods
Resins and Plastics	Pallet in Container
Chemicals and Minerals	Liquid Chemicals: Barrel over Pallet in Container/Minerals: Jumbo Bag over Pallet in Container
Food and Drink	Manufactured Packages Over Pallet in Container: Beer in Wooden Boxes and Cardboard Containers
Machinery	Depends on Size
Appliances and Electronics	Pallet in Container
Automotive	Depends on Size of Freight Ship w/o Container
Fabrics incl. Raw Cotton	Pallet in Container
Steel and Metals	Steel Bar: Pallet/ Metals Sheet: Pallet in Container
Hardware and Construction Materials	Pallet in Container
Retail Consumer Goods	Pallet in Container
Apparel and Accessories	Pallet in Container
Furniture	Pallet in Container
Other	Pallet in Container

Table 1-13 Import Items with Packaging Methods in Port of Houston (Port of Houston Authority, 2015)

Items	Packaging Methods
Food and Drink	Manufacture Package over Pallet in Container
Hardware and Construction Materials	Pallet in Container
Machinery	Depends on Size
Appliances and Electronics	Pallet in Container
Steel and Metals	Steel Bar: Pallet/ Metals Sheet: Pallet in Container
Retail Consumer Goods	Pallet in Container
Chemicals and Minerals	Liquid Chemicals: Barrel over Pallet in Container/Minerals: Jumbo Bag over Pallet in Container
Automotive	Depends on Size of Freight Ship w/o Container
Resins and Plastics	Pallet in Container
Furniture	Pallet in Container
Apparel and Accessories	Pallet in Container
Fabrics Incl. Raw Cotton	Pallet in Container
Other	Pallet in Container

Figure 1-19 shows a schematic layout of a typical UFT terminal for standard shipping containers, as well as crates and pallets. As vehicles arrive, they are directed to the first available unloading platform. Bypass shunts are designed to alleviate queueing of arriving vehicles during the peak time. Unloading the freight on each platform by using a handler is estimated to take about 90 seconds. In turn, the minimum headway between consecutive vehicles could be as low as 30 seconds. Therefore, there is a potential for a traffic back-up without bypass shunts to allow vehicles to continue downstream of the track to the next available platform.

After unloading their freight, vehicles are directed beyond the loading platform through the underpass lines. Underpass lines pass beneath the bypass shunts[6] and are designed with an approximate 10% grade. They direct the vehicles to the loading platforms or, if need be, to the layover and maintenance lines for service or repairs. Layover lines and maintenance lines run parallel to the main line to allow vehicles to return to the main line when needed. Vehicles then pass underneath a second bypass shunt and proceed to the outgoing loading platform to be loaded with outbound freight and be directed to the outgoing main lines.

1.9.2 Required Terminal Areas

The terminal area calculations entail required areas for handler operations, stack yards, truck access, service yard, and vehicle storage and parking. Eq. 1-7 yields the terminal area based on the pair of loading/unloading platforms. For the shipping container terminals, it has a constant value (56,000 sq. yds.) for the first pair of loading/unloading platforms, and a variable section for each additional pair of loading/unloading platforms, as follows:

$$A = 56{,}000 + 24{,}000(N - 1) \qquad \text{(Eq. 1-7)}$$

where:

A = total terminal area (sq. yds.), and
N = number of loading/unloading platforms.

The respective terminal area calculations for the two smaller UFT systems for crates and pallets are given in by Eqs. 1-8 and 1-9, respectively.

For crate UFTs: $A = 29{,}500 + 14{,}700\ (N - 1)$ (Eq. 1-8)

For pallet UFTs: $A = 11{,}980 + 5{,}990\ (N - 1)$ (Eq. 1.9)

Table 1-14 presents the resulting total number of loading/unloading platforms for each UFT system, the total terminal area and the terminal stacking area. For the shipping container size, Eq. 1-7 yields a total terminal area of 104,000 sq. yds. (21.5 acres) for the Houston-Dallas UFT line. The respective area sizes for terminals handling crate vehicles and pallet vehicles are 21.3 acres (Eq. 1-8) and 8.6 acres (Eq. 1-9), respectively. These estimates are based on 12 loading/unloading platforms for each of the two smaller UFT systems for crates and pallets.

[6] Pull or push a vehicle from the main track to a siding or from one track to another.

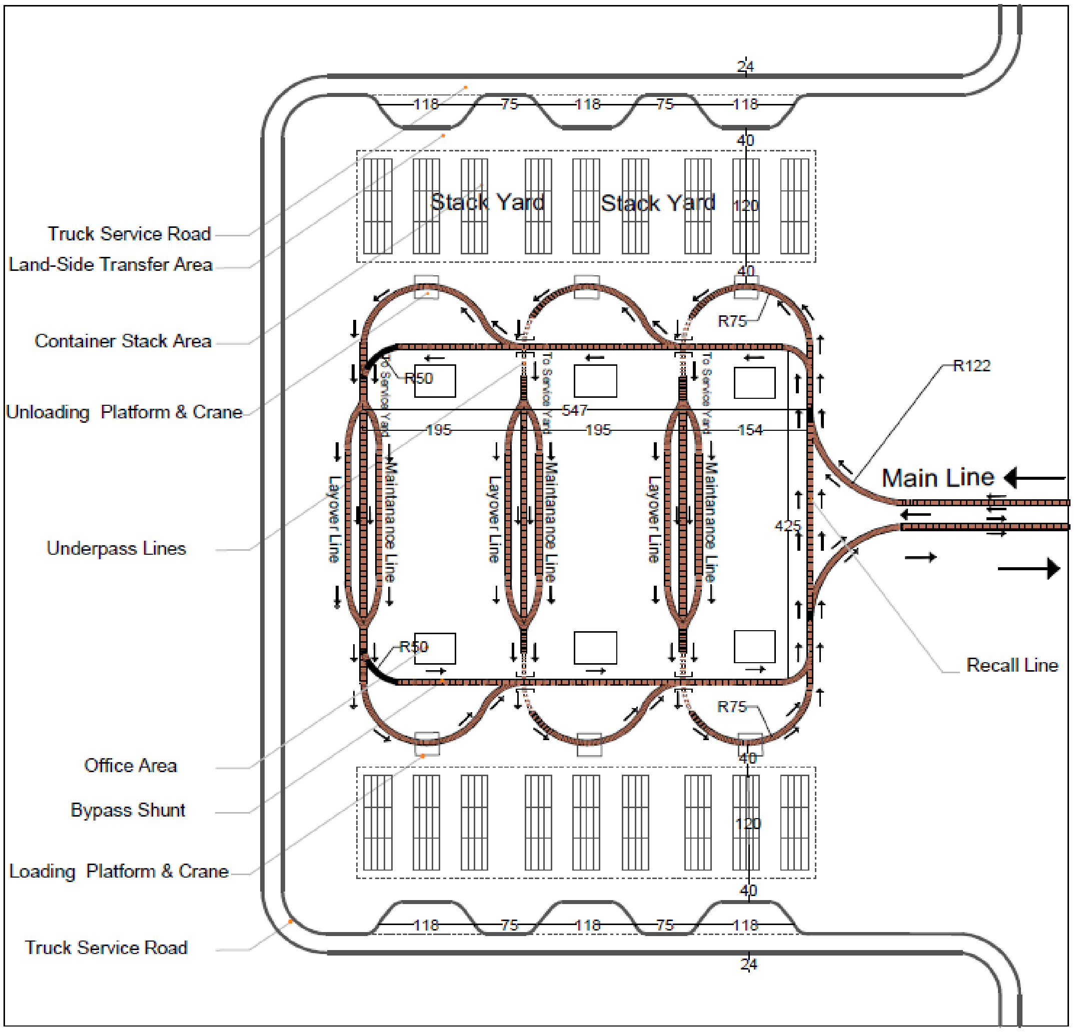


Figure 1-19 Typical Terminal Layout

Table 1-14 Required Terminal Area for Each UFT System

Freight Type	Number of Loading/ Unloading Platforms	Total Terminal Area (sq. yds.)	Stack-Yard Paved Area (sq. yds.)
Standard Shipping Container	6	104,000 (21.5 acres)	32,900 (6.8 acres)
Crate	12	103,000 (21.3 acres)	16,200 (3.3 acres)
Pallet	12	42,000 (8.6 acres)	6,850 (1.4 acres)

1.10 SECTION SUMMARY

Each proposed route has two end terminals (no intermediate terminals). At each terminal, there are a number of loading/unloading platforms. Forklifts and handlers are required at each platform for loading and unloading the containers, pallets, or crates. For each platform, at least two forklifts/handlers are needed; one to load/unload vehicles and to haul the containers to the stacking yard, and the other to load/unload the trucks. In each terminal, a total of four additional handlers/forklifts are recommended for backup. Table 1-15 shows the parameters related to handlers/forklifts in terminals for each of the three freight types (containers, crates, or pallets).

Table 1-15 Handler/Forklift Specifications and Operational Parameters

	Container	Crate	Pallet
Load weight (U.S. tons)	34	3.5	2.3
Min load/unload time (min)	1.5	2	2
System capacity (vehs/day/direction)	2,880	4,320	4,320
Number of platforms	6	12	12
Number of forklifts	N/A	12	12
Number of handlers	8	N/A	N/A

This Page is Intentionally Left Blank

PART 2-UFT PROPULSION SYSTEM (LIM)

1.11 INTRODUCTION

In this section, the design of the propulsion system to connect Port of Houston to the inland satellite distribution center at Baytown for all three sizes of containers, crates, and pallets is discussed. Other items covered here include:

- Using the same propulsion system to transport standard shipping containers and crates and pallets.
- Optimizing energy utilization of the LIM system.
- Increasing the utilization of the entire transportation system by decreasing the distance between the vehicles.
- Estimating the capital expenditure to construct and install the propulsion LIM system.
- Providing operational cost estimates for the electricity used in the LIM system.

1.12 DESIGN REQUIREMENTS AND PARAMETERS

Table 1-16 outlines the design requirements for the propulsion system with additional parameters for transportation of crates and pallets. Design requirements include payload weight, operating speed, the slope and the cross sectional area of the vehicle.

Table 1-16 UFT Design Parameters

Parameter	Quantity
Total Payload Weight – Standard Shipping Container	78,000 lb (39 tons)
Payload Cross Sectional Area – Standard Shipping Container	88 ft^2
Total Payload Weight – Crate (Two Crates per Vehicle)	18,600 lb (9.3 tons)
Payload Cross Sectional Area – Crate	38 ft^2
Total Payload Weight – Pallet (Two Pallets per Vehicle)	11,200 lb (5.6 tons)
Payload Cross Sectional Area – Pallet	19 ft^2
Distance to Complete the Travel (One Way)	250 miles
Vertical Distance from Terminal to Tunnel	50 ft
Slope of Ramp from Terminal to Tunnel	10 degrees
Speed of Vehicle at the Top of Ramp	2 miles/hour
Speed of Vehicle at the Bottom of Ramp (Calculated)	39 miles/hour
Operating Speed	45 miles/hour

1.13 FRICTIONAL FORCES AND ENERGY LOSSES

In this section, two main frictional forces that cause energy loss in the system and force the propulsion system to engage to maintain an average speed of 45 miles per hour are explored. Table 1-17 lists the various constants assumed in industry for the coefficient of friction between wheels and tracks to carry out the calculations, and such constants as air drag and air density at sea level.

Table 1-17 Coefficients of Friction

Parameter	Quantity
Coefficient of Friction between Wheels and Tracks (u)	0.001
Coefficient of Air Drag (c_d) at Sea Level	0.5
Air Density (ρ) at Sea Level	$0.075\ \frac{lb}{ft^3}$
Acceleration Due to Gravity	$32.8\ \frac{ft}{s^2}$

1.13.1 Frictional Forces between the Vehicle Wheels and the Tracks

The friction created by the spinning of the vehicle wheels on the tracks is calculated as follows:

$$F_w = nu \quad \text{(Eq. 1-10)}$$

where:

n = the normal force acting on the tracks, and

u = the coefficient of friction.

1.13.1.1 Frictional Force for Standard Shipping Containers

$$F_w = 78{,}000 \times 0.001$$
$$\boldsymbol{F_w = 78\ lbf}$$

1.13.1.2 Frictional Force for Crates

$$F_w = 18{,}600 \times 0.001$$
$$\boldsymbol{F_w = 18.6\ lbf}$$

1.13.1.3 Frictional Force for Pallets

$$F_w = 11{,}200 \times 0.001$$
$$\boldsymbol{F_w = 11.2\ lbf}$$

1.13.2 Air Resistance and Drag on the Vehicles

The following formula is used to calculate the amount of drag caused by air resistance:

$$F_d = \frac{1}{2g} \rho \, v^2 c_d \mathrm{a} \qquad \text{(Eq. 1-11)}$$

where:

v = the Operating speed, and

a = the surface area attributed to the profile of the container mounted on the vehicle.

Other variables are defined in Table 1-16.

1.13.2.1 Air Resistance for Standard Shipping Containers

$$F_d = \frac{1}{2 \times 32.8}(0.075)\,(45 \times 1.47)^2(0.5)(88)$$

$$\boldsymbol{F_d \cong 220\ lbf}$$

1.13.2.2 Air Resistance for Crates

$$F_d = \frac{1}{2 \times 32.8}(0.075)\,(45 \times 1.47)^2(0.5)(38)$$

$$\boldsymbol{F_d \cong 91\ lbf}$$

1.13.2.3 Air Resistance for Standard Shipping Pallets

$$F_d = \frac{1}{2 \times 32.8}(0.075)\,(45 \times 1.47)^2(0.5)(19)$$

$$\boldsymbol{F_d \cong 45\ lbf}$$

1.13.3 Total Frictional Forces and System Energy Loss

We sum up the individual forces to calculate the total amount of the friction:

$$F_t = F_w + F_d \qquad \text{(Eq. 1-12)}$$

$$\boldsymbol{F_t\ (standard\ shipping\ containers) \cong 300\ lbf}$$

$$\boldsymbol{F_t\ (crates) \cong 110\ lbf}$$

$$\boldsymbol{F_t\ (pallets) \cong 57\ lbf}$$

1.13.4 Power Requirements

To determine the power requirement for the UFT to maintain constant operating speed, the power formula is used for standard shipping containers as follows:

$$P = fv \qquad \text{(Eq. 1-13)}$$

$$f\ is\ force\ in\ lb$$
$$P = F_t v$$
$$P = 300 \times (45 \times 1.47) \times (\frac{1}{0.738})$$
$$P = 26{,}890\ W \cong 36\ \text{Hp}$$
$$\boldsymbol{P}\ (\textbf{standard shipping containers}) \cong \textbf{27 kW} (\approx \textbf{36}\ \boldsymbol{Hp})$$

Similarly, the power requirements are used for the other payload sizes:

$$\boldsymbol{P}\ (\textbf{crates}) \cong \textbf{10 kW} (\cong \textbf{13.5}\ \boldsymbol{Hp})$$
$$\boldsymbol{P}\ (\textbf{pallets}) \cong \textbf{5.5 kW} (\cong \textbf{7.5}\ \boldsymbol{Hp})$$

1.14 SPECIFICATIONS FOR RECOMMENDED LIM

A linear induction motor is prescribed with an approximate power of 400 kW as the main building block unit for the UFT propulsion system to inject energy into the system to offset the energy loss due to the frictional forces. Table 1-18 presents the size, voltage, and all other relevant parameters for the recommended LIM.

Table 1-18 Recommended LIM

Parameter	Quantity
Size	7 ft × 3 ft × 1 ft
Area	21 ft^2
Duty Cycle	3%
Voltage	400 VAC 3 phase
Current @ Duty Cycle	650 A (amps)
Power @ Duty Cycle	400 kW
Force @ Duty Cycle	3400 lbf
Air Gap	0.375 in.
Frequency	75 Hz
Conductor Material	Aluminum
Conductor Thickness	0.125 in.

1.15 INSTALLATION OF LIMS ON VEHICLES AND TRACKS

A LIM has two parts, a primary and a secondary, which are separated from each other by an air gap. The primary generates a magnetic field that produces a linear thrust along the secondary, causing the secondary to move in the longitudinal direction.

Figures 1-1 through 1-3 depict how the recommended UFT can be installed between a vehicle and tracks for various payload sizes. The primary will be affixed to the stationary bottom track, while the secondary will be affixed to the bottom of the vehicle with the same centerline as the primary. Note that the secondary runs all the way along the vehicle, from one end to the other end.

1.16 PROPULSION SYSTEM CAPACITY AND THROUGHPUT

Based on the LIM specifications outlined in the previous section and the other design parameters, the capacity of the system for the transportation of various payload sizes is determined. Tables 1-19 through 1-21 provide various capacity information, including each headway between the maximum number of vehicles transporting freight.

Table 1-19 System Capacity for Transporting Containers

Parameter	Quantity
Time Interval between Vehicles	30 seconds
Number of Vehicles per mile	3
Distance to Travel (One Way)	250 miles
Total Distance (Round Trip)	500 miles
Total Number of Vehicles on Tracks (Round Trip)	1,500

Table 1-20 System Capacity for Transporting Crates

Parameter	Quantity
Time Interval between Vehicles	15 seconds
Number of Vehicles per mile	6
Distance to Travel (One Way)	15 miles
Total Distance (Round Trip)	30 miles
Total Number of Vehicles on Tracks (Round Trip)	180

Table 1-21 System Capacity for Transporting Pallets

Parameter	Quantity
Time Interval between Vehicles	10 seconds
Number of Vehicles per mile	9
Distance to Travel (One Way)	15 miles
Total Distance (Round Trip)	30 miles
Total Number of Vehicles on Tracks (Round Trip)	270

1.17 CAPITAL EXPENDITURES AND OPERATIONAL ENERGY COSTS

In this section an estimated budget to construct the propulsion system and an estimate of the annual cost of electricity to operate the system are provided. Refer to Table 1-22 for the list of parameters used in this section.

Table 1-22 Quantities Used for Price Calculations

Parameter	Quantity
Approximate Cost to Procure and Install a LIM	\$25,000
Price of Electricity in Texas	\$0.0533 per kWH

1.17.1 Initial Capital Investment to Acquire and Install the LIMs

Regardless of the choice for the LIM placement configuration and the payload size, the propulsion system requires 10 LIMs for each mile. We can calculate the initial capital investment to build the propulsion system as follows:

$$Investment \cong LIMs\ Per\ Mile \times Total\ Miles \times Price \qquad \text{(Eq. 1-14)}$$

$$Investment\ (containers) \cong 10 \times 500 \times \$25{,}000$$

Investment (containers) ≅ \$125,000,000

Similarly, we calculate the operation costs for crates and pallets:

$$Investment\ (crates) \cong 10 \times 30 \times \$25{,}000$$

Investment (crates) ≅ \$7,500,000

$$Investment\ (pallets) \cong 10 \times 30 \times \$25{,}000$$

Investment (pallets) ≅ \$7,500,000

1.17.2 Operating Energy Costs

The annual electricity consumption charge can be estimated as follows. For standard shipping containers, the current design of the propulsion system assumes vehicles arrive at a LIM every 30 seconds, which means we have three vehicles on each mile of the track. Therefore, for the entire 500 miles (round trip) we need to transport 1,500 vehicles at any given time. Each vehicle on the average requires 30 kW of energy to maintain its operating speed. Therefore, the total annual energy usage is:

$$Energy = Total\ Capsules \times Power\ Per\ Hour \times Hours\ per\ Year \times Electricity\ Price \qquad \text{(Eq. 1-15)}$$

$$Energy\ (containers) \cong 1{,}500 \times 27 \times 8{,}765 \times \$0.0533$$

$$\boldsymbol{Energy\ (containers) \cong \$19,000,000\ per\ year}$$

Similarly, the operational costs are calculated for crates and pallets:

$$Energy\ (crates) \cong 180 \times 10 \times 8{,}765 \times \$0.0533$$

$$\boldsymbol{Energy\ (crates) \cong \$1,000,000\ per\ year}$$

$$Energy\ (pallets) \cong 270 \times 5.5 \times 8{,}765 \times \$0.0533$$

$$\boldsymbol{Energy\ (pallets) \cong \$700,000\ per\ year}$$

This Page is Intentionally Left Blank

CHAPTER 2-CONSTRUCTION METHODS

2.1 INTRODUCTION

Chapter 2 presents UFT construction methods with an estimation of project duration, construction equipment, and shaft construction methods for the three proposed routes as shown in Table 2-1.

Table 2-1 Summary of Three Proposed Routes

Route	Length (miles)	Size of Tunnel (Outside Diameter, ft)
Route 1-Port of Houston to City of Lancaster (near Dallas)	250	25, 16[7]
Route 2-Border between the U.S. and Mexico in Laredo, TX	4	25
Route 3-Port of Houston to an Inland Satellite Distribution Center in Baytown	15	25, 17.4, 13[8]

2.1.1 Objectives

The purpose of Chapter 2 is to select an appropriate construction method to build a tunnel or conduit based on freight size, ground and surface conditions for the proposed routes as shown in Table 2-1.

2.2 PROJECT PLANNING AND SAFETY

Safety should be a primary consideration from project inception and continue throughout the entire life-cycle of UFT. Such sources as the Texas Railroad Commission (TRRC) and Texas811 program will be incorporated early in the planning stage for routing considerations. Other resources will utilize large surface features (Google Earth) and approximate elevation data (Texas Natural Resources Information System or TNRIS). Other considerations will be permanent and temporary construction easements and construction staging areas.

2.3 BACKGROUND ON CONSTRUCTION METHODS

2.3.1 Cut-and-cover Method

Cut-and-cover is only considered for single-track system, as shown in Figures 1-1 through 1-3, and involves open trenching and installing a pipeline on a suitable bedding material and then embedding and backfilling (Najafi and Gokhale, 2005). Figure 2-1 illustrates a typical pipeline

[7] Two tunnel sizes are considered for Route 1 based on the method of construction and is discussed in more detail in Section 2.4.
[8] Route 3 is designed for three freight types: container, crate and pallet.

installation. Cut-and-cover construction for the UFT project is considered as an option at locations where minimal disturbances to traffic, surface development and the environment exist. Overall, it should be noted that in the cut-and-cover method, most construction efforts and resources are spent on trench excavation, shoring, dewatering, embedment, backfilling and compacting, and reinstating the surface (Najafi and Gokhale, 2005). As will be described in the following sections, for routes in urban areas, such as Route 3 for the Port of Houston to an inland satellite distribution center in Baytown, tunneling will be the only feasible option.

Figure 2-1 Typical Pipeline Installation

2.3.1.1 Use of Precast Concrete Pipe

One option for cut-and-cover method is using precast concrete pipe sections. The precast concrete cylinder pipe (PCCP) known by American Water Works Association (AWWA) as C300 (shown in Figure 2-2) with steel cylinder inside was found to be a feasible pipe for the cut-and-cover method and can be modified for UFT application.

The factory shipment of a large diameter concrete pipe requires meeting traffic regulations for weight and size, while onsite manufacturing of the pipe sections is possible with availability of surface space for the plant along with pipe section storage. Other issues include advantages of using pipe sections compared to other options (as shown in Figure 2-3), cost of pipe per mile, etc. The manufacturer interviews conducted by the research team showed a willingness to manufacture the pipe onsite as per specific requirements of the project for the additional invert reinforcement needed to accommodate tracks and the weight of the vehicles.

A single manufacturing plant may have the capacity to make 10 miles of pipe per year. For pipe design, material procurement, and plant setup, approximately 18 months is required. The concrete segments illustrated in Figure 2-3 can also be manufactured at the jobsite.

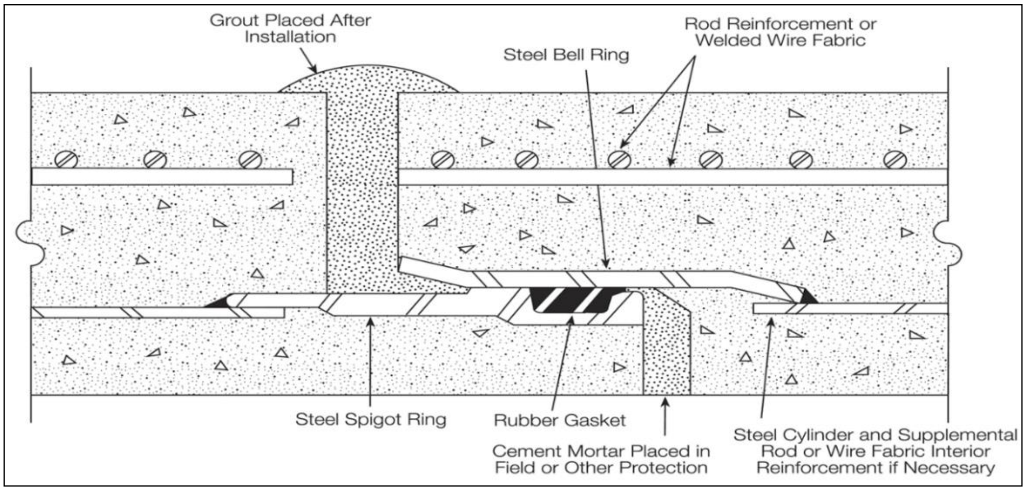


Figure 2-2 Reinforced Concrete Cylinder Pipe (AWWA C300)

Figure 2-3 Cut-and-cover Construction with Precast Concrete Segments (Source: www.alamy.com)

2.3.2 Tunneling

Tunneling techniques can be used for installation of pipelines and conduits underground with minimum amount of surface and subsurface excavation. As a result, tunneling techniques are more environmentally friendly compared to the conventional cut-and-cover method and result in less carbon footprint. They also add to the safety and productivity of construction operations (Najafi and Gokhale, 2005). These methods utilize a custom-made tunnel boring machine (TBM). The TBM is assembled inside a launch shaft at one end of the tunnel alignment from where it initiates the boring operation through the ground. The front of the TBM is equipped with a cutterhead with a number of mounted cutting wheels. The cutterhead is designed to suit the geological conditions expected during the tunnel drive. The excavated soils (spoils or mucks) are transported back through the tunnel to the launch shaft or accessible shaft locations where they can be raised to the surface and removed from the jobsite by dump trucks. As the tunnel is excavated, reinforced precast concrete segments are installed behind the TBM to form the tunnel lining and provide the jacking mechanism for the TBM to move forward. The annular space between the outside of the segmental lining and the ground is filled with grout to ensure full contact between the ground and the lining and to minimize ground surface settlements. Figure 2-4 illustrates a typical TBM and its components.

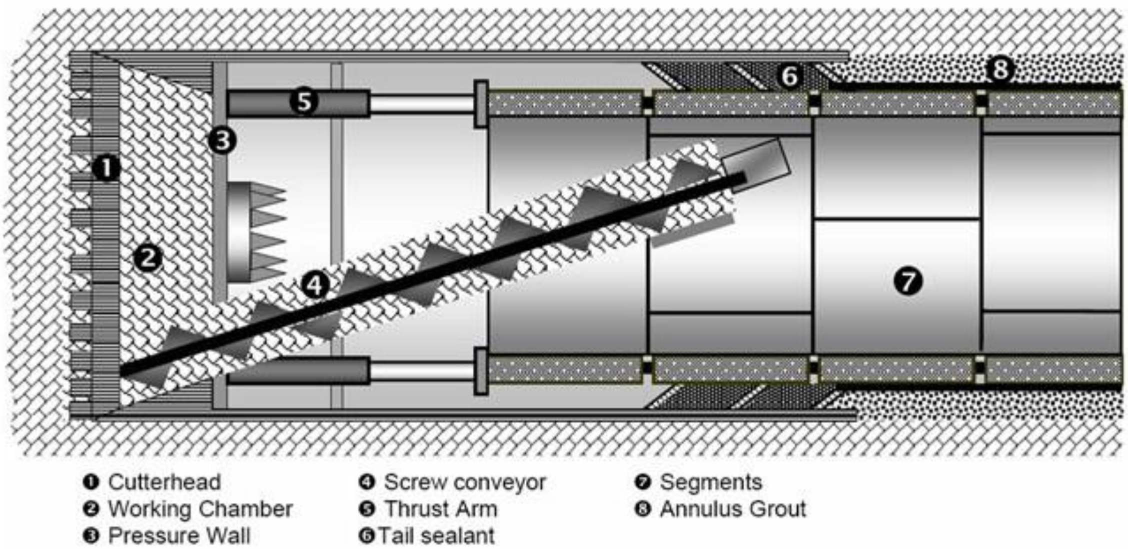


Figure 2-4 TBM Schematic Diagram
(Tunneling and TBM Method, 2008)

2.3.2.1 Disposal of Tunnel Spoils

Excavated material (spoils) are moved to the rear of the TBM by a screw conveyor and deposited on a conveyor belt. The conveyor belt drops the spoils into hopper-type mine cars, which are then taken back to the launching area by a locomotive operating on temporary rail tracks fastened to the bottom of the tunnel. At the shaft, the mine cars are lifted out by a crane or excavator and the excavated spoils are loaded into trucks or temporarily stockpiled for off-site disposal. Alternatively, belt conveyor systems can be used to transport spoils through the tunnel and/or from the shaft to the surface.

2.3.2.2 Segmental Lining for Tunneling Method

As stated above, the tunnel is lined immediately behind the TBM using precast concrete segments. This method reduces the risk of ground settlement in the vicinity of the tunnel. The precast concrete segments can be fabricated at the jobsite or transported from the manufacturer’s plant. Individual concrete segments are bolted together and gaskets are used to resist groundwater infiltration into the tunnel. The concrete segments will form a closed ring to resist normal compressive forces and axial loads exerted by TBM (Gamarra, 2016).

There are several parameters impacting segmental design, such as soil conditions, tunnel diameter and the tunnel boring machine's (TBM) jacking loads. Dependent on the size of the tunnel and size of concrete segments, reinforcement is used to withstand the stresses induced during the handling of the segments before installation and to resist the loads imposed by TBM rams. Unreinforced segments are only used in the case of small tunnel cross-sections (Abbas, 2014).

The introduction of steel fiber reinforced concrete (SFRC) in tunnel linings is relatively recent. Steel fibers can be used to reduce a standard reinforcement cage, and under appropriate project conditions (i.e., tunnel diameter and ground conditions), they can even serve as a complete substitution for a standard cage reinforcement (Barták, 2007). However, high jacking forces and concentrated loaded joints demand additional reinforcement.

2.3.2.3 Pipe Jacking

Pipe jacking is another tunneling method suitable for a UFT project. In this method, prefabricated pipes are pushed through the ground from a drive shaft to a reception shaft while the TBM excavates the soil similar to tunneling operation described above. The jacks located in the drive shaft propel the pipes, and the jacking force is transmitted through pipe-to-pipe interaction to the TBM. For longer distances (usually more than 1,500 ft), intermediate jacking stations (IJS) can be used. Pipe jacking could be used for installation of various pipeline materials such as reinforced concrete pipe (RCP), centrifugally cast glass-fiber-reinforced polymer mortar (CCFRPM), and polymer concrete pipe for diameters above 42 in. (more than 3.5 ft). The typical components of a pipe jacking operation are illustrated in Figure 2-5 (Najafi and Gokhale, 2005). This method potentially can be used for crate and pallet tunnels.

2.3.2.4 Utility Tunneling

The other tunneling method applicable for UFT is utility tunneling. The soil excavation for this method is similar to tunneling and pipe jacking, but the tunnel lining process is different. In pipe jacking, for ground support the pipe is the lining whereas in utility tunneling, special liner plates or steel rib and wood lagging liners are used. For this reason, pipe jacking is called "one-pass" or "one-phase" operation and utility tunneling is called a "two-pass" or "two-phase" operation, as pipe sections are installed after the tunneling is completed and annular space is grouted. Figure 2-6 presents the pipe installation by the utility tunneling method (Najafi and Gokhale, 2005).

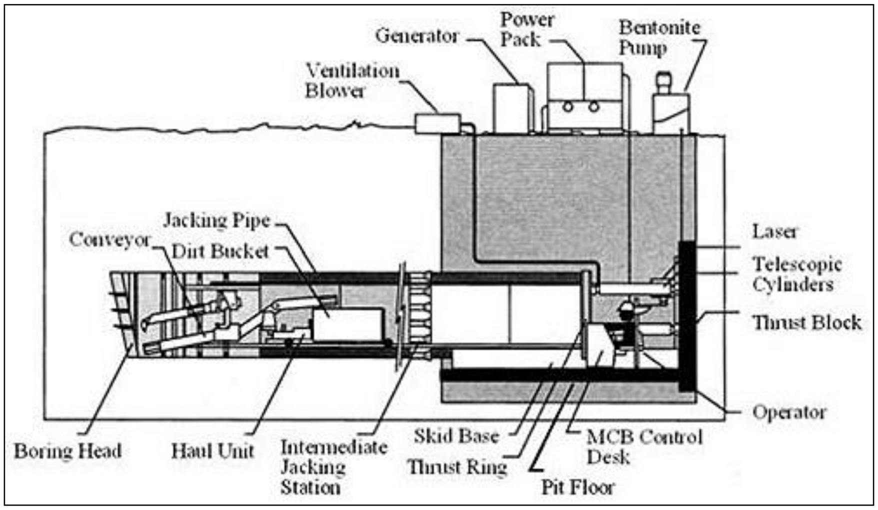


Figure 2-5 Typical Components of a Pipe Jacking Operation (Najafi and Gokhale, 2005)

Figure 2-6 Pipe Installation During Utility Tunneling (Najafi and Gokhale, 2005)

2.3.2.5 Shaft Construction

Shafts Locations. There are two types of shafts: entry/exit shafts and access shafts. The TBM enters through the entry shaft and exits at the end of the bore through the exit shaft. The access shafts take less surface area and are used for construction logistics and ventilation both during tunnel construction and UFT operation. They also provide emergency access and provide entry points for utilities and segmental linings as well as exit points for spoil removal. Access shaft might be one mile apart while entry/exit shafts might be 10 to 25 miles apart. Access shafts can be considered as smaller versions of the entry/exit shafts but a similar excavation method and wall support method are utilized. Figures 2-7 and 2-8 illustrate a proposed location for an entry/exit shaft in a congested area near City of Dallas, and two access shafts along IH-45, respectively.

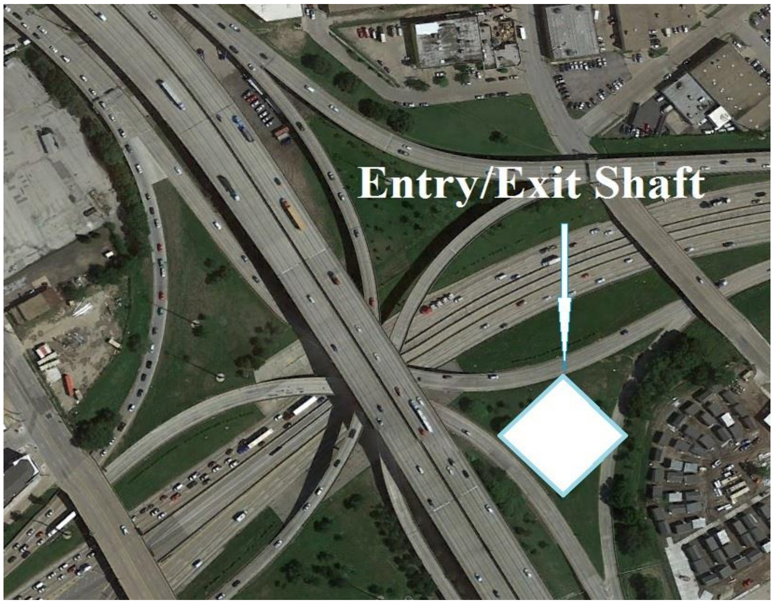


Figure 2-7 Possible Entry/Exit Shaft Location in a Congested Area (Source: Google Earth)

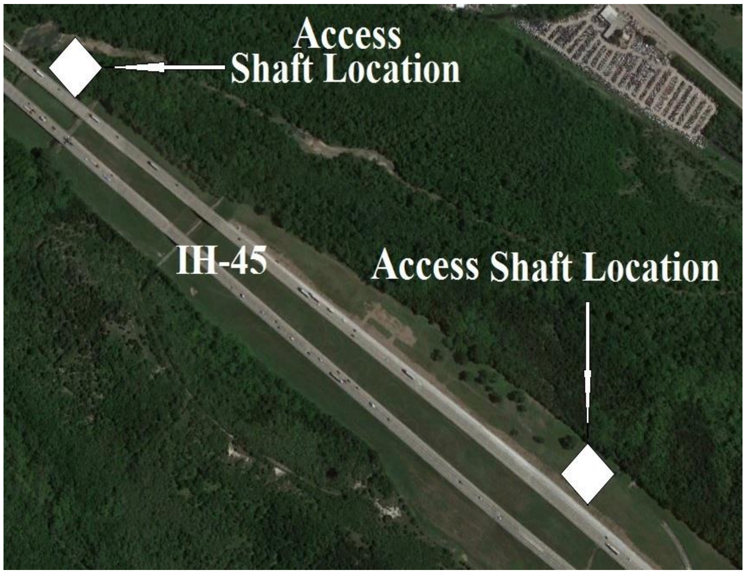


Figure 2-8 Possible Access Shafts Locations along IH-45 ROW (Source: Google Earth)

Shaft Area. The required shaft areas for both entry/exit access shafts are determined by different parameters dependent on project and site factors as shown in Tables 2-2 and 2-3, respectively (O' Conner and Syed, 2001). Figure 2-9 illustrates a shaft layout.

Table 2-2 Required Site Area for Entry/Exit Shafts

Type	Required Dimensions	Area
Working Shaft	150 ft × 100 ft	15,000 ft^2
Crane Placement	40 ft × 40 ft	1,600 ft^2
Spoil Stockpile	200 ft × 50 ft	10,000 ft^2
Truck Staging and Queuing Area	150 ft × 30 ft	4,500 ft^2
Welding Machine and Electric Shop	50 ft × 40 ft	2,000 ft^2
Air Compressor Station	20 ft × 20 ft	400 ft^2
Hydraulic Units	10 ft × 40 ft	400 ft^2
Testing Laboratory	10 ft × 40 ft	400 ft^2
Electric Transformers/Generators	30 ft × 30 ft	900 ft^2
Jobsite Trailer	20 ft × 30 ft	600 ft^2
Batch Plant, TBM Assembly Area, and Storage	300 ft × 400 ft	120,000 ft^2
Workers' Parking	150 ft × 30 ft	4,500 ft^2
Subtotal		160,000 ft^2
Additional 15% for Contingency		24,000 ft^2
Total Area (approx.)	**430 ft × 430 ft**	**184,000 ft^2 (4.3 acres)**

Table 2-3 Required Site Area for Access Shafts

Type	Required Dimensions	Equivalent Required Area
Working Shaft	20 ft Diameter	320 ft^2
Crane	40 ft × 40 ft	1,600 ft^2
Spoil Stockpile	50 ft ×40 ft	2,000 ft^2
Truck Staging and Queuing Area	150 ft ×30 ft	4,500 ft^2
Electric Shop	10 ft ×40 ft	400 ft^2
Air Compressor Station	20 ft ×40 ft	800 ft^2
Hydraulic Units	10 ft ×40 ft	400 ft^2
Electric Transformers/Generators	30 ft ×30 ft	900 ft^2
Jobsite Trailers	20 ft × 30 ft	600 ft^2
Equipment Assembly, and Storage	80 ft × 60 ft	4,800 ft^2
Workers' Parking	100 ft ×30 ft	3,000 ft^2
Subtotal		19,500 ft^2
Additional 15% for Contingency		3,000 ft^2
Total Area (approx.)	**150 ft × 150 ft**	**22,500 ft^2 (0.5 acre)**

Figure 2-9 Entry/Exit Shaft Details
(Source: Herrenknecht AG)

Shaft Construction at UFT Terminals. It is proposed that the tunnel connects with UFT terminal by ramps with a slope of 10 to 20 percent. The tunnel boring machines (TBMs) are able to excavate above slopes as shown in Figure 2-10.

Figure 2-10 Declined-shaft (Sloped Shaft) Tunneling
in St. Petersburg, Russia (TunnelTalk, 2016)

The sloped shaft excavation has the following benefits:

- Reduces surface area required for entry/exit shaft.
- Reduces the need to reconstruct the ramp with cut-and-cover method after the tunneling portion is completed.

Shaft Wall Support Methods. The design and construction of the shafts are governed by factors such as:

- Barrier for underground water
- Constructability for Austin Chalk and expansive clay
- Costs
- Equipment space requirements
- Geometry of the shaft
- Ground conditions
- Health, safety and environment (HSE) requirements
- Impact on traffic during construction
- Relocation of underground utilities
- Reusing the shaft support system materials, such as sheet pile
- The construction production rate (schedule)
- The local contractors' experience
- Watertable fluctuations during construction
- Whether the shaft will be used as a permanent structure for UFT operation as maintenance location
- Whether the UFT is in urban or rural area

Table B-1 (Appendix B) presents common methods for the shaft wall support with advantages and limitations of each method. Based on shaft location and site conditions, a combination of methods might be considered. Stability of nearby structures, foundations, and utilities, must be considered in shaft design and construction.

2.4 CONSTRUCTION METHODS FOR ROUTE 1

As stated in Chapter 1, Route 1 is 250 miles long and extends from the Port of Houston (Barbour's Cut Terminal) to the Dallas Logistic Hub south of Dallas in the suburban town of Lancaster. For Route 1, the suitable methods of construction are considered along Interstate Highway 45 (IH-45). The construction methods for this route are divided into TBM tunneling and cut-and-cover methods based on site conditions and availability of surface space, as described in the following sections.

Route 1 is designated for a large size tunnel (to accommodate shipping containers). "Cut-and-cover" and "tunneling" methods are considered for "Two Single-Track Tunnels" and "One Twin-Track Tunnel," respectively. These two methods will be used as discussed in the following sections.

2.4.1 Cut-and-cover Method

2.4.1.1 Construction along IH-45 Median

The IH-45 median has a limited space which is not suitable for cut-and-cover construction. The average median width along this highway is 40 ft. In addition, at both Lancaster and Houston, no medians are available for almost 10 miles. Almost 40 miles of the entire route, has a median width of over 50 ft (between 50 ft and up to 80 ft), which is not enough for cut-and-cover construction. Figure 2-11 presents the typical median size at IH-45. The cut-and-cover method requires at least 80 ft space at the surface for loading trucks, material stockpiles, ancillary equipment, and so on. Therefore, the median is not considered as an option for the cut-and-cover method here.

2.4.1.2 Construction along IH-45 Right-of-Way

The highway right-of-way (ROW) along IH-45 is approximately 100 ft on each side, which is where the cut-and-cover method can be implemented. It should be noted that a 20-ft distance from edge of pavement is considered for traffic safety and highway embankment protection. Therefore, the cut-and-cover method is considered along the ROW, as shown in Figure 2-12.

Figure 2-11 Typical Median at IH-45
Source: Google Earth

Figure 2-12 Typical Right of Way along IH-45
Source: Google Earth

2.4.1.3 Cut-and-Cover Trench Options

To compare trench options and to consider earthwork volumes, three different cross sections for two single-track tunnels are selected as shown in Figures 2-13 through 2-15. The safe excavation depth determines the allowable vertical trench depth based on the soil type as shown in Table 2-4.

Table 2-5 presents a volume of excavation in bank cubic yards (BCY) per mile of tunnel for each type of trench. The following are factors considered for trench selection[9]:

- The construction location is the IH-45 ROW.
- A 5-ft depth from ground surface to top of the pipe is selected.
- The watertable is assumed to be below the bottom of the trench.
- The cut-and-cover method is only applicable to two single-track tunnels.
- Flowable fill or what is commonly referred to as controlled low-strength material (CLSM)[10] can be used for bedding and haunch areas of the pipe. Flowable fill may consist of native soils at some locations along the route.

[9] The selection of trench type will be determined during design and construction phase of the project and will be based on boring logs and field data (such as, using a pocket penetrometer) as change of slope from 1H:1V to more steep excavation walls should be based on a threshold for soil compressive strength of approximately 150 psi (1 tsf).
[10] http://www.cement.org/cement-concrete-basics/products/controlled-low-strength-material

- The amount of spoil removal will be reduced if there is a possibility for building a berm on the tunnel alignment. For additional spoil disposal, low terrain farmland areas can be considered.
- A trench box can be used at the pipe joint locations to satisfy the U.S. Occupational Safety and Health Administration (OSHA) requirements.

According to Table 2-5, Trench Type 1 is not suitable for excavation along the ROW because it does not meet the surface space requirements. Trench Type 3 also is not acceptable compared with Trench Type 2 because of the need for a higher volume of excavation.

For Trench Type 2, as illustrated in Figure 2-14, the vertical excavation depth is 12 ft. According to data received from TxDOT, the clayey soil along IH-45 is generally assumed to be medium to stiff clays from depths below 10 ft. The allowable vertical depth of 12 ft is a reasonable assumption for this soil, especially if the watertable is beneath the excavation.

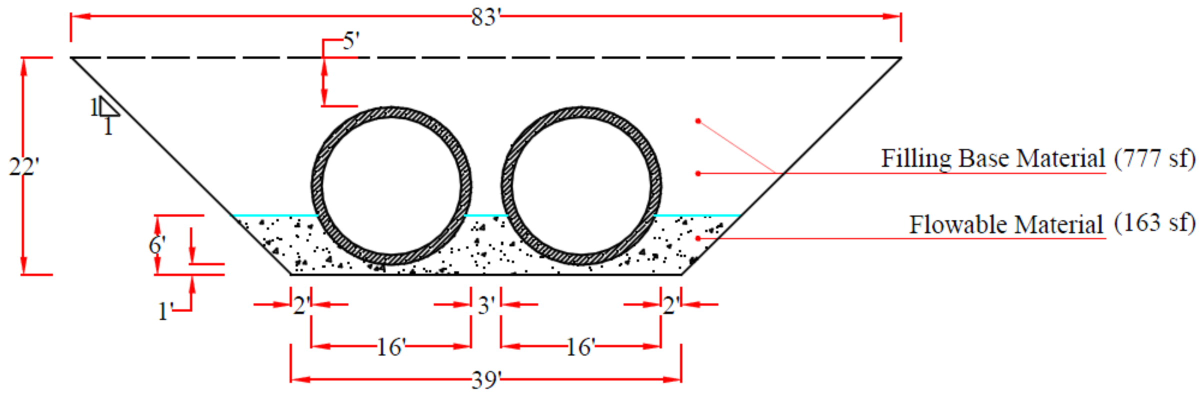


Figure 2-13 Trench Type 1 with Cross Sectional Area of 1,342 ft^2

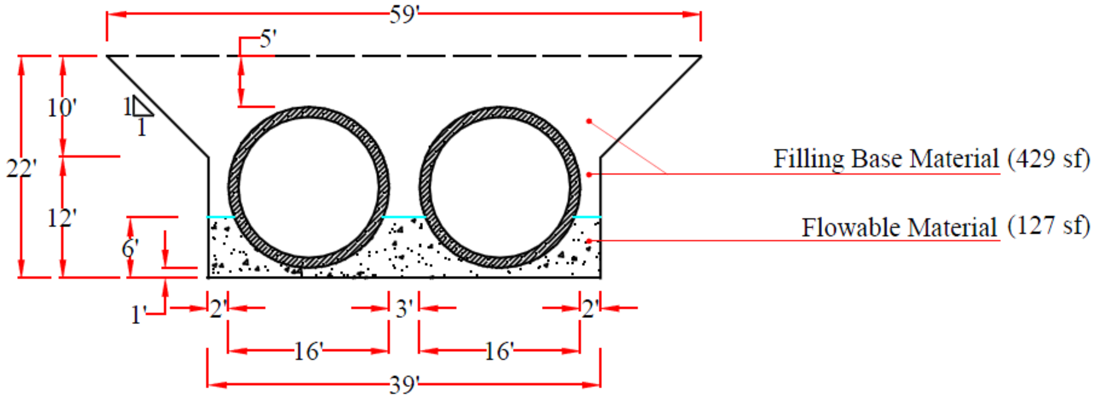


Figure 2-14 Trench Type 2 with Cross Sectional Area of 958 ft^2

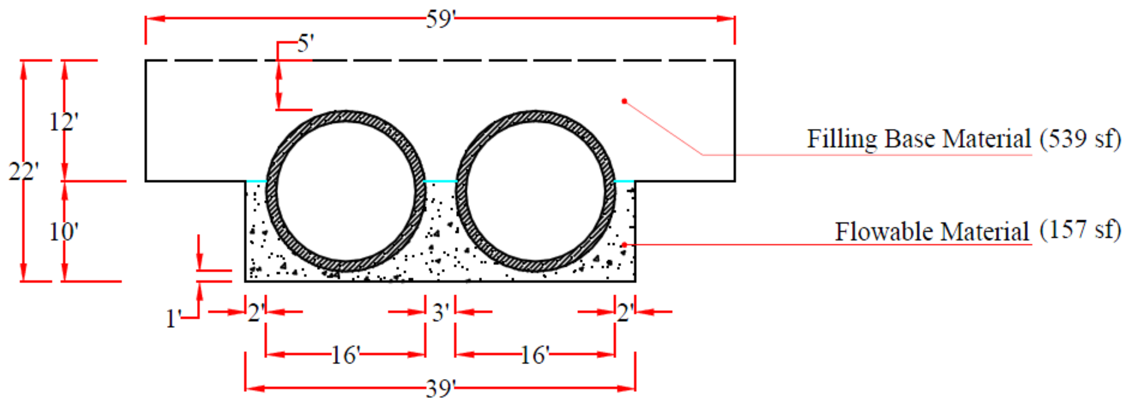


Figure 2-15 Trench Type 3 with Cross Sectional Area of 1,098 ft^2

Table 2-4 Safe Depths for Trenching in Clayey Soils (Nemati, 2007)

Soil Consistency	Unconfined Compressive Strength q_u (tsf)	Cohesion, c (tsf)	Safe Height, H (ft)
Very soft	< 0.25	< 0.125	< 5
Soft	0.25 – 0.5	0.125 – 0.25	5 –10
Medium	0.5 – 1	0.25 – 0.5	10 – 20
Stiff	1 – 2	0.5 – 1	20 – 40
Very stiff	2 – 4	1 – 2	40 – 80
Hard	> 4	> 2	> 80

Table 2-5 Size and Volume of Excavation for Different Trench Types

Trench Type	Section Width at Top (ft)	Section Area (ft^2)	Volume of Excavation/mile (BCY)	Volume of Flowable Fill/mile (CY)
1	83	1,342	263,000	32,000
2	59	958	188,000	25,000
3	59	1,098	215,000	30,700

2.4.1.4 Disposal of Trench Spoils

The extra soil (spoil) after trenching and backfill must be transported off-site for disposal. If possible, the elevation on top of the trench can be raised to a level permitted by TxDOT to allow for backfill settlement. This option will reduce spoil removal significantly. Additionally, since the spoil from the excavation is considered as clean soil, it might be suitable for use in nearby farmlands. Lowlands along IH-45 can be considered as the spoil disposal sites and potentially, except for hauling costs, there will not be any additional cost for disposal. Table 2-6 presents some examples of landfills which might be potential disposal sites near Route 1 as well.

Table 2-6 Potential Dump Sites and Their Distances to IH-45

Land Fill/Dump Site	Distance to IH-45 (mile)	Distance to Dallas (mile)	Distance to Houston (mile)
Republic Services ECD Landfill	0	30.2	209
McCommas Bluff Landfill	2	10.6	231
Mexia Landfill	20	86.3	163
Brazos Valley Solid Waste Management Agency, Inc.	45	196	80

2.4.1.5 Trench Support Systems

Trench support systems are needed to increase trench safety and to protect bridge and building foundations. The construction methods applicable to trench support systems are discussed in Section 2.3.2.5 and Table B-1, Appendix B.

2.4.1.6 Dewatering

In case of groundwater existence, a number of dewatering methods are available, such as the wellpoint system and deep wells. Pumped water might be released in nearby creeks or wetlands with the proper permit.

2.4.2 Tunneling Method

2.4.2.1 TBM Advance Rate

Ground conditions along the IH-45 alignment mainly consist of cohesive soils, shale and limestone called Austin Chalk. Austin Chalk has a stability suitable for tunneling. Table 2-7 shows some similar tunneling projects for similar geological conditions and TBM diameters. The range for TBM advance rate is between 80 and 215 ft per day dependent on subsurface conditions. The average advance rate of 100 ft per day (for 20-hour work-days) is assumed to be a reasonable value for boring along IH-45 and in Austin Chalk strata.

Table 2-7 Average Rate of TBM Excavation for Different Projects

Project	Soil Type	Tunnel Diameter (ft)	Year Constructed	Average Excavation Rate (ft/day)
Tunneling and Construction at the Dallas - Ft. Worth SSC Site, (Nelson, 1989)	Taylor Marl	10.5-11.5	1989	150
	Austin Chalk	10.5-11.5	1989	215
Cobb County Water Systems, Atlanta, Georgia, (Robbins Company, 2015)	Medium Grade Metamorphic Rocks with Some Granite	18.3	2002	80
Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), (Robbins Company, 2015)	Dolomitic Limestone	18.3	2002	150
The Channel Tunnel, Between UK and France (Robbins Company, 2015)	Chalk Marl and Stiff Clay	29, 27, 18, 16	1991	100

2.4.3 Route 1 Tunneling and Cut-and-Cover Locations

To determine which part of the project will need traditional tunneling and which will need the cut-and-cover method, Route 1 was divided into nine segments. These segments were selected as the distance between two major locations such as cities or national parks as shown in Table 2-8. The first segment starts in Houston at Barbour's Cut Port and the final segment ends at Lancaster, TX (Figure 2-16). To find the best method for each segment: First, the main parameters were introduced, weighed and sorted according to Table 2-9, and a decision was made as shown in Table 2-10. Table 2-11 presents the selected method for each segment.

Table 2-12 presents final results from Tables 2-10 and 2-11. In this table, two alternatives for each segment are compared. The comparison is obtained from the sum of scores of different alternatives. For example, in Segment 2, the cut-and-cover is not selected, since the score is 5, which is calculated as follows:

$$(5\times1) + (4\times0) + (3\times0) + (3\times0) + (3\times0) + (2\times0) + (1\times0) + (1\times0) = 5$$

Approximately, it can be concluded that 50 percent of Route 1 will be cut-and-cover and another 50% will be tunneling. Figure 2-16 shows all the segments for Route 1 divided into three divisions as shown in Figure 2-17 and Table 2-13.

Table 2-8 Construction Segments

No.	Segment Local Name	Segment Length (mile)	Suggested Method of Construction
1	Houston National Park Willis	68.1 3.4 1.4	Tunneling
2	Rural area	18.3	Cut-and-cover/Tunneling
3	Huntsville	6.2	Tunneling
4	Rural area	108	Cut-and-cover / Tunneling
5	Corsicana	1.4	Tunneling
6	Rural area	20.7	Cut-and-cover / Tunneling
7	Ennis	1.8	Tunneling
8	Rural area	15.8	Cut-and-cover / Tunneling
9	Dallas	11.1	Tunneling

Note: A value of "0" shows that the chosen alternative does not meet required quality in that segment, and "1" shows that the chosen alternative covers in this segment.

Table 2-9 Parameters Impacting Construction Methods

Parameter	Weight
Construction Time	5
ROW Restrictions	5
Rock and Soil Condition	5
Land Use and Social Impacts	4
Buildings and Bridges	3
Underground Utilities	3
Watertable	2
Road, Railroad, River and Creek Crossing	2
Construction Permits (i.e., Wetlands)	1

Table 2-10 Method Selection Process for Each Segment

Segment	Segment Length (mile)	Alternative	Construction Time	Land Use and Social Impacts	ROW Restrictions	Buildings and Bridges	Underground Utilities	Watertable	Rock and Soil Conditions*	Road, Railroad, River and Creek Crossings	Construction Permit (i.e., Wetland)
			Preference Parameter Acceptance								
1	74.3	Tunneling (Urban Area Zone)									
2	16.1	Cut-and-cover	1	0	0	0	0	0	0	0	0
		Tunneling	0	1	1	1	0	0	0	1	1
3	8.3	Tunneling (Urban Area Zone)									
4	107.0	Cut-and-cover	1	1	1	1	1	1	0	1	0
		Tunneling	0	1	1	1	1	0	0	1	1
5	12.1	Tunneling (Urban Area Zone)									
6	17.9	Cut-and-cover	1	0	0	1	1	1	0	1	0
		Tunneling	0	1	1	1	1	0	0	1	1
7	1.8	Tunneling (Urban Area Zone)									
8	16.4	Cut-and-cover	1	0	0	0	0	1	0	0	0
		Tunneling	0	1	1	1	0	0	0	1	1
9	4.0	Tunneling (Urban Area Zone)									

*In this table, the value of "0" shows that the chosen alternative does not meet required quality in that segment, and "1" shows that the chosen alternative covers in this segment. Please note that in the rock and soil conditions column ground conditions are not considered in this phase.

Table 2-11 Selected Method for Each Segment

Segment	Segment Length (mile)	Alternative	Construction Time	Land Use and Social Impacts	ROW Restrictions	Buildings and Bridges	Underground Utilities	Watertable	Rock and Soil Conditions*	Road, Railroad, River and Creek Crossings	Construction Permits (i.e., Wetland)	Total	Selected Alternative
			Weight										
1	74.3	Tunneling (Urban Area Zone)											
2	16.1	Cut-and-cover	5	0	0	0	0	0	0	0	0	5	Tunneling is selected
		Tunneling	0	4	5	3	0	0	0	2	1	**15**	
3	8.3	Tunneling (Urban Area Zone)											
4	107	Cut-and-cover	5	4	5	3	3	2	0	2	0	**24**	Cut-and-cover is selected
		Tunneling	0	4	5	3	3	0	0	2	1	18	
5	12.1	Tunneling (Urban Area Zone)											
6	17.9	Cut-and-cover	5	0	0	3	3	2	0	2	0	15	Further Study Needed
		Tunneling	0	4	5	3	3	0	0	2	1	18	
7	1.8	Tunneling (Urban Area Zone)											
8	16.4	Cut-and-cover	5	0	0	0	0	2	0	0	0	7	Tunneling is selected
		Tunneling	0	4	5	3	0	0	0	2	1	**15**	
9	4.0	Tunneling (Urban Area Zone)											

*Please note that ground conditions in the Rock and Soil Conditions column are not considered in this phase.

Table 2-12 Construction Segments

No.	Segment	Segment Length (mile)	Suitable Construction Method
1	City of Houston	74.3	Tunneling
2	Rural Zone	16.1	Tunneling
3	City of Huntsville	8.3	Tunneling
4	Rural Zone	107	Cut-and-cover
5	City of Corsicana	12.1	Tunneling
6	Rural Zone	17.9	Tunneling
7	City of Ennis	1.8	Tunneling
8	Rural Zone	16.4	Tunneling
9	City of Dallas	4.0	Tunneling

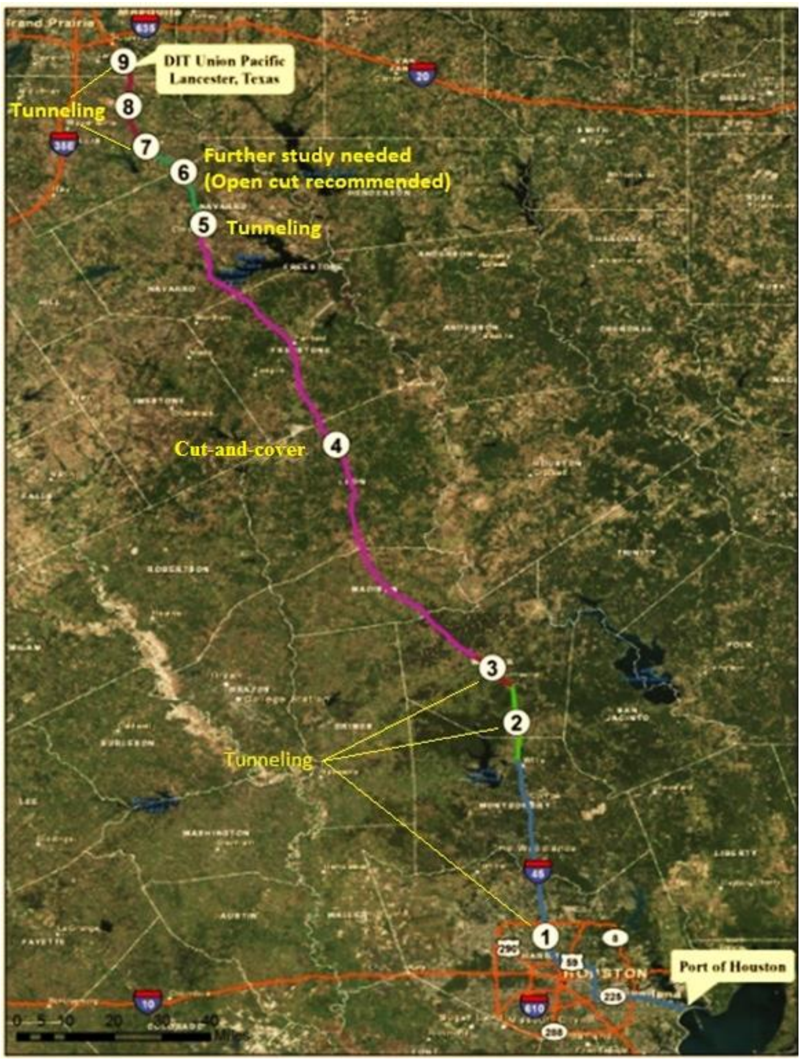


Figure 2-16 Segments from Houston to Dallas Route

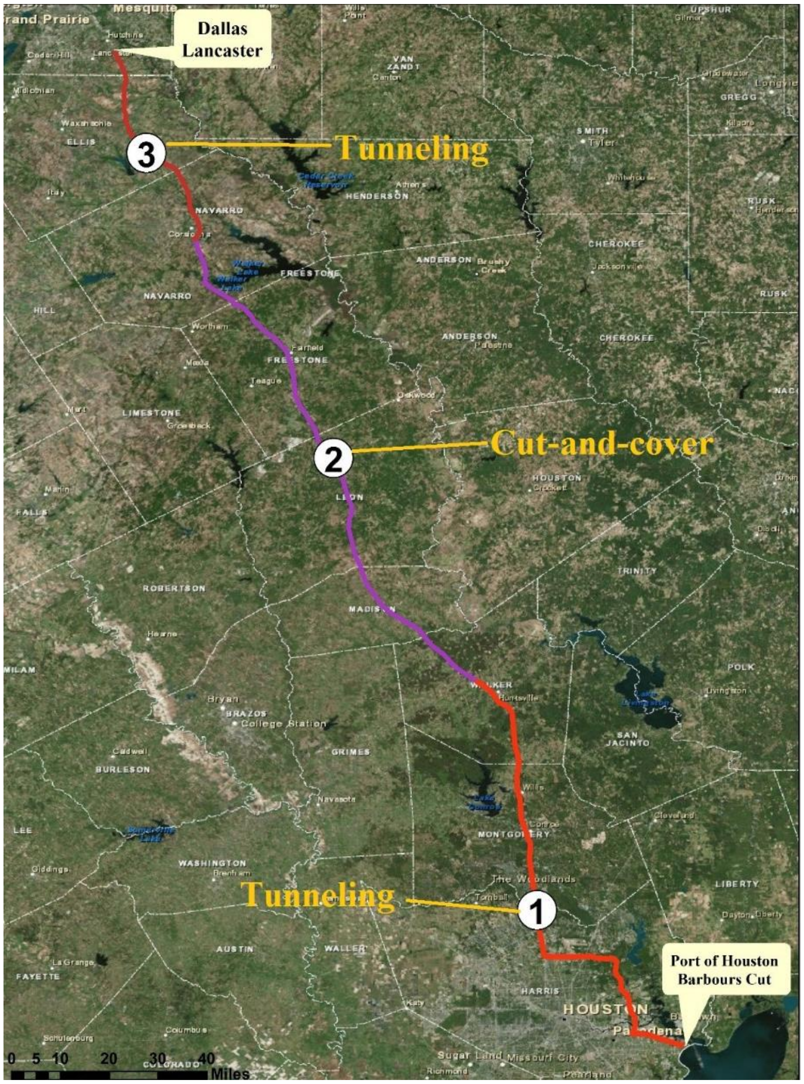


Figure 2-17 Three Divisions for Route 1

Table 2-13 Summary of Divisions from Houston to Dallas Route

Construction Method	Division No.	Description	Length (mile)
Tunneling	1	Houston to Huntsville	100
Cut-and-cover	2	Huntsville to Corsicana	100
Tunneling	3	Corsicana to Lancaster	50

2.4.4 Route 1 Geotechnical Information

A geotechnical study was conducted through collecting data from past projects completed along IH-45 and reported to TxDOT. For these projects, soil boring tests were conducted at depths of up to 80 ft. Since the excavation by both cut-and-cover and tunneling methods will be conducted at depths of less than 100 ft, the soil boring results for projects near the IH-45 were selected as representative of native soil. Table 2-14 shows the boring test results for projects from Dallas to Corsicana for a distance of approximately 50 miles. According to geotechnical investigation, expansive clay, shaley clay or Austin Chalk soils are available along Route 1. Austin Chalk is considered to be a stable material and suitable for tunneling. The soil at the shallow depths mostly consists of expansive clay (CH) as identified in Unified Soil Classification System (USCS). Swelling must also be considered for tunneling.

Table 2-14 Soil Boring Test Results[11]

Project Name	Route	Distance to Dallas (mile)	Boring Depth (ft)	Soil Type
SH161	Between SH 183 and McArthur Blvd	0	25	0-10: Clay to Shaley Clay 10-15: Clay 15-25: Shaley Clay
Retaining Wall and Bridge Foundation Test Borings I-45, Between Dowdy Ferry and Mars Road	Dowdy Ferry to Mars Road	13.5	65	0-5: Clay with Trace of Sand 5-10: Clay with Trace of Sand & Calcareous Nodules, Dark Gray 10-20: Silty Clay 20-40: Sandy Silty Clay, Soft to Stiff 40-65: Calcareous Shale, Shaley Limestone, Hard to Very Hard
IH-45 Widening	Rice to Corsicana	44.6	50	2-5: Clay with Sand and Gravel 5-25: Clay, Medium to Stiff, Very Stiff (CH), 25-30: Clay, Shaley, Hard, Light Gray (CH) 30-50: Shale
Navarro County and IH-45	Navarro County and IH-45	55	70	0-15: Clay, Gray, Soft, Moist 15-35: Clay, Gray, Tan, Soft, Moist 35-45: Clay, Silty 45-60: Sand, Silty 60-70: Shale
Data Was Not Available from Navarro to Houston				

[11] We thankfully acknowledge TxDOT for contributing this helpful data. Detailed soil analysis and potential impacts of expansive clayey soils must be considered during the future phases of the UFT project.

2.4.5 Route 1 Project Duration

This section provides an estimation of project durations for Route 1.

2.4.5.1 Cut-and-cover Construction Assumptions

The main construction parts of the cut-and-cover method includes excavation, construction of trench support system, installation of pipe sections or concrete segments, embedding with flowable materials (or select materials) and backfilling. It is assumed to have one maintenance shaft for every one mile of tunnel.

In addition, there can be one contractor for each 25-mile segment of Route 1 with an average construction rate of approximately 50 ft per day. It is assumed that contractors work simultaneously on different segments of the project. Additionally, 6 days a week and 16 hours per day are assumed. Table 2-15 presents a summary of cut-and-cover construction assumptions.

Table 2-15 Summary of of Assumptions for Cut-and-Cover Construction

Type	Description
Contractor	One every 25 miles
UFT Access Point	One every 5 miles
Working Time	6 Days a week/16 hours a day

2.4.5.2 Tunneling Construction Assumptions

The major construction parts of tunneling are construction of entry/exit shafts, access shafts, and tunnel construction. It is assumed to have one entry/exit shaft for every 25 miles and one access shaft every mile and tunnel diameter does not impact TBM production rate.

Considering a different contractor for each 25-mile section, an average production rate of 100 ft per 20 hours will be achieved. It is assumed that contractors work simultaneously on different segments of project. The actual daily production time could be 20 hours per day to allow 4 hours for maintenance. Table 2-16 presents a summary of tunneling assumptions

Table 2-16 Summary of Assumptions for Tunneling Construction

Type	Description
Contractor	One every 25 miles
Entry/Exit Shaft	One every 25 miles
Access Shaft	One every mile
TBM	Production rate of 100 ft/day
Working Time	7 Days a week/20 hours a day

2.4.5.3 Division 1-Port of Houston to Huntsville

The first division of Route 1 is designated between Port of Houston and Huntsville and it is assumed to be constructed using the tunneling method. Table 2-17 presents a summary of this division and Table 2-18 shows an estimation of project duration.

Table 2-17 Summary of Division 1 of Route 1
(100 miles from Houston to Huntsville)

Type	Description	Quantity (each)
Contractor	One every 25 miles	4
Entry/Exit Shafts	One every 25 miles	3 entry and 2 exit shafts
Access Shafts	One every mile	96
TBM	Production rate of 100 ft/day	4

Table 2-18 Estimation of Project Duration Division 1 of Route 1
(Adapted from East Area CSO Tunnels Project Schedule, 2001)

Description	Duration
Mobilization and site preparation	3 Months
Entry/exit shaft construction	3 Months
TBM assembly and boring operation	47 Months
Terminal Construction (concurrently with tunnel construction)	13 Months
Total Duration (Considering Concurrent Activities)	**50 Months**

2.4.5.4 Division *2-Huntsville to Corsicana*

The second division of Route 1 is from Huntsville to Corsicana and assumed to be constructed with cut-and-cover method. Tables 2-19 and 2-20 present assumptions and construction schedule for Division 2 of Route 1.

Table 2-19 Summary of Assumptions for Division 2 of Route 1
(100 miles from Huntsville to Corsicana)

Type	Description	Quantity (each)
Contractor	One every 25 miles	4
Access Point	One every 5 miles	19

Table 2-20 Project Duration for Segment 2 of Route 1

Description	Duration
Mobilization and site preparation	3 Months
Access Point	8 Months
Excavation, construction of support systems	20 Months
Pipe installation, embedment and backfill	9 Months
Total Duration (Considering Concurrent Activities)	**35 Months**

2.4.5.5 Division 3-Corsicana to Lancaster (Dallas)

Division 3 of Route 1 starts from Corsicana and ends at the City of Lancaster (near Dallas) and it is assumed to be constructed by tunneling method. Table 2-21 presents a summary of assumptions and Table 2-22 shows an estimation of project duration.

Table 2-21 Summary of Segment 3 of Route 1
(50 miles from Corsicana to Lancaster)

Type	Description	Quantity (each)
Contractor	One every 25 miles	2
Entry/Exit Shafts	One every 25 miles	Two entry and one exit shafts
Access Shafts	One every mile	48
TBM	Production rate of 100 ft/day	2

Table 2-22 Estimation of Project Duration-Division 3 of Route 1

Description	Duration
Mobilization and site preparation	3 Months
Entry/Exit shaft construction	3 Months
TBM Assembly and boring operation	44 Months
Terminal construction	13 Months
Total Duration (Considering Concurrent Activities)	**50 Months**

2.4.6 Estimation of Construction Equipment

This section provides an estimation of number, type and size of equipment used for loading and hauling the spoil (muck) material for Route 1 segments. The equipment was selected according RSMeans Heavy Construction Cost Data (2016).

2.4.6.1 Cut-and-cover Construction

General Assumptions. The following equipment was selected for cut-and-cover construction:

- 3.5-CY excavator (one excavator every 5 miles) to excavate the trench.
- 3-CY bucket, front-end wheel-mounted loader for loading the stockpiled soils in trailer trucks.
- 20-CY trailer dump trucks
- Front-end loader for loading dump trucks and backfilling.
- Sheepsfoot wheel roller with 1-ft lifts and 4 passes.
- 300-horsepower dozer for hauling the soil up to 50 ft.
- 16.5-CY trailer truck, 15 mph average speed with a total cycle of two miles to haul the flowable fill materials.
- Two crawler cranes for each segment.

RSMeans Heavy Construction Cost Data (2016) was used to select the proper equipment in different parts of the project. The cut-and-cover method is considered for Division 2. To select proper equipment, the following assumptions are made:

- Since the excavation is in rural area, the working time for trench excavation and hauling soils can be 16 hours per day (two 8-hour working shifts).
- Hauling cycle is 20 miles.
- Loader cycle time is 140 sec.
- According to White et al. 2010, the swell factor in highly plastic and expansive clay (CH) and limestone (Austin Chalk) is 60%.
- Compaction factor for clay soil (limestone) is 90% (Sowers, 1979).
- One 3.5 CY trench excavator is considered every 5 miles. The excavator works 16 hours per day. Table 2-23 shows the rate of excavation for cut-and-cover method according to daily production of excavator.

Table 2-23 Daily Production Rate of 3.5 CY Excavator

Type	Productivity BCY/Day	Volume of Excavation/ft (BCY)	Excavation/Day (ft)
3.5 CY Excavator	1,848	36	50

Daily Earthwork Volume. According to Table 2-24, the expected daily trench excavation for each jobsite is 50 ft. Considering the trench cross section area to be 960 ft^2 as presented in Figure 2-14, the total volume of excavation will be 1,810 BCY or 2,900 loose cubic yards (LCY) per day. The pipe sections can be embedded with 240 CY of flowable material. Table 2-24 shows the total number of manually driven machines (loaders, dozers, excavators, and trucks) used for the cut-and-cover method.

Table 2-24 Type and Number of Construction Equipment for Route 1, Division 2

Construction Equipment	Daily Output (8 hours)	No. of Construction Equipment Per Day
300 HP Dozer, 50-ft Haul	1,025 BCY	18
3.5 CY Excavator	924 BCY	20
200 HP Loader, 50 ft Haul (Hauling and backfilling)	1,950 LCY	20
Sheepsfoot Wheel Roller, 12 in. Lifts, 4 Passes	2,600 ECY	16
Front End Wheel Mounted Loader 3 CY Bucket (Filling trucks)	1,575 BCY	20
20 CY Truck, Cycle 20 Miles	1,440 LCY	65
16.5 CY Truck, Cycle 6 Miles Hauling the Flowable Materials	2,800 LCY	60

2.4.6.2 Tunneling Construction

General Assumptions. As said previously, it is assumed that the TBM excavation is performed 24 hours per day and seven days per week. The daily production time is limited to 20 hours per day to allow 4 hours for maintenance. In urban areas, the hauling of spoil material by truck is limited to 8 hours per day from 10:00 PM to 6:00 AM to enhance safety and reduce congestion. In this case, spoil is removed from the tunnel and stockpiled at the site until it is loaded on dump trucks and hauled away. In rural areas, since there is no congestion, spoil might be either stockpiled before hauling or hauled directly as soon as it is removed from the tunnel. The working time in rural areas is considered to be 16 hours per day. Other assumptions are:

- According to White et al. (2010), swell factor is 60% in highly plastic and expansive clay (CH) and limestone (Austin Chalk).
- TBM production rate is 100 ft per day as mentioned previously.
- Average hauling cycle is 40 and 20 miles to dump sites in urban and rural areas, respectively.
- 20-CY trailer trucks are used and average hauling and returning speed is 35 miles per hour (mph).
- Loader bucket size is 3 CY.
- Loader cycle time is 130 seconds.

Daily Earthwork Volume. The tunnel diameter in Route 1 is designated for container size freight with an outside diameter of 25 ft. According to Figures 2-18 and 2-19, the first 50 miles and the last 25 miles of Divisions 1 and 3 are in urban areas, respectively. To calculate the required number of construction equipment, the combination of TBM production rate and hauling equipment capacity must be considered. Since one TBM bores 100 ft per day, the volume of excavated material is 2,900 LCY per day per TBM. For all routes, it is assumed that the TBM excavation is performed through Austin Chalk layers.

Based on total volume of excavated material and hourly production rates of equipment, the total number of trucks and loaders in each area are calculated according to RSMeans Heavy Construction Cost Data (2016) and the results are shown in Table 2-25. The total length of tunneling in Route 1 is 150 miles and one TBM covers 25 miles. So there should be six TBMs for the tunneling operation in Route 1. Three 25-mile sections are in urban areas and the remaining sections are in rural areas.

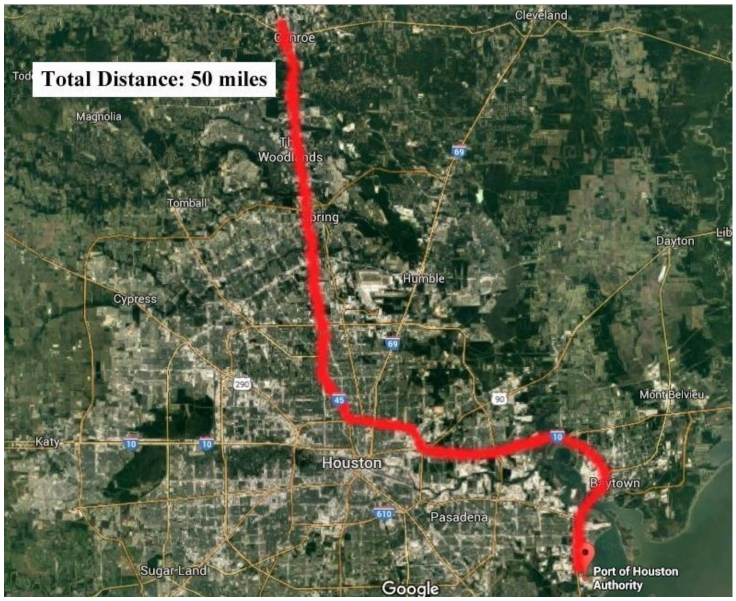


Figure 2-18 Urban Area in Division 1 of Route 1 (Source: Google Earth)

Figure 2-19 Urban Area in Division 3 of Route 1 (Source: Google Earth)

Table 2-25 Construction Equipment for Route 1-Divisions 1 and 3

Jobsite	Type of Construction Equipment	Hourly Output	Total Volume of Excavation (LCY/Day)	No. of Construction Equipment per Day per TBM	No. of Construction Equipment per Day
Urban	20 CY Trailer Truck-Cycle 40 Miles	12.5 (LCY)	3,000	30	90
	3 CY Bucket Loader	197 (BCY)		2	6
Rural	20 CY Trailer Truck-Cycle20 Miles	22.5 (LCY)		6	18
	3 CY Bucket Loader	197 (BCY)		1	3

2.5 CONSTRUCTION METHODS FOR ROUTE 2

Route 2 starts from the southwest end of the World Trade Bridge in Nuevo Laredo, Mexico and terminates at the intersection of IH-35 and Tx-20 Loop, on the north side of the Union Pacific Intermodal Terminal. The route is four miles long, with less than one mile located on the Mexican side of the border. Figure 2-20 shows Route 2 from IH-69 to IH-35.

The most important challenge for this route is passing underneath the Rio Grande River. To avoid the flood zone, the entry/exit shaft at the Mexican side should be at least 1,000 ft away from the river. The flood zone is approximately 350 ft, and the wetland (the zone with high a watertable and loose soil conditions) is 300 ft from the Rio Grande River. Therefore, during construction operations, the entry shaft should be protected from surface runoff, since it is located in the flood zone. As shown in Figure 2-20, the length of Route 2 is approximately four miles.

Figure 2-20 Route 2-Border between the U.S. and Mexico in Laredo, TX (Source: Google Earth)

2.5.1 Comparison between Construction Methods

Tunneling method using TBM are most applicable for the first two miles of Route 2 (starting from the Mexico border) and one mile ending in the interchange of loop 20 and I-35 near the Union Pacific rail yard for the following reasons:

- Passes underneath Rio Grande River; and
- Passes through the congested urban area on the U.S. side of Laredo.

As shown in Figure 2-20, for Segment 2, which includes the remaining one mile of Route 2, the cut-and-cover method could be applicable (due to availability of ROW and enough space for stockpiling of spoil material); however, it is not practical to change construction methods for only one mile. Therefore, the cut-and-cover method for this segment is not selected for the following reasons:

- Requires additional entry/exit shafts for tunneling.
- Requires assembling TBM twice.

By using tunneling method using TBM, the four-mile tunneling construction can be performed with one TBM, one entry/exit shaft and three access shafts. Figure 2-21 illustrates plan and cross section views of the tunnel.

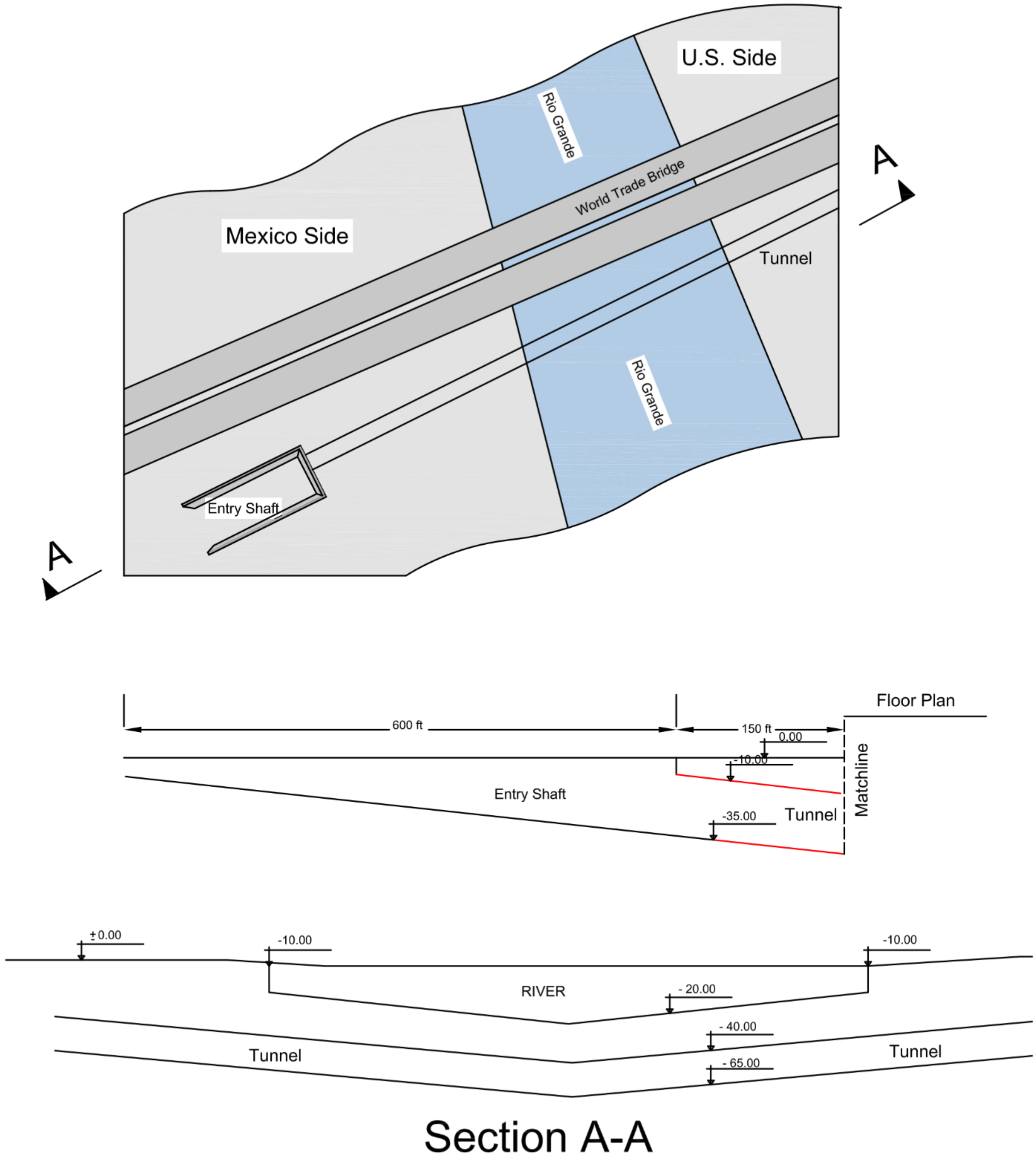


Figure 2-21 Entry Shaft Location and Tunnel Alignment under Rio Grande River

2.5.2 Route 2 Project Duration

This section presents an estimation of project duration for Route 2. The same general assumptions are used for Route 2 as presented previously for Route 1. Table 2-26 presents a summary of Route 2 assumptions and Table 2-27 shows the estimation of project duration.

Table 2-26 Summary of Route 2
(Four miles from the southwest end of the World Trade Bridge in Nuevo Laredo, Mexico to intersection of IH-35 and TX-20 Loop, on the north side of the Union Pacific Intermodal Terminal)

Type	Description	Quantity (each)
Contractor	Only one contractor is required.	1
Entry/ Exit Shafts	Total distance is four miles.	One entry and one exit shaft
Access Shafts	One every mile	3
TBM	Production rate of 100 ft/day	1

Table 2-27 Estimation of Project Duration-Route 2

Description	Duration
Mobilization and site preparation	3 Months
Entry/Exit shaft construction	3 Months
Install TBM and begin boring	10 Months
Total Duration	**16 Months**

2.5.3 Estimation of Construction Equipment

The tunnel diameter in Route 2 is designated for container-size freight with an outside diameter of 25 ft. Table 2-28 presents type and number of trucks and bucket loaders for loading and hauling excavated spoil. The general assumptions as mentioned previously applied to Route 2.

Table 2-28 Type and Construction Equipment Needs for Route 2

Jobsite	Type of Construction Equipment	Hourly Output	Total Volume of Excavation (LCY/Day)	No. of Construction Equipment per Day per TBM	No. of Construction Equipment per Day
Urban	20 CY Trailer Truck Cycle 40	12.5 (LCY)	2,910	30	30
	3 CY Bucket Loader	197 (BCY)		2	2

2.6 CONSTRUCTION METHOD FOR ROUTE 3

Figure 2-22 illustrates the 15-mile congested area for Route 3 from the Port of Houston to a Satellite Distribution Center in Baytown, which will be used for the three sizes of container, crate, and pallet. Figure 2-23 shows how Route 3 passes underneath the Tabbs Bay.

2.6.1 Comparison between Construction Methods

Tunneling methods are applicable for this route for the following reasons:

- Passes underneath the Tabbs Bay.
- Passes through congested urban area.
- Passes underneath crossing of Cedar Bayou River and adjacent watershed.
- Lower costs than cut-and-cover methods due to high watertable.

As a result, the 15-mile route for tunneling construction as shown in Figure 2-22 is the best option for all three sizes of containers, crates and pallets.

2.6.2 Challenges for Tunneling Operation

- Unavailability of nearby dump site for spoils.
- Due to possible obstructions under bay and river, the tunnel depth may have to be deeper.
- Dewatering is needed for all entry/exit shafts as well as for the access shafts.

At the bay, as shown in Figure 2-23, the nearest access shaft must be five miles from the entry shaft.

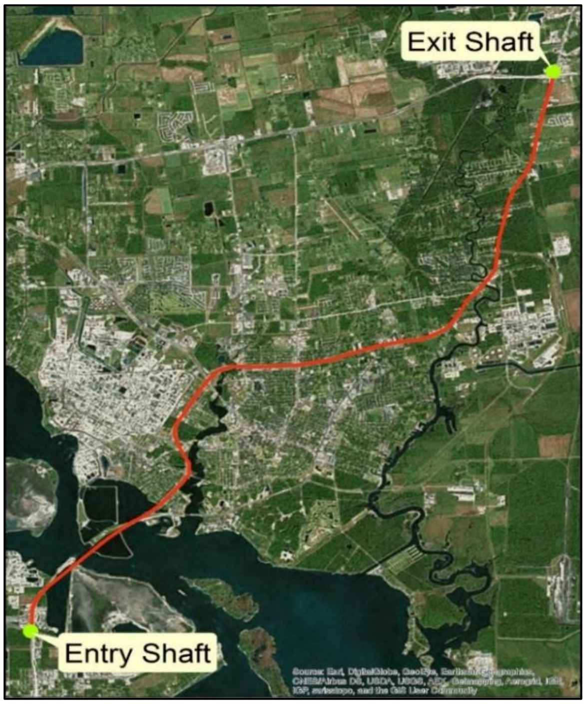


Figure 2-22 Port of Houston to an Inland Satellite Distribution Center in Baytown (Source: Google Earth)

Figure 2-23 Tunneling at the Tabbs Bay
(Source: Google Earth)

2.6.3 Route 3 Project Duration

This section provides an estimation of project durations for Route 3. The same general assumptions presented previously apply to this section. Different tunnel sizes, do not impact shaft and tunnel construction. Table 2-29 presents the summary of Route 3 assumptions and Table 2-30 shows an estimation of project duration for all three freight sizes.

Table 2-29 Summary of Route 3
(15 miles from Port of Houston to an Inland Satellite Distribution Center in Baytown)

Type	Description	Quantity
Contractor	Only one contractor is required.	1
Entry/Exit Shafts	Total distance is 15 miles.	One entry and one exit shaft
Access Shafts	One every mile after the Tabbs Bay	8
TBM	Production rate of 100 ft/day	1

Table 2-30 Estimation of Project Duration for Route 3

Description	Duration
Mobilization and site preparation	3 Months
Entry/Exit shaft construction	3 Months
Install TBM and begin boring	30 Months
Total Duration	**36 Months**

2.6.4 Estimation of Number and Types of Construction Equipment

As stated previously, Route 3 is designated for the container as well as crate- and pallet-size freight and tunneling is the preferred method for all these three freight sizes. Table 2-31 shows the tunnel diameters and volume of excavation for all three tunnel sizes. Table 2-32 presents type and number of trailer dump trucks and front-end loaders for hauling soil. The general assumptions as mentioned previously apply to Route 3.

Table 2-31 Volume of Excavation per Day

Freight Type	Tunnel External Diameter (ft)	Total Volume of Excavation by TBM/Day (LCY)
Container	25	3,000
Crate	17.4	1,500
Pallet	13	800

Table 2-32 Type and Construction Equipment Needs for Route 3

Jobsite	Type of Construction Equipment	Hourly Output	Total Volume of Excavation (LCY/Day)	No. of Construction Equipment per Day per TBM	No. of Construction Equipment per Day
Urban	Container	20 CY Trailer Truck-Cycle 40 Miles	12.5 (LCY)	30	30
		3 CY Bucket	197 (BCY)	2	2
	Crate	20 CY Trailer Truck-Cycle 40 Miles	12.5 (LCY)	15	15
		3 CY Bucket Loaders	197 (BCY)	1	1
	Pallet	20 CY Trailer Truck-Cycle 40	12.5 (LCY)	8	8
		3 CY Bucket Loaders	197 (BCY)	1	1

2.7 TERMINAL CONSTRUCTION

As an option, a terminal slab can be constructed with roller compacted concrete (RCC), which was successfully used for the Port of Houston in 2009. The RCC production/placement rates are high, making this an ideal concrete paving material for large, thick industrial pavements. Additionally, no steel (neither dowels nor reinforcing material) will be needed, further speeding placement and reducing cost. Wide allowable joint spacing and thin saw cut joints will keep long-term maintenance to a minimum (Singel, 2009). Table 2-33 provides volume of RCC for each route.

Table 2-33 Terminal Construction

Route	Freight Type	Terminal Area (acre)	Required RCC (CY)*
Port of Houston to City of Lancaster (near Dallas)	Container	21.5	40,500
Border between the U.S. and Mexico in Laredo, TX	Container	21.5	40,500
Port of Houston to an Inland Satellite Distribution Center in Baytown	Container	21.5	40,500
	Crate	21.3	40,000
	Pallet	8.7	16,500

*Concrete Thickness = 14 in.

2.8 CHAPTER SUMMARY

This chapter presented considerations for two main construction methods, tunneling and cut-and-cover. Two single-track tunnels can use the cut-and-cover method, but one twin-track tunnel is only suitable for tunneling. In this chapter, both of these methods were compared.

The construction method for Route 1, Port of Houston to City of Lancaster (near Dallas) along IH-45, showed that the cut-and-cover method is an option in rural areas while tunneling is suitable in urban areas. Accordingly, the entire route is divided into nine segments, and a comparison between tunneling and cut-and-cover methods was made. It was concluded that 50 percent of the entire Houston to Dallas route will be cut-and-cover and the rest will be tunneling. For the cut-and-cover method, three trench cross sections were evaluated, and based on the basis of volume of excavated material, a trench cross section was selected.

The construction method for Route 2, the border crossing at Laredo from the World Trade Bridge in Nuevo Laredo, Mexico to the Union Pacific railyard on the U.S. side, and Route 3, Port of Houston to an inland satellite distribution center in Baytown, showed that tunneling using TBM via the tunnel boring machine is the most suitable method. For the first five miles of Route 3 (passing under the Tabbs Bay), installation of an access shaft is not possible. For the remaining part of Route 3, an estimated eight access shafts are planned for construction.

In this chapter different methods of shaft and support systems were also discussed. For all three proposed routes, a rough estimation of number and type of required construction equipment (trailer trucks and bucket loaders) and expected time of project duration were provided. Furthermore, it was assumed that each project would require one contractor every 25 miles for the tunneling using TBM and one contractor with five excavators every 25 miles for the cut-and-cover tunneling. Table 2-34 summarizes expected project duration and the total number of construction equipment for each proposed route.

Table 2-34 Summary of Expected Project Duration and Total Number of TBMs and Excavators

Route	Division	Length (mile)	Freight Type	Size of Tunnel (Outside Diameter, ft)	Method of Construction	Estimated Duration	No. of TBMs or Excavators
Route 1- Port of Houston to City of Lancaster (near Dallas)	1	100	Container	25	Tunneling	50 Months	4 TBMs
	2	100		16	Cut-and-cover		20 Excavators
	3	50		25	Tunneling		2 TBMs
Route 2-Border between the U.S. and Mexico in Laredo, TX	-	4	Container	25	Tunneling	13 Months	1 TBM
Route 3-Port of Houston to an Inland Satellite Distribution Center in Baytown	-	15	Container	25	Tunneling	33 Months	1 TBM
			Crate	17.4			1 TBM
			Pallet	13			1 TBM

This Page is Intentionally Left Blank

CHAPTER 3-COST ANALYSIS

3.1 INTRODUCTION

Cost estimating is one of the most important steps in feasibility analysis of innovative infrastructure systems, such as Underground Freight Transportation (UFT). This chapter estimates capital and annual costs of UFT systems. UFT systems have several major capital and annual cost components:

- Capital Costs
  - Tunnel Construction
    - Tunneling
    - Cut-and-cover
    - Track
    - Track Bedding
  - Vehicles
  - Linear Induction Motors (LIM)
    - Hardware, Installation, and Control System
  - Terminals
    - Land purchase
    - Land Development and Office Construction
  - Handler & Forklift
- Annual Costs
  - Maintenance
    - Tunnel
    - LIM
  - LIM Energy Consumption
  - Administration

Section 3.2 describes our methodology to achieve Task 3 objectives as provided in the following sections. Section 3.3 provides background on tunneling cost estimation. It presents our regression model for estimating the tunneling costs. Cost estimating of tracks and track bedding are also provided in this section. Section 3.4 presents the cost estimation of vehicles. Section 3.5 provides cost estimation of hardware, installation and control systems of LIMs. Section 3.6 presents cost estimation of terminals. Section 3.7 explains cost estimation of handlers. Sections 3.8, 3.9, 3.10 and 3.11 present estimation of annual costs of tunnel maintenance, LIM maintenance, LIM energy consumption, and administration.

3.1.1 Objectives

The objective of this chapter is to provide a conceptual cost estimate of UFT for the three routes previously presented in Table 1-2. The cost estimate includes capital, operation and maintenance costs for the three sizes of the primary shipping facilitators: shipping container, crate and pallet.

3.2 METHODOLOGY

Different methods were used to estimate the capital and annual cost components of the UFT systems. Historical tunneling costs found in the literature or acquired from recent relevant tunneling projects were used to create a regression model to estimate cost of tunnels with various sizes. RSMeans cost data (2016) was used to estimate costs of cut-and-cover, track bedding, terminal and office construction. Quotes from the industry were used to estimate costs of vehicles, handlers and forklifts. They were also used for estimating terminal land purchase cost, costs of LIM hardware, installation and control system, and LIM maintenance and energy costs. Administrative costs were estimated using data from the U.S. Bureau of Labor Statistics. Literature data were used to estimate track cost and tunnel maintenance cost.

3.3 TUNNELING COSTS

3.3.1 Background on Tunneling Cost Estimation

Bennet (1981) authored one of the earliest reports on tunnel cost estimating methods. He provided three tunnel cost estimating case studies. His most notable case study focused on the Nast Tunnel. This tunnel was built from 1970 to 1973 in Pitkin County, Colorado. This 2.96-mile 10 ft-diameter circular tunnel was excavated through hard rocks, such as granite. The tunneling cost was about $477 (1973 dollars) per foot (Bennett, 1981). Goff et al. (1998) adjusted the cost of this tunnel to estimate the tunneling cost of a project in Dallas. They adjusted the tunneling cost based on the location factors and historical cost indices provided by RSMeans Cost Data and the size adjustment equations proposed by Sinfield and Einstein (1998). The cost adjustment results reported by Goff et al. (1998) are summarized in Table 3-1.

Table 3-1 Cost Adjustment by Goff et al. (1998)

Parameter	Adjusted from	Adjusted to
Year	1973	1998
Location	Colorado	Dallas
Diameter	10 ft	6.5 ft

3.3.2 UFT Tunneling Cost Estimating Approach

Based on the literature, adjusting the tunneling costs of similar past projects based on location factors and historical cost indices and conducting size adjustment by developing regression model based on location- and time-adjusted costs is the most common approach to estimating preliminary tunneling costs for future projects. We followed this common approach by selecting similar tunneling projects and adjusting their costs to estimate the UFT tunneling cost.

3.3.3 Tunneling Cost Assumptions

A regression model was created using location- and time-adjusted tunneling cost data from literature to calculate the tunneling costs for various tunnel sizes. The costs used in this regression analysis were based on the contract costs of the existing tunnels. To further clarify the estimated tunneling costs, the items that are included in these contract costs are listed here:

1. Costs in the database are contract costs. The costs do not include many of the subsequent change orders, claims, and cost adjustments to the project, if any.
2. Cost of tunnel liner is included in the contract.
3. Cost of necessary entry/exit shaft is included in the contract cost.
4. Cost of subsequent access shafts is included in the contract cost.
5. Cost of the TBM itself is included in the contract cost.
6. Cost of handling the spoils from the excavation is included in the contract cost.

The tunneling costs are reported per linear foot of the tunnel length. It is common to report the results of preliminary cost estimation of tunnels per linear foot.

3.3.4 Tunneling Costs

We adjusted the cost of the DART tunnel in Dallas, Texas (Dart, 2015) to be used in our regression model. The DART tunnel specifications are summarized here (DART, 2015):

- Name: DART Tunnel Project
- Location: Dallas, TX
- Year Completed: 1997
- Length: 3.25 miles
- Bore: Twin
- Diameter: 21.5 ft
- Starting Depth: 40 ft Below US-75
- Station Depth: 120 ft Below US-75
- Ground Condition: Austin Chalk
- Cost: $122M in 1997 dollars (Urban Ohio, 2015)
- Construction cost of the DART tunnel per foot was $3,555 in 1997.

We also included the cost of the Dallas Mill Creek Drainage Relief Tunnel in our regression model. The Dallas Mill Creek Drainage Relief Tunnel is a new tunneling project that has recently been put up for bid. This tunnel has the following project specifications (Dallas, 2015):

- Approximately $250 million construction project
- Tunnel length is approximately 5 miles (Figure 3-1)
- Tunnel depth varies between 70 and 150 feet (Figure 3-2)
- Diameter – 30 ft (Figure 3-3)
- Seven (7) Shafts – 14 to 40-ft diameter
- Cast-in-place concrete liner
- One million cubic yards of tunnel excavation
- Ground condition is Austin Chalk

Figure 3-1 Map of Dallas Mill Creek Tunnel (Dallas, 2015)

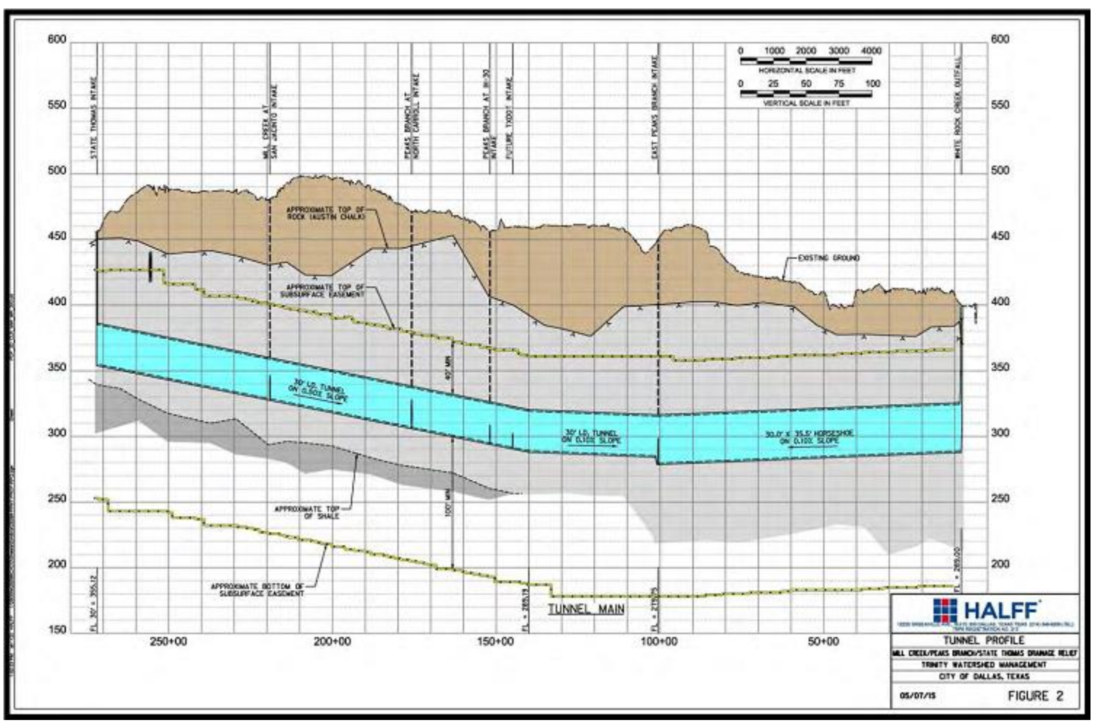


Figure 3-2 Tunnel Profile (Dallas, 2015)

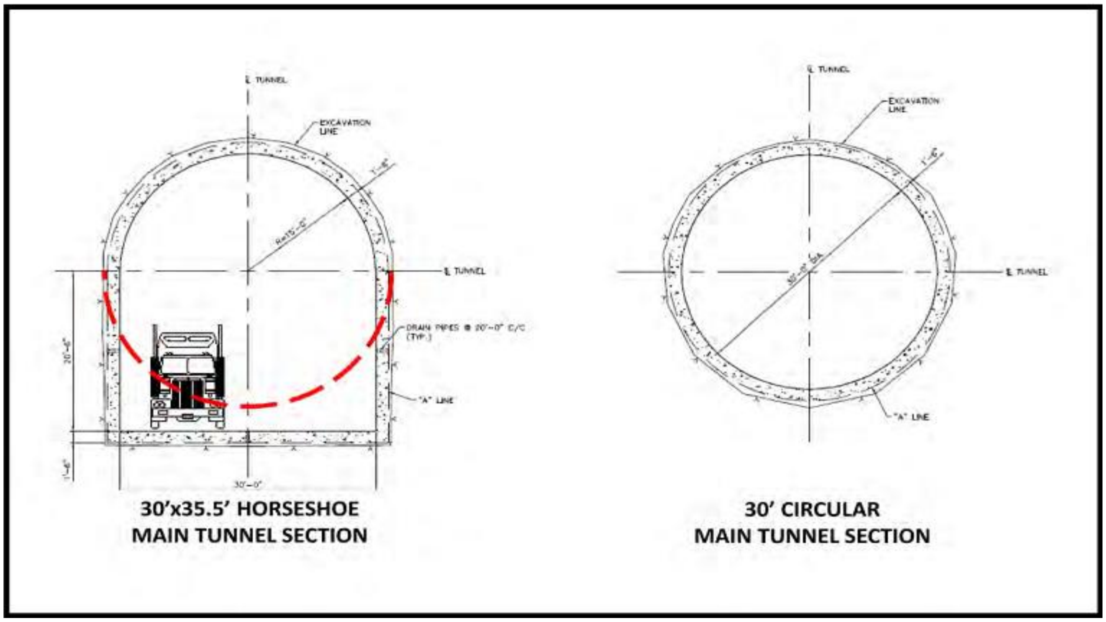


Figure 3-3 Tunnel Section (Dallas, 2015)

The tunneling costs available in Sinfield and Einstein (1998) along with the costs of the DART tunnel and Dallas Mill Creek Drainage project were used to create a regression model to estimate costs of tunnels with various sizes. The tunneling costs were adjusted for time and location using RSMeans year and location indices before regression analysis was conducted. Figure 3-4 shows the relationship between tunnel diameter and cost per foot.

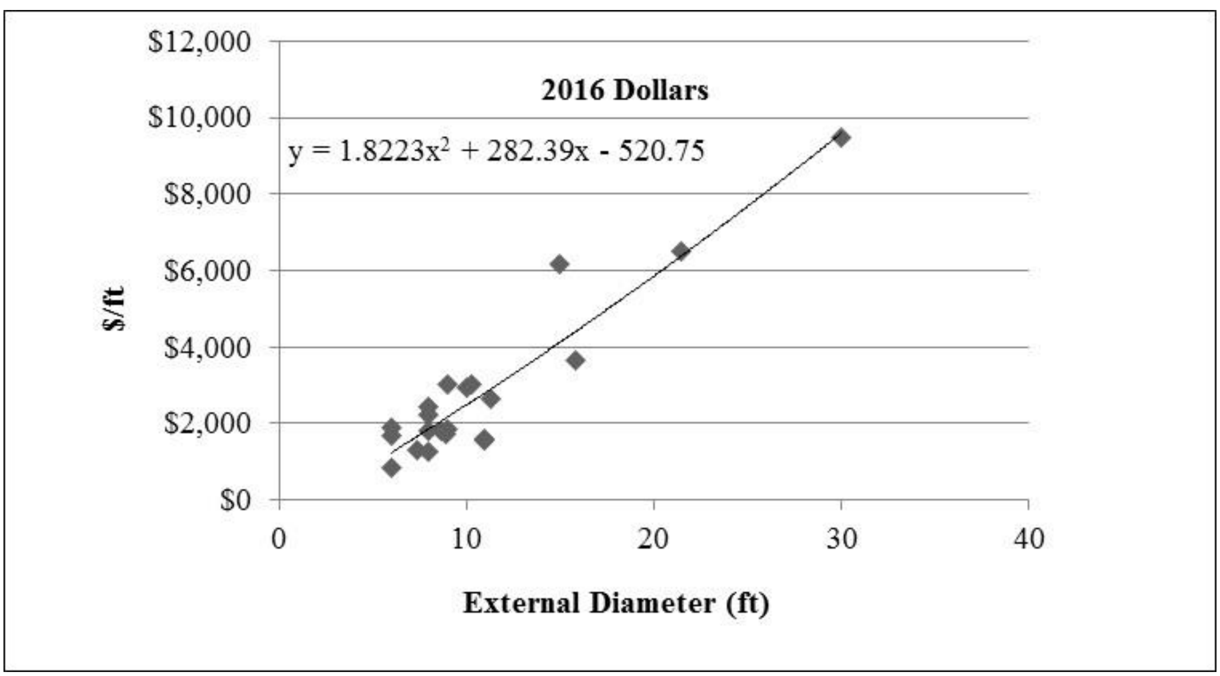


Figure 3-4 Relationship between Tunnel Diameter and Cost per foot

The regression model presented in Figure 3-4 was used for calculating the costs of tunnels with different diameters. The best-fitted line was obtained using a polynomial regression of Order 2 with the R^2 value of 0.875. Table 3-2 shows the summary of tunneling construction costs in the pallet, crate and shipping container UFTs. The external diameters of tunnels were used to create the regression model and 15% cost contingency was added to the costs found from regression to calculate the costs in Table 3-2.

Table 3-2 Summary of Construction Costs for One Twin-Track Tunneling System (2016 dollars)

Freight Type	External Diameter (ft)	Cost ($/ft)	Cost with Contingency ($/ft)
Pallets (3.3 ft W × 3.3 ft H × 4 ft L)	13	3,547	3,976
Crates (5 ft W × 5.3 ft H × 10.4 ft L)	17.4	4,943	5,685
Shipping Containers (8 ft W × 9.5 ft H × 40 ft L)	25	7,676	8,827

3.3.5 Cut-and-cover Cost

This section estimates the cut-and-cover construction cost for the UFT system. Figure 2-14 showed the cross section of the trench design for the cut-and-cover construction. RSMeans Heavy Construction Cost Data 2016 were used to estimate the cost for the cut-and-cover construction of the UFT. Table 3-3 presents cost breakdown of the cut-and-cover construction according to RSMeans (The Gordian Group, RSMeans® 2016). The costs of concrete tunnel tubes including transportation and installation costs were acquired using quotes from a pipe manufacturer in Texas. The trenching operation cost is $964 per linear foot of trench excluding concrete tube costs. The cost of manufacturing, transportation and installation of two concrete tubes is about $5,000 per linear foot. The total cost for the cut-and-cover construction considering 15% contingency is about $6,859 per linear foot.

3.3.6 Track Costs

The cost of track construction depends on the availability of roadbed. Since track should be laid on tunnel invert for the UFT systems, we can assume the track would be constructed on existing roadbed for cost estimating. The total cost of track installation including the material, equipment and labor costs is $1,025,541 per mile in 2009 dollars (Quandel Consultants, 2011). This cost is equivalent to $1,003,119 per mile in 2016 dollars in Dallas and was adjusted using RSMeans year and location indices. Table 3-4 provides breakdown of track costs.

Table 3-3 Cut-and-cover Construction Cost Breakdown (2016 dollars)

RSMeans Item No.	Description	Unit Cost Including Overhead and Profit	Volume/ft	Cost/ft
31 23 16.13	3.5 CY Excavator	$4.10/BCY	35.5 BCY	**$146**[12]
31 23 23.20	12 CY Truck 15 min avg. wait 30 min Miles cycle with 35 mph avg.	$15.25/LCY	19.36 LCY	**$295**
31 13 13.14	200 hp Loader with 50 ft cycle for clay	$1.23/LCY	19.36 LCY	**$24**
03 31 13.35	140 psi flowable fill delivered	$88.50/CY	4.7 CY	**$416**
03 31 13.70	Concrete direct chute over 20 CY for foundation mats	$8.45/CY	4.7 CY	**$40**
31 13 13.14	Backfill with 200 hp Loader with 50 ft cycle for clay	$1.23/LCY	20.7 LCY	**$26**
31 23 23.23	Sheepsfoot wheel roller, 12 in. lifts and 4 passes	$0.84/CY	20.7 CY	**$17**
Total				**$964**

Table 3-4 Costs of Track Construction (Quandel Consultants, 2011) (2016 dollars)

Description	Cost ($/mile) (National, 2009)	Cost ($/mile) (Dallas, 2016)
Materials	$471,378	$461,071
Labor	$208,144	$203,593
Track labor	$149,977	$146,698
Material Handling and Distribution (5% of Material Subtotal)	$23,569	$23,054
Track Labor Overhead (85% of Track Labor)	$127,480	$124,693
Equipment (30% of Track Labor)	$44,993	$44,010
Total	$1,025,541	$1,003,119

3.3.7 Concrete Work for the Invert of the Tunnel

Concrete bedding is required to install rail tracks on the invert of tunnels. According to Chapter 2, 3,000 psi normal-weight concrete with minimal reinforcement is required for concrete bedding. This concrete type is cast in place and very similar to a foundation mat with reinforcements. According to RSMeans Heavy Construction Cost Data (RSMeans, 2016), the cost

[12] For trench box approximately $10 per linear foot need to be added.

of this type of concrete work is $345 per cubic yard including placement and finish. Table 3-5 shows the number of cubic yards per mile (CY/mile) needed to complete the required concrete work

Table 3-5 Amount and Cost of Concrete Bedding for Each Tunnel Type (2016 dollars)

Type of Tunnel	Amount of Concrete (CY/Mile)	Cost ($/Mile)	Cost ($/ft)
Container Tunnel	11,343	$3,913,335	**$741**
Crate Tunnel	4,694	$1,619,430	**$307**
Pallet Tunnel	3,912	$1,349,640	**$256**

3.4 VEHICLES

The costs of UFT vehicles operating in the tunnel were estimated using similar costs used in the railroad industry. Baumgartner (2001) reported the costs of various North-American freight cars, such as flat cars, mill gondola, coal gondola, open hopper, and covered hopper. The average reported cost was $53,000 in 2001 dollars. This cost is equivalent to $87,600 in 2016 dollars (adjusted using RSMeans indices). According to the Association of American Railroads (AAR, 2015), the average cost of a new vehicle is estimated to be $85,396 in 2012 dollars. This cost is equivalent to $90,750 in 2016 dollars (adjusted using RSMeans indices). Based on the costs reported in Baumgartner (2001) and AAR (2015), it is safe to assume that the cost of one UFT vehicle is about $90,000.

Since these vehicles are completely metal, we assumed that their cost is mostly attributed to the material and workmanship costs. To calculate the cost for smaller crate and pallet sizes, we adjusted the cost based on the weight of each vehicle unit presented in Chapter 1. The calculated cost for each vehicle unit is presented in Table 3-6.

Table 3-6 Weight and Cost of each Vehicle (2016 dollars)

UFT System	Empty Vehicle Weight (U.S. tons)	Cost per Vehicle ($)
Shipping Container	5.0	$90,000
Crate	2.3	$42,000
Pallet	1.0	$18,000

3.5 LINEAR INDUCTION MOTOR (LIM)

There are two major costs associated with LIM: (1) Costs of hardware, installation, and control system and (2) energy cost. Section 3.5.1 provides capital LIM costs based on the design provided in Chapter 1. The LIM energy costs, which are annual costs, are presented later in Section 3.10.

3.5.1 Hardware, Installation, and Control System

Ten LIMs are required for each mile of the UFT project in each direction. There are two directions for each tunnel; therefore, 20 LIMs are required for each mile of the system. Each LIM costs about $25,000 (acquisition, installation, control systems in tunnel and terminals). Hence, the cost of LIM hardware, installation, and control system is about $500,000 per mile.

3.6 TERMINALS

Two terminals are designed for loading and unloading freight for each UFT alternative. The cost for a terminal has the following components:

- Land purchase
- Land development and office construction

The costs of these components are estimated in Section 3-6-1 and 3-6-2.

3.6.1 Land Purchase

According to the Texas Small Land Sales Report (2014), the state of Texas has been divided into seven sections with different average land costs (see Figure 3-5). These costs are averages of the region costs and may not reflect the purchasing cost of land. In fact, the cost of large parcels (more than 20 acres) listed in realtor.com website in March 2016 (Realtor, 2016) varies significantly; therefore, the average cost of different plots of land in the terminal locations were acquired from the realtor.com website to estimate the land purchase cost of UFT terminals.

The terminals for both pallet and crate size freights are in the Houston area. Different types of terminals require different sized land areas. According to Chapter 1, we need the following size plots for each type of terminal:

- 21.5 acres of land for container terminal.
- 21.3 acres of land for the crate terminal.
- 8.7 acres of land for pallet terminal.

According to realtor.com (Realtor, 2016), the average cost of land in our terminal locations is as follows:

- $51,529 per acre in Houston, TX.
- $15,000 per acre in Lancaster, TX.
- $36,886 per acre in Laredo, TX.

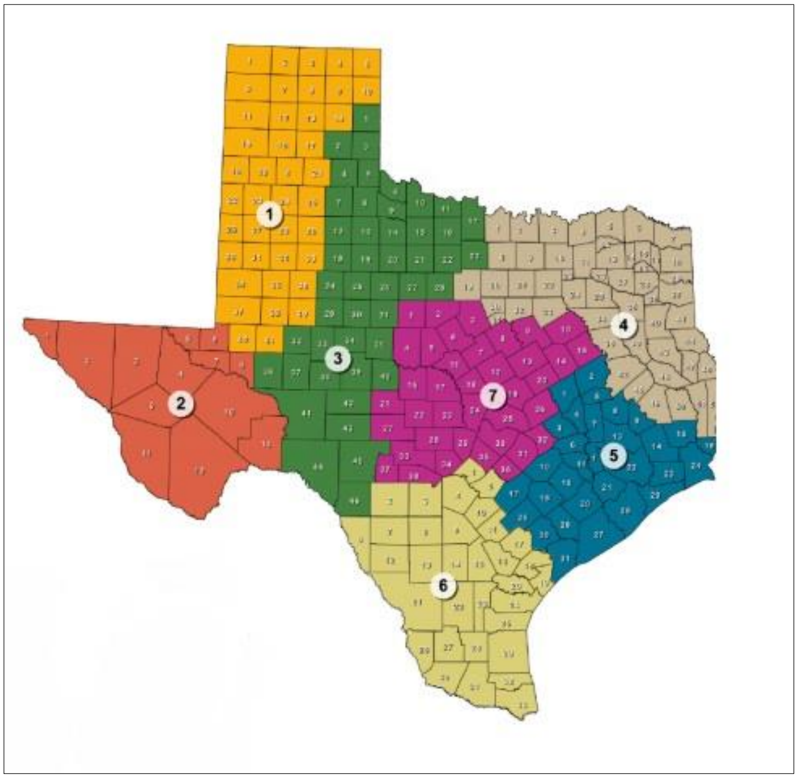


Figure 3-5 Region Divisions by Texas Small Land Sales Report (2014)

The costs of purchasing lands for the UFT terminals are summarized in Table 3-7.

Table 3-7 Land Costs for different UFT Terminals (2016 dollars)

Terminal Location	UFT Type	Terminal Area (Acres)	Unit Cost (per acre)	Total Cost
Houston, TX.	Pallet	8.7	$51,529	$448,303
Houston, TX.	Crate	21.3	$51,529	$1,097,568
Houston, TX.	Container	21.5	$51,529	$1,107,874
Laredo, TX.	Container	21.5	$36,886	$793,049
Lancaster, TX.	Container	21.5	$15,000	$322,500

The costs provided in Table 3-7 are average costs of lands and the actual costs may vary based on where the actual terminal is located.

3.6.2 Land Development and Office Construction

A reinforced concrete slab on grade must be constructed at the terminal to carry heavy loads. The cost of an 8-in. thick reinforced concrete slab is $11.50/ft^2 in Dallas (RSMeans, 2016). The whole terminal will not be covered by slab. The covered area is 1.4 acres, 3.3 acres, and 6.8

acres for pallet, crate, and container terminals, respectively. Therefore, the estimated total costs of concrete slab construction are:

- Pallet Terminal: $701,316
- Crate Terminal: $1,653,102
- Container Terminal: $3,406,392

Based on Chapter 1 findings, a 1,000-yard^2 office building is required for each terminal. The construction cost of building a 2- to 4-story office building in Dallas adjusted for 2016 is \$140/ft^2 (RSMeans, 2016), plus \$25/ft^2 for accessories and \$15/ft^2 for electronic devices. Therefore, the total cost of constructing the terminal office in 2016 is approximately $1,620,000.

3.7 HANDLER COSTS

The container size handler selected in Chapter 1 is the “Kalmar DCF410-CGS model.” This container handler is a large forklift (Figure 3-6). For pallet and crate freights, regular forklifts will be used (Figure 3-7). Two handlers/forklifts will be used for each loading/offloading platform in each terminal. Based on the quotes received from the Kalmar Company (Kalmarglobal, 2016) and several local dealerships in Arlington, TX, the costs of each container handler and forklift are $550,000 and $160,000, respectively. Each container terminal will need six operating handlers and two backups. Therefore, the cost of eight handlers for each terminal is $4,400,000. Each of the pallet and crate terminals has 12 loading/unloading platforms. Therefore, 12 crate and pallet forklifts, and 2 back-up forklifts are required for each terminal. The cost of 28 required forklifts for each terminal is $2,240,000.

Figure 3-6 Kalmar’s DCF410-CGS Model (Kalmarglobal, 2016)

Figure 3-7 Kalmar's Model for Crates and Pallets (Kalmarglobal, 2016)

3.8 TUNNEL MAINTENANCE

Zhang et al. (2005) analyzed the total life cycle cost (TLCC) of Holland and Lincoln Tunnels in New York. They suggested that the ratio of total life cycle cost to initial cost of these two tunnels at age of 75 was 2.1. The average cost of maintenance, rehabilitation, and repair was 1.5 percent of the initial cost per year. In another study, Baumgartner (2001) suggested a ratio of 0.1 percent to 2 percent of the initial cost per year for maintenance cost. Based on the tunneling maintenance costs reported in Baumgartner (2001) and Zhang et al. (2005), it was assumed that the maintenance cost of the tunnel is 1 percent of the initial cost (including tunnel construction, tracks, track bedding) for a design life of 100 years.

3.9 LIM MAINTENANCE

LIM systems have no mechanically moving parts. As long as they are operated within their duty cycles and are not stressed due to overheating, they should last many years. According to an LIM consultant, life expectancy of LIMs can be extended to the overall lifecycle of the tunnel infrastructure. During maintenance, the installations need to be checked on a periodic basis, and the air gap between the primary and secondary must be kept tight. This gap must be checked to assure it is within specification thresholds in order to maintain the energy efficiency of the system. Overall, it would be prudent to allocate a budget for maintenance and LIM replacement due to operation. Therefore, 5 percent of the total capital cost of an LIM system on an annual basis was assumed to maintain the entire LIM system.

3.10 ENERGY COST OF LIM OPERATION

Eq. 3-1 was introduced in Chapter 1 to calculate the energy cost of the LIM system.

$$\text{Energy} = \text{Total Vehicles} \times \text{Power Per Hour} \times \text{Hours per Year} \times \text{ Electricity Price} \quad \text{(Eq. 3-1)}$$

Chapter 1 introduced five different alternatives for implementing the UFT system. Table 3-8 shows the assumed values of equation variables and calculated energy costs for five different UFT alternatives. The annual energy costs reported in Table 3-8 were calculated based on the assumption that the system is working in full capacity.

Table 3-8 Annual Energy Costs for UFT Systems

Route and Freight Type	No. of Vehicles	Power Per Hour (kWh)	Hours Per Year	Price of Electricity	Annual Energy Cost
Houston to Dallas, Container	1,334	27	8,765	0.0533	$16,826,691
Laredo Border, Container	22	27	8,765	0.0533	$277,502
Houston to Baytown, Container	80	27	8,765	0.0533	$1,009,097
Houston to Baytown, Crate	122	10	8,765	0.0533	$569,952
Houston to Baytown, Pallet	122	5.5	8,765	0.0533	$313,474

3.11 ADMINISTRATIVE COSTS

Administrative costs are expenses associated with the personnel running the UFT system. Based on Chapter 1, the UFT system was designed to work 24/7; therefore, three 8-hour shifts for all personnel in each terminal were considered. Only one shift per day was considered for the maintenance crew. Table 3-9 summarizes personnel job descriptions, the number of people needed for each job, and the number of required shifts.

To calculate the number of employees and their salaries, the man-hours required per week was calculated for each personnel type. It was assumed that each person can only work 40 hours per week to prevent overtime payments. The following is a sample calculation to find the number of handler operators working in each terminal:

$$(24\text{ hrs} \times 7\text{ days} \times 6\text{ handler per shift} = 1{,}008\text{ worker} - \text{hr}) \div 40\text{ hrs} = 25\text{ handler operators}$$

The annual wages of personnel in Texas reported by the U.S. Bureau of Labor Statistics were used to calculate the administrative costs. Table 3-10 presents the administrative cost estimates.

Table 3-9 No. of Personnel per Shift per Terminal

Personnel	Job Description	No. of People per Shift in Container Terminal	No. of People per Shift in Crate/Pallet Terminal	No. of Shifts/Day
Handler Operator	Operate Handlers to Lift and Move Containers	6	12	3
Operation Supervisor	Directly Supervise and Coordinate Activities of Material-Moving Machines	1	1	3
LIM Operation	Monitor the Movement of Vehicles	1	1	3

Table 3-10 Cost of Personnel in Each Terminal

Personnel	Total Number of People in Container Terminal	Total Number of People in Crate/Pallet	Annual Wage Rate[13]	Total in Container Terminal	Total in Crate/Pallet Terminal
Handler Operator	25	50	$52,540	$1,313,500	$2,627,000
Operation Supervisor	5	5	$55,030	$275,150	$275,150
Operation	4	4	$34,820	$139,280	$139,280
Total				$1,727,930	$3,041,430

3.12 CHAPTER SUMMARY

The costs of UFT systems were divided into annual and capital costs. Table 3-11 summarizes the annual costs of UFT for the five different proposed alternatives for this project. Table 3-12 summarizes the capital costs of UFT for the five different proposed alternatives for this project. The terminal land costs and the terminal development costs include the costs of these items for both terminals for each route except the Laredo border route for which we could not find reliable cost of land and development for the Mexico side of this route; therefore, we used the same Laredo costs for the Mexico side.

[13] U.S. Bureau of Labor Statistics, 2016

Table 3-11 Summary of Annual Costs (2016 dollars)

Route and Freight Type	Tunnel Maintenance Cost	LIM Maintenance Cost	LIM Energy Cost	Administrative Costs	Total (Cost/Year)
Houston to Dallas, Container	$131,315,333	$625,000	$16,826,691	$1,727,930	$150,494,954
Laredo Border, Container	$2,101,045	$10,000	$277,502	$1,727,930	$4,116,477
Houston to Satellite, Container	$7,878,920	$37,500	$1,009,097	$1,727,930	$10,653,447
Houston to Satellite, Crate	$5,046,370	$37,500	$569,952	$3,041,430	$8,695,252
Houston to Satellite, Pallet	$3,652,373	$37,500	$313,474	$3,041,430	$3,396,056

Table 3-12 Summary of Capital Costs in Millions (2016 dollars)

Route and Freight Type	Length (mile)	Tunneling Cost	Track Cost	Bedding Cost	No. of Vehicles	Vehicles Cost	LIM Cost	Terminal Land Cost	Terminal Dev. Cost	Handler/ Forklift Cost	Total ($M)
Houston to Dallas, Container	250	$11,652	$251×2 = $502	$978	1,334	$120.5	$12.5	$0.32 +$1.1= $1.43	$3.76×2= $7.52	$8.8	$13,283
Laredo Border, Container	4	$187	$4×2= $8	$16	22	$1.98	$0.2	$0.79×2=$1.58	$3.76×2= $7.52	$8.8	$231
Houston to Satellite, Container	15	$700	$15×2= $30	$59	80	$7.2	$0.75	$1.1×2= $2.2	$3.76×2= $7.52	$8.8	$815
Houston to Satellite, Crate	15	$450	$15×2= $30	$24	122	$5.12	$0.75	$1×2= $2	$1.96×2= $3.92	$4.48	$520
Houston to Satellite, Pallet	15	$315	$15×2= $30	$20	122	$2.19	$0.75	$0.44×2= $0.88	$1.06×2= $2.12	$4.48	$375

CHAPTER 4-ENVIRONMENTAL IMPACT ASSESSMENT

4.1 INTRODUCTION

In this chapter, advantages and limitations of UFTs compared with the truck freight transportation system are evaluated based on an Environmental Impact Assessment (EIA). EIA is the required process to predict the positive and negative environmental consequences prior to the decision to move forward with the proposed action. EIA is governed by rules of administrative procedure regarding public participation and may be subjected to judicial review. An impact assessment may propose measures to adjust impacts to acceptable levels or to investigate new technological solutions (EPAIE, 2015).

The purpose of the impact assessment is to ensure that decision makers consider the environmental impacts when deciding whether or not to proceed with a capital project. The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as “the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made.” EIAs are unique in that they do not require adherence to a predetermined environmental outcome, but rather they require decision makers to account for environmental values in their decisions and to justify those decisions in light of detailed environmental studies and public comments on the potential environmental impacts (IAIA, 1999).

4.1.1 Objectives

The objectives of this chapter are to consider and quantify environmental impacts of UFT based on two categories of (1) positive impacts or social benefits, and (2) negative impacts or social costs. Both of these impacts will be quantified in dollar value for UFT construction and operation phases as shown in Figure 4-1.

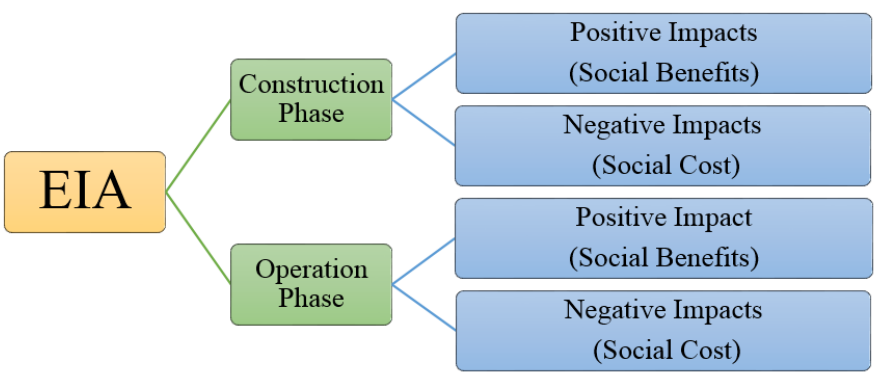


Figure 4-1 Environmental Impact Assessment Steps

4.2 EIA PROCESS

The EIA process is a systematic process of identifying future consequences of the project in two mentioned phases. A description of each phase follows (FHWA, 2015):

a) Construction Phase

Social costs of this phase are:

- Air, noise, and water pollution
- Dust
- Vibration
- Traffic disruption
- Damage to adjacent utilities, pavement, and other structures
- Site and public safety

Social benefits of construction phase are:

- Generates job opportunities in the construction industry
- Improves the local economy by utilizing construction activities, such as the sale of new construction materials, construction equipment and tools

The social costs of construction phase are considered in EIS analysis (Appendix C, Table C-1).

b) Operation Phase

Social costs of UFT during operation are:

- Air pollution due to power generator emissions.
- Loss of tax revenue due to less fuel and tire purchased by truckers.

Being part of an intermodal system, the impact of UFT on the trucking industry will be minimal. Social benefits of UFT during operation due to fewer trucks on highways are:

- Decreased air, noise, and water pollution due to fewer trucks emitting pollution
- Decreased traffic congestion and accident rate by reducing number of trucks from affected area
- Decreased infrastructure (pavement, bridges, etc.) damage by eliminating number of trucks from affected area
- Decreased petroleum product consumption by reducing number of trucks from affected area.
- Reduced land usage
- Increased safety

4.3 RELATED RESEARCH

Liu (2005) investigated environmental impacts of a proposed underground freight transportation system and its benefits for the New York City (NYC) Economic Development Commission (EDC). This project utilized the surface transportation efficiency analysis model (STEAM) to assess the potential impacts of several proposed alternatives for improving freight transportation across New York City. In this report, the annual diversion from using trucks for each alternative, in terms of vehicle miles traveled (VMT) by trucks, was presented along with the corresponding environmental impacts in terms of the reduction of various air pollutants. This study also found that future use of an underground freight transportation system would significantly reduce the number of trucks needed to enter the City, resulting in reduced traffic congestion, accidents and air pollution, enhanced transportation safety and security, and economic development-creation of a new industry and several new jobs in the City (Liu, 2005).

TTI (2009) calculated public benefits based on a federal highway cost allocation study (HCAS) updated in 2001. This analysis evaluated the cost of pavement damage, traffic congestion, traffic noise, roadway accidents, and nitrogen oxide (NO_x) production due to truck operations, as well as NO_x from the electric power generating plants required to provide power to the freight shuttle system (FSS). The amount of federal fuel taxes not collected as a result of truck operations would be replaced through ROW lease fees for FSS. Truck-generated NO_x was estimated using the U.S. Environmental Protection Agency (EPA, 2008). Their Mobile 6.2 computer model was used to assess pollutants from heavy duty diesel trucks. The FSS, similar to UFT, can reduce the adverse impacts associated with over-the-road freight transport-highway congestion and safety, infrastructure damage, air quality, carbon emissions, and fossil fuel dependency (TTI, 2009).

4.4 METHODOLOGY

To calculate the total annual cost/benefit of UFT during its operation, first, a net impact should be quantified in dollar value per ton-mile. A net impact of UFT is the difference between dollar value of positive impacts and negative impacts, which is then multiplied by freight distance (mile) and annual freight tonnage (ton). Figure 4-2 shows the methodology of calculating the total annual social cost/benefit of UFT's operation.

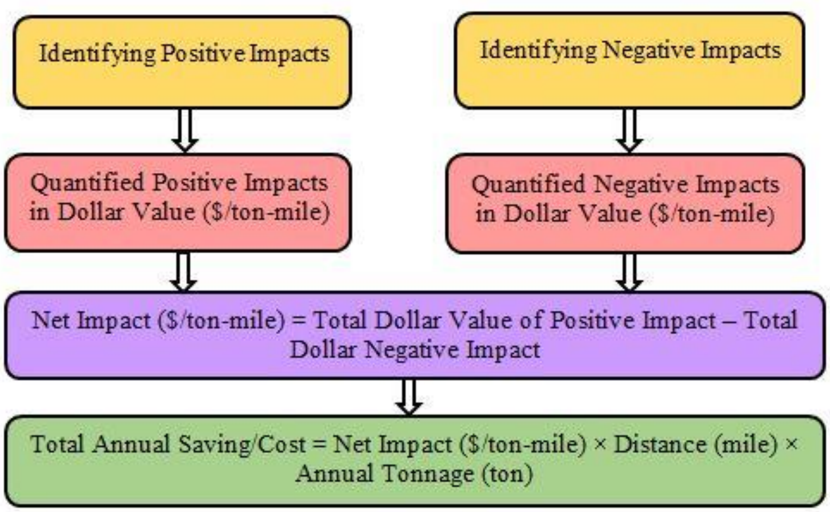


Figure 4-2 Methodology

4.5 AIR POLLUTION

Air pollution, is caused by many different human activities such as transportation by heavy duty trucks, effects on climate change as well as human and animal health. For example, truck diesel engines emit a complex mixture of air pollutants composed of gaseous and solid material. The visible emissions in diesel exhaust are known as particulate matter or PM.

Usually air pollution is considered the most important environmental threat posed by transportation. Based on Kurer (1991), Table 4-1 shows summary of major pollutants emitted by over-the-road (long-haul) vehicles, their sources, and impacts to humans, ecosystems, global climate, and quality of life.

The majority of greenhouse gas emissions from transportation are CO_2 emissions resulting from the combustion of petroleum-based products, like diesel, in internal combustion). The majority of emissions from this sector comes from freight trucks, passenger cars and light-duty trucks, pickup trucks, minivans, and trains. Also, small amounts of methane (CH_4) and nitrogen oxides (NO_x) are emitted during fuel combustion. In addition, a small amount of hydro fluorocarbon (HFC) emissions are included, which is the result of using mobile air conditioners and refrigerated transport (EPA, 2015a).

According to the EPA, in 2013, total greenhouse gas emissions were 6,673 million metric tons of carbon dioxide equivalents and these emissions increased 2.0% from 2012 to 2013. Recent trends can be attributed to multiple factors, but the most important one is an increase in miles traveled by over-the-road vehicles, especially trucks (EPA, 2015a). Figure 4-3 provides an overview of greenhouse gas emissions in the United States based on information from the inventory. Figure 4-4 provides an overview of greenhouse gas sources in the United States.

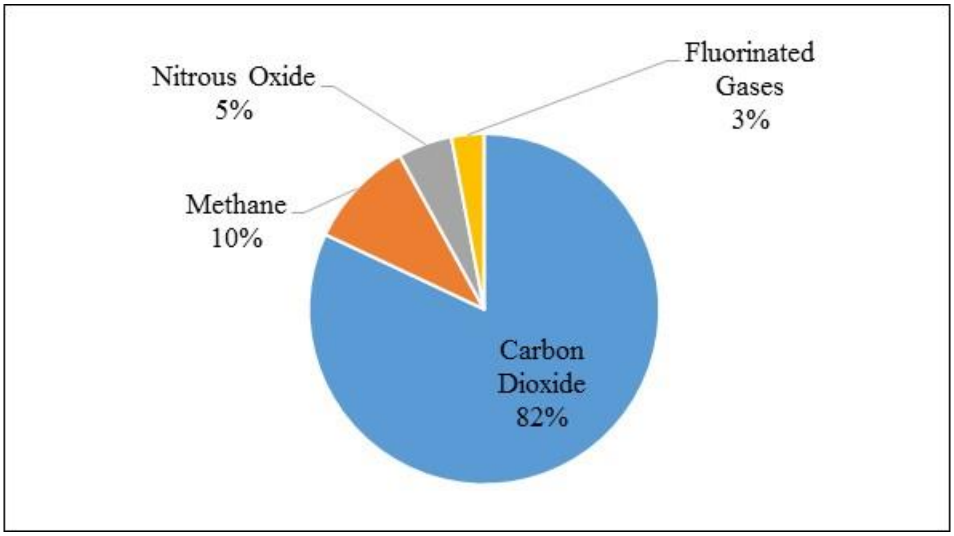


Figure 4-3 Overview of Greenhouse Gases (EPA, 2015a)

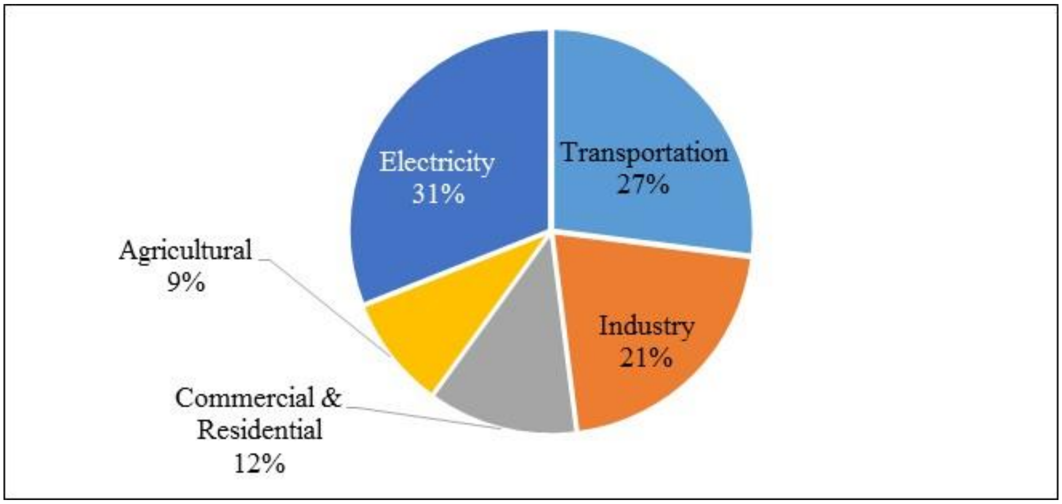


Figure 4-4 Overview of Greenhouse Gases Sources
(EPA, 2015)

Greenhouse gas concentrations in the atmosphere will increase unless the billions of tons of our annual emissions decrease substantially. Increasing greenhouse gas concentrations is the primary cause of increasing earth average temperature, which is expected to increase by 2 °F to 11.5 °F by 2100. This predicted 11.5 °F temperature increase is dependent on the level of future greenhouse gas emissions, reduction of ice and snow cover, rise in sea level, increase in ocean acidity, climate change, and the pattern and amount of precipitation such as unprecedented heavy rain in Texas on May 2015 (EPA, 2015).

Table 4-1 Air Pollutions and Their Impacts

Pollutant	Source	Impact			
		Humans	Vegetation	Global Climate	Properties
Carbon Monoxide (CO)	Incomplete combustion	Inadequate oxygen supply, heart, circulatory, nervous system	N/A	Indirect through ozone formation	N/A
Carbon Dioxide (CO_2)	Combustion	N/A	N/A	Major greenhouse gas	N/A
Hydrocarbons (HC-includes methane, isopentenyl, pentane, toluene, etc.)	Incomplete combustion, carburetion	Some are carcinogenic ozone precursor	Build-up in soil, feed, food crops	Methane has high greenhouse potential, leads to ozone formation	N/A
Nitrogen Oxides (NO_x)	Oxidation of N_2 and N-compounds in fuels	Respiratory irritation and other problems.	Acidification of soil and water, over fertilizing	NO_2 has high greenhouse potential, leads to ozone formation	Weathering, erosion
Particulates	Incomplete combustion, road dust	Respiratory damage, various toxic content	Reduced assimilation	N/A	Dirt
Soot (diesel)	Incomplete combustion	Carcinogenic	N/A	N/A	Dirt
Ozone (formed by interaction of other pollutants)	Photochemical oxidation with NO_x and HC	Respiratory irritation, ageing of lungs	Risk of leaf and root damage, lower crop yields.	High greenhouse potential	Decomposition of polymers

4.5.1 Air Pollution in Texas

According to the American Lung Association, based on EPA data, the Houston and Dallas-Fort Worth metropolitan areas are the most polluted in Texas by ozone, ranking sixth and seventh highest in the United States. Also, Houston is the most polluted city in Texas as a result of round particle pollution (RPP) (American Lung Association, 2015).

Ozone (O3) is a highly reactive gas composed of three oxygen atoms. Tropospheric or ground level ozone, which we breathe, is formed primarily from photochemical reactions between two major air pollutants, volatile organic compounds (VOC) and nitrogen oxides (NO_x). When inhaled, ozone pollutants react chemically with many biological molecules in the respiratory tract, leading to a number of adverse health effects (EPA, 2015c).

Figure 4-5 shows carbon monoxide emission density (tons per square mile) in each county divided into three groups, with the darker shaded counties having higher relative emission density. As shown in Figure 4-5, the triangle of DFW, Houston, and San Antonio, especially along highway IH-35 and IH-45, which are the most polluted areas in Texas.

Carbon monoxide (CO) is a colorless, odorless gas formed by the incomplete reaction of air with fuel. The pollution from CO occurs primarily from emissions produced by fossil fuel–powered engines, including motor vehicles and non-road engines and vehicles such as construction equipment and boats. Higher levels of CO generally occur in areas with heavy traffic congestion. Other sources of CO emissions include industrial processes, residential wood burning, and natural sources such as forest fires. Woodstoves, gas stoves, cigarette smoke, and unvented gas and kerosene space heaters are indoor sources of CO. The highest levels of CO typically occur during the colder months of the year when inversion conditions are more frequent (EPA, 2011).

.

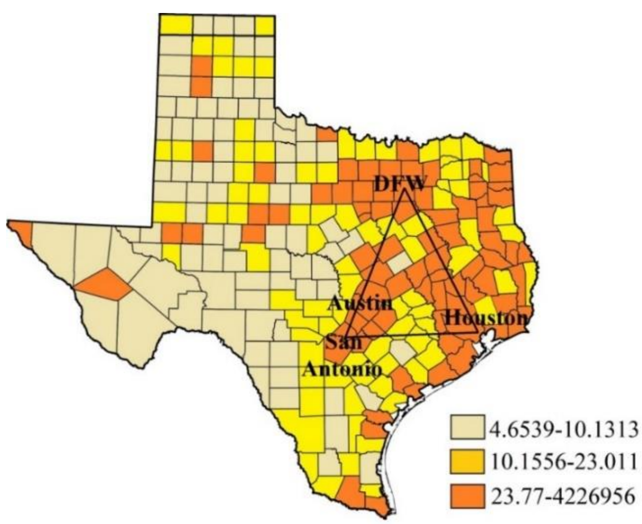


Figure 4-5 Carbon Monoxide Emission in Texas

Carbon monoxide (CO) can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues. Exposure to lower levels of CO is most serious for those who suffer from heart disease, and can cause chest pain, reduce the ability to exercise, or with repeated exposures may contribute to other cardiovascular effects. Even healthy people can be affected by high levels of CO. Breathing high levels of CO can cause vision problems, reduced ability to work or learn, reduced manual dexterity, and difficulty performing complex tasks. At very high levels, CO is poisonous and can cause death (TCEQ, 2015). Figure 4-6 shows Texas level of carbon monoxide emissions grouped by major source section (EPA, 2011).

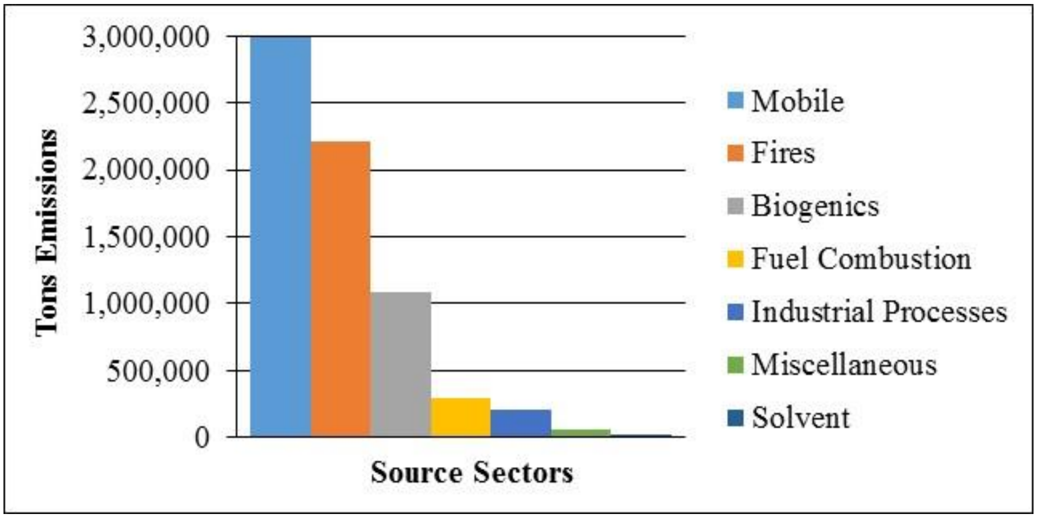


Figure 4-6 Carbon Monoxide Emissions by Source Sectors in Texas

Figure 4-7 shows the majority of the carbon monoxide emissions are mobile which includes on-road and non-road sources, aircraft, locomotives, and commercial marine vessels (EPA, 2011).

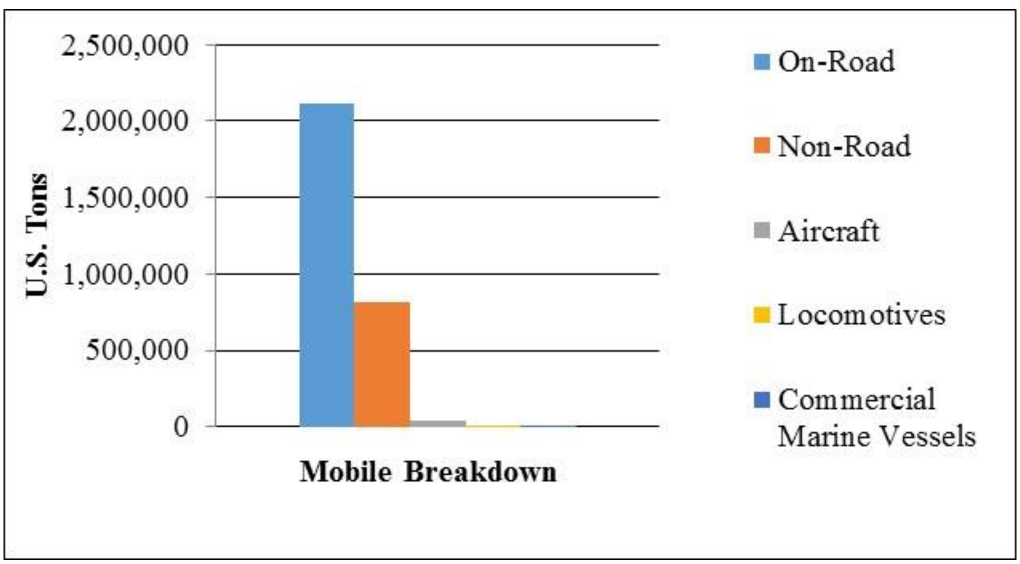


Figure 4-7 Carbon Monoxide Emissions Mobile Breakdown in Texas

4.5.2 Emissions Produced by Heavy Trucks

There are several factors that affect the amount of air pollution trucks emit and the resulting stress on the environment, whether the vehicle is being driven or is at idle. Some of the most important are (EPA, 2008):

- Truck type and truck size
- Truck age and accumulated mileage
- Fuel type
- Ambient weather conditions (temperature, precipitation, wind)
- Maintenance condition of the truck

The vehicle emission modeling software that EPA uses to estimate average emissions from highway vehicles is MOBILE 6.2, which estimates emission factors for gasoline-fueled and diesel highway motor vehicles, and for certain specialized vehicles such as natural-gas-fueled or electric vehicles that may replace them, for the following:

- Hydrocarbon (HC)
- Carbon monoxide (CO)
- Oxides of nitrogen (NO_x)
- Sulfur dioxide (SO_2)
- Ammonia (NH_3)
- Carbon dioxide (CO_2)
- Six hazardous air pollutants (HAPs)
- Exhaust particulate matter (which consists of several components)
- Tire wear particulate matter
- Brake wear particulate matter

A US DOE Energy Efficiency and Renewable Energy online article entitled "Long-haul truck idling burns up profits" states that even when the trucks are parked, the truckers do not turn them off. They run the air conditioning and heater just as if they were in their homes because they sleep in their trucks during the long haul, and spend more time in their trucks than out. From the DOE article[14]:

"Argonne estimates that rest-period idling results in the emission of about 11 million tons of carbon dioxide, 55,000 tons of nitrogen oxides, and 400 tons of particulate matter annually in the U.S. These emissions contribute to climate change and diminish local air quality, which can affect the health of not only those living in the community, but the truck drivers themselves."

Based on the EPA emission modeling MOBILE 6.2 software, average idle emission rates for heavy-duty diesel trucks by gross vehicle weight (GVW) in grams per minutes and average emission rate for heavy-duty diesel trucks by GVW in grams per mile traveled are shown in Tables

[14] http://www.afdc.energy.gov/uploads/publication/hdv_idling_2015.pdf (Accessed on August 10, 2016)

4-2 and 4-3. At the time of submission of this report, these data are the latest available on the EPA Website[15].

Vehicle emissions depend on the gross vehicle weight, quantity of goods, idle time, and traveled distance. Also, the amount of produced carbon dioxide for heavy-duty trucks is 90 grams per ton-mile (McKinnon and Piecyk, 2011).

4.5.3 Social Costs of Carbon Dioxide

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. It is naturally present in the atmosphere as part of the earth's carbon cycle. Due to high amount of produced carbon dioxide per year and its effect on environment, carbon dioxide is the most important and costly pollutant. Table 4-4 shows social cost of carbon dioxide (SC-CO_2) based on different models from different sources summarized by Whitehouse (2010).

[15] http://www.epa.gov/otaq/consumer/42of08027.pdf, (Accessed on July 10, 2016).

Table 4-2 Average Idle Emission Rates for Heavy-Duty Diesel Trucks by GVW Class (EPA, 2008)

		Heavy-Duty Diesel Vehicle Classifications (Gross Vehicle Weight)							
Pollutant	**Unit**	**8501-10,000 lb**	**10,001-14,000 lb**	**14,001-16,000 lb**	**16,001-19,500 lb**	**19,501-26,000 lb**	**26,001-33,000 lb**	**33,001-60,000 lb**	**>60,000 lb**
VOC	gr/min	0.024	0.026	0.034	0.035	0.047	0.058	0.059	0.07
THC	gr/min	0.025	0.026	0.034	0.036	0.048	0.059	0.059	0.071
CO	gr/min	0.155	0.168	0.215	0.220	0.253	0.318	0.442	0.575
NO_x	gr/min	0.211	0.226	0.298	0.311	0.405	0.506	0.596	0.706
PM 2.5	gr/min	0.018	0.017	0.018	0.017	0.018	0.018	0.018	0.019
PM 10	gr/min	0.02	0.018	0.019	0.018	0.019	0.019	0.019	0.020

Table 4-3 Average Emission Rate for Heavy-Duty Diesel Trucks by GVW Class (EPA, 2008)

		Heavy-Duty Diesel Vehicle Classifications (Gross Vehicle Weight)							
Pollutant	**Unit**	**8501-10,000 lb**	**10,001-14,000 lb**	**14,001-16,000 lb**	**16,001-19,500 lb**	**19,501-26,000 lb**	**26,001-33,000 lb**	**33,001-60,000 lb**	**>60,000 lb**
VOC	gr/mile	0.189	0.201	0.262	0.274	0.365	0.453	0.455	0.545
THC	gr/mile	0.194	0.204	0.266	0.278	0.37	0.459	0.461	0.552
CO	gr/mile	0.839	0.908	1.163	1.189	1.367	1.719	2.395	3.109
NO_x	gr/mile	3.088	3.298	4.352	4.548	5.99	7.471	9.191	10.99
PM 2.5	gr/mile	0.091	0.073	0.089	0.079	0.172	0.177	0.215	0.238
PM 10	gr/mile	0.099	0.079	0.096	0.085	0.186	0.192	0.233	0.259

Table 4-4 Social Cost of Carbon Dioxide Based on Different Models

Model	Study by	Social Cost of Carbon Dioxide		
		$/ton	Dollar value date	$/ton (2016 dollars)
PAGE	Hope (2006)	$5.00	2000	$6.87
PAGE	Stern (2007)	$85.00	2000	$116.86
DICE	Nordhause (2008)	$6.00	2000	$8.25
FUND	Anthoff et al. (2011)	$8.00	2010	$8.69
PAGE	Hope (2013)	$106.00	2010	$115.08

Due to differing sets of assumptions in each model, calculated carbon dioxide costs vary. Table 4-5 shows the social cost of carbon dioxide in the next 35 years by EPA.

Table 4-5 Social Cost of Carbon Dioxide Per Ton-Mile 2015-2050 (EPA, 2015 b)

	Discount Rate			
Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2015	$12	$40	$62	$117
2020	$13	$47	$69	$140
2025	$16	$51	$76	$150
2030	$18	$56	$81	$170
2035	$20	$61	$87	$190
2040	$23	$67	$93	$200
2045	$26	$71	$99	$220
2050	$29	$77	$106	$240

Based on EPA databases, information provided in previous sections, and "External Costs of Intercity Truck Freight Transportation" (Forkenbrock, 1999), total social cost of air pollution is $0.0177 per ton-mile (See Table 4-6).

Table 4-6 Social Cost of Produced Air Pollution by Heavy-Duty Trucks

Pollutant	Emission Rate (gr/ton-mile)	Social Cost of Pollutant per ton (2016-dollars)	Social Cost of Air Pollution per ton-mile Traveled
VOC	0.55	$590.00	$0.00036
NO_x	10.99	$326.00	$0.00395
SO_x	0.039	$408.00	$0.00002
PM_{10}	0.26	$6,168.00	$0.00177
CO_2	90	$117.00	$0.01161
Total			**$0.01770**

4.6 NOISE POLLUTION

Noise pollution is unwanted or disturbing sound and can be harmful to human health due to its quality and characteristic. Because noise is invisible, its impact on the surrounding environment is often more difficult to recognize than is the case with chemical pollutants found in the air or water. However, the effects of noise on our lives are very real. One of the most important noise sources is heavy duty trucks which is a concern to residents. UFT can reduce the amount of noise in high density areas by reducing the number of heavy duty trucks. UFT vehicles run underground and are not only invisible to the populace above, but they are also silent. UFTs will reduce the number of long-haul trucks wherever they are the predominant mode of transportation.

Sound becomes unwanted when it either interferes with normal activities such as sleeping, conversation, or disrupts or diminishes one's quality of life. The persistent and escalating sources of sound can often be considered an annoyance. This "annoyance" can have major consequences, primarily to one's overall health (EPA, 2012a). Sound is measured logarithmically in decibels (dB), which is amplitude or magnitude of the pressure wave, and a range of 0–140 dB can be received by the human ear. Noise levels above 55 to 65 dB may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure, and hormonal changes. In addition, noise exposure increases as a co-factor the risk of cardiovascular diseases and decreases subjective sleep quality. The negative impacts of noise on human health results in various types of costs, such as medical costs, costs of productivity loss, and the costs of increased mortality. Noise level greater than 100 dB is extremely loud and will cause annoyance while 130 dB is threshold of physical pain (Becker and Gerlach, 2012).

4.6.1 Noise Pollution Parameters

Trucks and locomotives produce significant amount of noise, and it is harmful to human, animals, and other parts of the environment. There are several parameters that are related to the level of truck noise.

a) Truck Related:

- Engine type
- Weight on truck
- Number of axles
- Age of truck
- Truck maintenance condition
- Speed
- Shape of truck

b) Environment Related:

- Pavement condition
- Traffic volume
- Composition

- Distance
- Trees and hills
- Buildings and other obstacles
- Noise absorption of ground surface

4.6.2 Social Costs of Noise Pollution

To calculate the social cost of noise pollution, two costs of annoyance and health should be considered (Ricardo, 2014):

a) Cost of Annoyance:

Cost of annoyance is economically based on preferences of individuals. Transport noise imposes undesired social disturbance, which results in social and economic costs like reducing productivity, any restriction on enjoyment of desired leisure activities, discomfort or inconvenience.

b) Health Cost:

Transport noise can cause physical health damages. Hearing damage can be caused by noise levels above 85 dB while lower levels (above 60 dB) may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure and hormonal changes. In addition, noise exposure increases the risk of cardiovascular diseases. Finally, transport noise can result in a decrease of subjective sleep quality.

FHWA STAMINA and MINNOISE (Minnesota STAMINA noise prediction computer model) are the two most useful computer-base model applications to calculate the social cost of noise; each utilizes a different set of assumptions. Table 4-7 shows social cost of noise pollution by trucks in three different literature reviews (Forkenbrock, 1999). Forkenbrock calculated social cost of produced noise pollution by heavy-duty truck to be $0.00028 per ton-mile.

Table 4-7 Social Costs of Noise Pollution

Study by	Year	Cost ($/VMT)	Cost in 2016 dollars	Description
Nelson et al.	1978	$0.0024	$0.009	Densely settled rural area/55mph
Haling and Cohen	1996	$0.05-0.07	$0.07-0.105	Combination truck depends on weight/ Based on percentage loss of housing value
Forkenbrock	1999	$0.006	$0.008	90% in sparsely settled rural areas and 10% in densely settled rural areas

4.7 WATER POLLUTION

The normal operation of transportation vehicles does not generate water pollution in the way that it generates air pollution. In fact, oil, fuel, coolant, and other chemicals leak or are discarded from motor vehicles, and eventually pollute rivers, lakes, wetlands, and oceans. Additionally, some motor fuel leaks from underground storage tanks, contaminates groundwater which causes health problems and property damage. A substantial fraction of the nitrogen emitted from motor vehicles deposits out of the atmosphere onto soil, plants, structures, and water bodies. Also, water can be polluted by heavy metals, organic pollutants, and de-icing salt (EPA, 2012b).

4.7.1 Acid Rain: Interface of Water Pollution and Air Pollution

Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are the principal pollutants that cause acid precipitation. SO_2 and NO_x emissions released to the air react with water vapor and other chemicals to form acids that fall back to Earth as rain, snow, or fog. The air pollutants that cause acid rain can damage our health as well as damage the environment and property. Acid rain is particularly damaging to lakes, streams, and forests and the plants and animals that live in these ecosystems. Acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage (EPA, 2012b).

4.7.2 Social Cost of Water Pollution

In general, there has been much less research on the dollar value of the impacts of water pollution than on the dollar value of the impacts of air pollution. In any event, quantifying the social cost of water pollution is a relatively low priority, because it appears to be small compared to the other external social costs of transport. Based on "The Annualized Social Cost of Motor-Vehicle Use in the U.S." by Delucchi (2000 and 2004), the social cost of water pollution is 0.003 cent/ton-mile to 0.005 cent/ton-mile (2006 dollars). On average, social cost of water pollution is 0.0047 cent/ton-mile with 2016 dollars.

4.8 TRAFFIC CONGESTION

The objective of this section is to estimate the cost of delay and wasted fuel associated with truck congestion. Traffic congestion costs consist of incremental delay, vehicle operating costs (fuel and wear), pollution emissions and stress that result from interference among vehicles in the traffic stream (Muller and Laird, 2007). Congestion results when traffic demand approaches or exceeds the available capacity of the system. Traffic congestion impacts on drivers, passengers and economy as a result of the freight delay caused by congestion. According to the list of "100 Most Congested Roadways" (TxDOT, 2014), most of the traffic congestion between the Port of Houston and DFW occurs in the center of Houston and DFW metropolitan area.

4.8.1 Estimate of Traffic Congestion Costs

Traffic congestion is defined as a condition of traffic delay (i.e., when traffic flow is slowed below reasonable speeds) because the number of vehicles trying to use a road exceeds the design capacity of the traffic network to handle it. Total delay is the sum of time lost due to congestion. Total delay in an urban corridor is calculated as the sum of individual segment delays (Eisele et al. 2013).

The following general steps are used to calculate the congestion performance measures for each urban roadway section:

Step 1: Identify traffic (truck) volume data (trucks per hour) by road section.

The most widespread and consistent traffic counts available are annual average daily traffic (AADT) counts. Annual average daily traffic (AADT) is the total volume of traffic on a highway segment for one year, divided by the number of days in the year. (Florida Department of Transportation, 2007). Truck volume for two peak times in AM and PM are calculated based on the K-factor, which is a factor used for design and analysis of traffic flow on highways unless otherwise stated, it is the proportion of annual average daily traffic (AADT) occurring in the 30th highest hour of the year (Table 4-8). K-factors can only be calculated at continuous count stations that have a full year of data (Florida Department of Transportation, 2007).

Step 2: Calculate average prevailing speed (mph) and free-flow speed (mph).

Average prevailing speed is calculated by using speed data from 12:00 AM to 12:00 PM (morning periods) and 12:00 PM to 12:00 AM (evening periods). Free-flow speed or speed limit during light traffic hours (e.g., 10:00 PM to 5:00 AM) is used as the baseline for congestion calculations (Houston and Transtar, 2015).

Step 3: Calculate free flow travel time (hour) and prevailing travel time (hour).

Free flow travel time and prevailing travel time are calculated by using Eqs. 4-1 and 4-2. (Fricker and Whitford, 2004).

$$Free\ flow\ travel\ time = Section\ Length\ (miles)/Free - flow\ speed\ (mph) \quad \text{(Eq. 4-1)}$$

$$Prevailing\ travel\ time = Section\ Length\ (miles)/Prevailing\ speed\ (mph) \quad \text{(Eq. 4-2)}$$

Table 4-8 Truck Volume Calculation

Information Required	Formula
Number of trucks in peak hours	10% of AADT (K factor in urban area) that occurs in peak hours
Number of trucks in remaining 22 hours	0.8 AADT / 22
$ADT_{n\text{-years}}$	ADT_p (1+ Annual population growth rate (i))^n

Step 4: Calculate delay per truck (by hr.) and truck hours of delay for each time interval.

Delay per vehicle (truck) is the difference between prevailing travel time and free flow travel time (Fricker and Whitford, 2004).

$$Delay\ per\ vehicle = Prevailing\ travel\ time - Free\ flow\ travel\ time \quad \text{(Eq. 4-3)}$$

$$Truck\ hours\ of\ delay = Truck\ volume\ (per\ hour) \times Delay\ per\ vehicle\ (by\ hour) \quad \text{(Eq. 4-4)}$$

Step 5: Calculate future truck volume (trucks per hour) and future speed (mph).

Future truck volume is dependent on annual population growth rate. The annual growth rate for Houston is around 3% to 4% (Houston-Galveston Area Council, 2014). Future truck volume and future speed are calculated based on the following Eqs. 4-5 and 4-6 (Fricker and Whitford, 2004).

$$Fn - years = Present\ truck\ volume\ (P) \times (1 + Annual\ population\ growth\ rate)^n \quad \text{(Eq. 4-5)}$$

$$Future\ speed = Current\ speed\ (mph) / (1 + Annual\ population\ growth\ rate)^n \quad \text{(Eq. 4-6)}$$

Step 6: Calculate congestion cost.

Two cost components are associated with congestion: delay cost and fuel cost. These values are directly related to the travel speed calculations. Eqs. 4-7 and 4-8 show how to calculate the cost of delay and fuel effects of congestion (Lomax, 2011).

a) Passenger vehicle delay cost:

The delay cost is an estimate of the value of lost time in passenger vehicles in congestion. Eq. 4-7 shows how to calculate the passenger vehicle delay costs that result from lost time (Lomax, 2011):

$$Passenger\ vehicle\ delay\ cost = Daily\ passenger\ vehicle\ hours\ of\ delay \times Value\ of\ person\ time\ (\$/hour) \times Vehicle\ occupancy\ (per\ vehicle) \quad \text{(Eq. 4-7)}$$

b) Truck delay cost:

The delay cost is an estimate of the value of lost time in a truck due to increasing the number of trucks on a highway that leads to truck delivery delay and the increased operating costs of truck in congestion. Eq. 4-8 shows how to calculate the truck delay costs that result from lost time.

$$Truck\ delay\ cost = Daily\ truck\ hours\ of\ delay \times Value\ of\ truck\ time\ (\$/hour) \quad \text{(Eq. 4-8)}$$

c) Cost of fuel for delay/vehicle:

Fuel cost due to congestion is calculated for vehicles in Eq. 4-9. This is done by associating the wasted fuel, average time waiting, and the fuel costs (Najafi, 2005).

$$Cost\ of\ fuel\ for\ delay/vehicle = (average\ gal/unit\ time) \times (average\ time\ waiting) \times (average\ cost\ of\ fuel/gal) \quad \text{(Eq. 4-9)}$$

d) Total Congestion Cost:

Eq. 4-10 combines the cost due to travel delay and wasted fuel to determine the total cost due to congestion resulting from incident and recurring delay.

$$Total\ congestion\ cost = Passenger\ vehicle\ delay\ cost + Passenger\ vehicle\ fuel\ cost + Truck\ delay\ cost + Truck\ fuel\ cost \quad \text{(Eq. 4-10)}$$

4.8.2 Traffic Congestion Cost from the Port of Houston to Dallas at Lancaster Based on TxDOT Data

By using the list of "100 Most Congested Roadways" (TxDOT, 2014) the average cost of traffic congestion for each truck in the PHA area is roughly \$7,944.10 per year (See Appendix C, Table C-2)

$$Total\ annual\ social\ benefit\ of\ UFT\ with\ 3{,}000\ containers\ per\ day = 7{,}944.10 \times 3{,}000 \cong \$24{,}000{,}000$$

$$Annual\ benefit\left(\frac{\$}{ton - mile}\right) = \frac{\$24{,}000{,}000}{3000\ (No.of\ containers) \times 365\ days \times 250\ miles} \cong \$0.0022/ton - mile$$

4.9 ROAD MAINTENANCE COST REDUCTION

Freight traffic and loads that transfer to the roads are major factors considered in pavement design. Heavy vehicles, such as trucks, cause the most damage to pavements (Regin et al. 2005). The pavement deterioration over time is caused by a combination of several factors such as traffic, environment, material and design considerations. Traffic loads by heavy duty trucks play a key role in reducing pavement and bridge life. Truck loads are transferred to the pavements through various combinations of axle loads and configurations dependent on truck type (Chatti, 2006). Although light passenger vehicles are the dominant users of highways, they are generally not considered in pavement design because of the relatively low amount of damage imparted by these vehicles compared with trucks. Overall, the pavement damage caused by heavy-duty trucks could be equivalent to thousands of lightweight passenger vehicles (Dey, 2014). Therefore, freight traffic is the primary traffic input considered in pavement design. The heavier truck loads develop excessive stress and strain on pavement structural layers and result in several forms of distress and ultimate pavement fatigue failure. Although, pavement damage increases exponentially with increasing load magnitude and the number of axles, repetition of loads is the major factor for bridge deterioration.

As stated in Section 4.6, the volume of freight transportation by trucks will double in the near future. The UFT system as a low maintenance freight transportation system can transport the extra demand and reduce the cost of road maintenance.

4.9.1 Texas Bridge and Pavement Conditions

Texas has 192,150 lane-miles of state roadway including interstate highways (IH), U.S. highways (U.S.), state highways (SH), and farm-to-market (FM) roads, as well as other state highway system types such as loops, spurs, business routes and state park roads. These paved lane-miles represent more paved roads than any other state and it is TxDOT's responsibility to maintain them. Also, Texas has the largest system of state highway bridges in the United States with more than 50,000 bridges (2030 Committee, 2008). Figure 4-8 shows Texas roadway conditions according to the FHWA (TRIP, 2013). As stated by TRIP (2013), approximately 18 percent of Texas bridges are rated as structurally deficient or functionally obsolete.

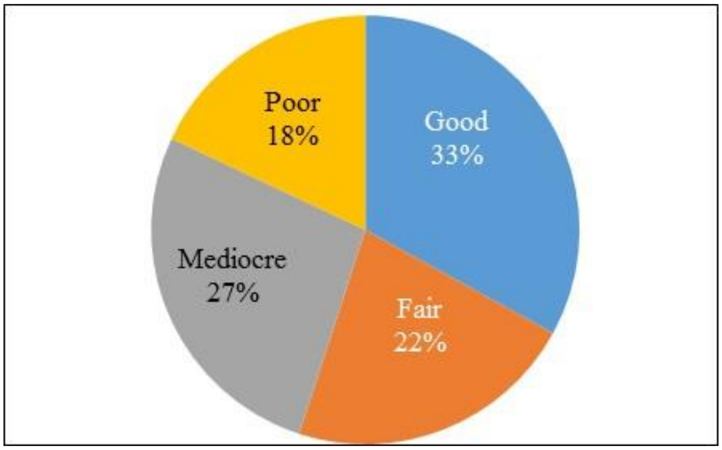


Figure 4-8 Texas Roadway's Conditions

4.9.2 Cost of Pavement and Bridge Maintenance

A report issued by the 2030 Committee (2030 Committee, 2008) calculated that an annual statewide investment of $9.9 billion was needed just to maintain road and bridge conditions and congestion at the 2010 levels in Texas. However, after fiscal year 2014, annual state highway investment is anticipated to average just $2.4 billion annually. Under current budget funding, overall pavement quality will decrease by 43% by 2022. Failing to address pavement deterioration in a timely manner will increase repair costs over time. In Texas, underfunding maintenance on the state's roads will increase the cost to preserve and restore the pavement by $6.5 billion over the next 10 years based on the projected minimum funding amount (2030 Committee, 2008). Additionally, based on a Proposition 1 funding report by TxDOT (2015), the annual statewide cost of pavement and bridge maintenance is approximately $145,000,000.

According to "The Highway Construction Equity Gap" report by TxDOT in 2008, the maintenance cost of roads in Texas was $4,400 per lane-mile in 2004, which with a 6% annual growth rate and inflation rate would be approximately $10,536 per lane-mile in 2015. This maintenance ranges from repairs to address localized problems such as potholes to larger repairs such as strip seals or hot mix treatments that preserve and prepare a pavement for a planned seal coat or heavier treatment (2030 Committee, 2008). Since heavy trucks cause a high portion of damage to pavement and bridges, by reducing the number of trucks and using UFT instead, TxDOT and other government agencies could save approximately $5,628,000 per year (see Appendix C). Additionally, the federal highway administration (FHA) estimates for each dollar spent on road, highway and bridge improvements, an average benefit of $5.20 results in the form of reduced vehicle maintenance costs, reduced delays, reduced fuel consumption, improved safety, reduced road and bridge maintenance costs, and reduced emissions as a result of improved traffic flow (TIRP, 2013).

4.10 ACCIDENT COST REDUCTION

Texas residents and businesses require a high level of personal and commercial mobility. Population increases and economic growth in the state have resulted in an increase in the demand for mobility as well as an increase in vehicle miles traveled (VMT). To foster a high quality of life and boost economic growth in Texas, it will be critical that Texas provides a safe and modern freight transportation system, such as the UFT system. Based on Figure 4-9, from 2003 to 2014[16], the annual vehicle miles traveled (VMT) in Texas increased by 14 percent, from 218 billion miles to 248.8 billion miles (see Appendix C, Table C-4).

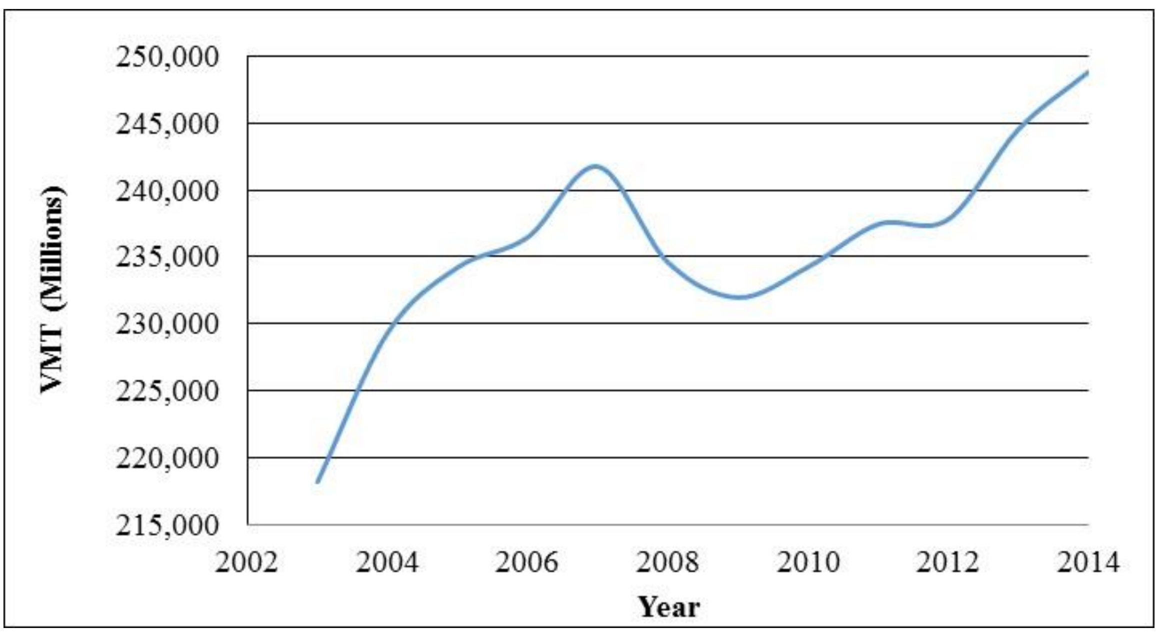


Figure 4-9 Increasing Vehicle Miles Traveled in Texas from 2003 to 2014

[16] http://ftp.dot.state.tx.us/pub/txdot/trf/crash-statistics/2014/a.pdf (Accessed on September 10, 2015)

Also, from 2003 to 2014, the cost of accidents in Texas increased by 40 percent, from $20.7 billion to $28.8 billion. Heavy trucks and semi-trailer trucks are involved in approximately 11% of all fatal accidents in Texas (see Figure 4-10).

According to TxDOT data,[17] and by assuming the an averaged cost of accidents per VMT for trucks and other vehicles, the average cost of accidents is estimated to be $0.0029 per ton-mile for heavy trucks. By taking advantage of the UFT system to increase capacity of freight transportation without increasing truck traffic, the general public can save up to $31,755,000 per year by reducing the number of trucks transporting freight on the highways (see analyses in Appendix C, Eq. C-1).

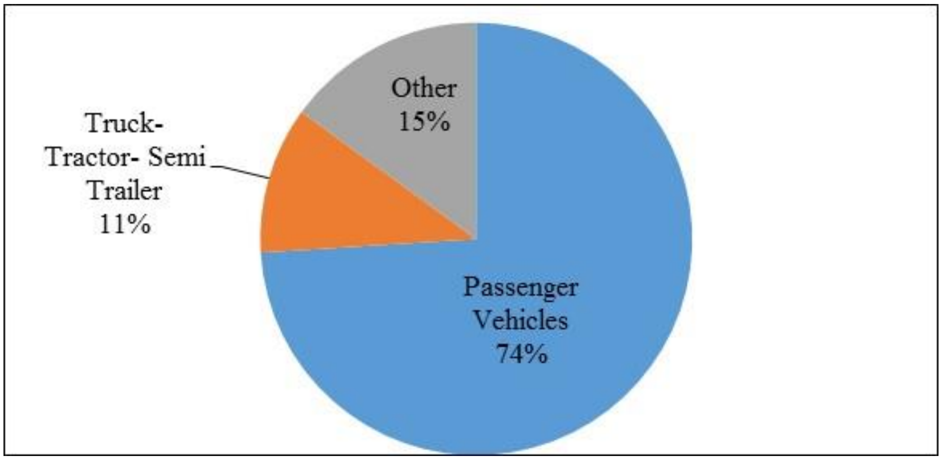


Figure 4-10 Percent of Vehicles in Fatal Crashes by Type in 2014

4.11 ELECTRICITY TAX REVENUE

According to Chapter 1, each UFT vehicle which carries one 40-ton container, at a constant speed of 45 mph is estimated to consume 30 kWh electricity[18]. Since electricity costs $0.0533 per kWh for transportation[19] and taxes on electricity is 8.25%, by using UFT to transport freight, the electricity tax revenue will increase up to $800,000 per year, which is $0.00007 per ton-mile (see analyses in Appendix C, Eqs. C-2, C-3, and C-4). This cost is just for the propulsion system. Electricity tax revenue of ancillary equipment such as overhead cranes, terminal facilities, offices, and so on is not considered.

4.12 ENERGY EFFICIENCY

The highly efficient propulsion UFT system reduces the energy requirement associated with freight transportation. Each vehicle requires 30 kWh electricity to transport containers for 45 miles per hour (see Chapter 1). Furthermore, each truck approximately consumes eight miles per

[17] http://www.txdot.gov/government/enforcement/annual-summary.html (Accessed on September 15, 2015).
[18] According to estimate by Jalal Feghhi (LIM Consultant).
[19] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a (Accessed on September 15, 2015).

gallon of fuel (Franzese and Davidson, 2011). As shown in Figure 4-11, the UFT system consumes 7.5 times less energy than the trucking system (see analyses in Appendix C, Eqs. C-5 and C-6).

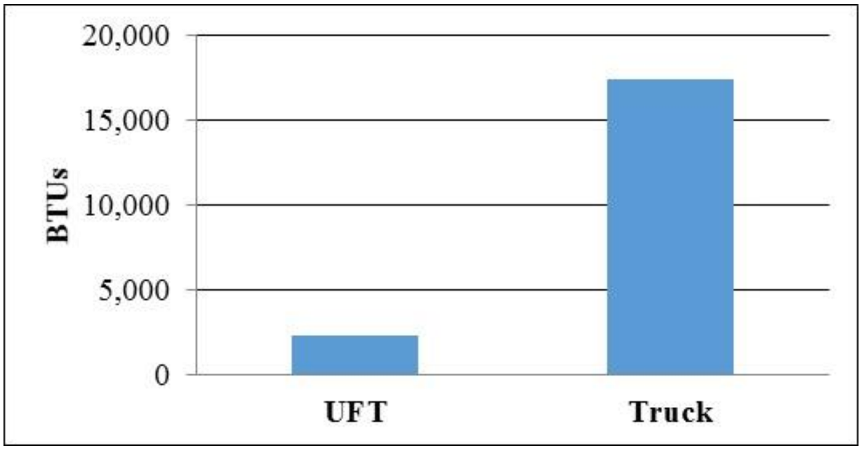


Figure 4-11 Comparison of Truck and UFT Energy Efficiency

As shown in Figure 4-11, the energy consumption saving of the UFT, as compared to trucks, translates to a lower emission mode of transportation, which will automatically cut down on the toxic truck emissions such as nitrogen oxides (NO_x) and carbon monoxide (CO) by virtue of there being less trucks on the road once the UFT system becomes effective. The only emissions that UFT uses are indirect due to fossil fuels burned by power plants to produce electricity. By developing renewable energy plants in the state of Texas, these emissions will also decrease as traditional electricity production becomes less dependent on coal.

4.13 SAFETY AND SECURITY

Stolen trucks and freight is a common concern in the trucking industry. Other observed threats include the transport of illegal freight and the use of illicit means (e.g., vandalism) to support terrorist groups (Friedman and Mitchell, 2003). After the 9/11 event, there are more concerns for freight transportation security. The use of trucks to commit terrorism continues to be a threat because of the large number of trucks carrying freight (Donath and Murray, 2005). The FBI estimates $12 billion to $20 billion is lost annually in truck freight thefts, which is a fraction of a percent of the Bureau of Census estimation of approximately $4.9 trillion in annual U.S. truck freight loss due to theft. Even if the commercial trucking industry were perfectly secure and unreachable to terrorists, the means and the opportunity for performing a terrorist act involving trucks would not be eradicated and perhaps not even reduced (Friedman and Mitchell, 2003). Therefore, the need for more secure systems for shipping containers will be substantial in the future. It is expected that the UFT system will be a suitable option for increasing safety and security on Texas highways in the future.

4.14 IMPACT ON TRUCKING AND RAILROAD INDUSTRY

4.14.1 Trucking Industry

Texas freight transportation predicted major growth in the trucking industry by 2020. As mentioned earlier, there will be major surge in tonnage transportation in the Port of Houston. Table 4-9 shows estimates of container volumes at 5-year intervals to 2020. The Port of Houston Authority (PHA) officials have stated that with the first phase of Bayport handling freight, they expect the number of twenty-foot-equivalent units (TEUs) handled to grow at an average of 11 percent in the near-term (Harrison et. al., 2007). Based on the data reported by the port, Figure 4-12, illustrates that the 5-million-TEU mark may be reached at 2016. Furthermore, using this rate, future forecast indicates that the PHA will handle more than 7,000,000 TEUs by 2020 (Harrison et. al., 2007).

Table 4-9 Forecast Estimates of Container Volumes (Harrison et al., 2007)

Year	Forecast TEUs
2005	1,491,839
2010	2,142,663
2015	3,110,434
2020	4,536,482

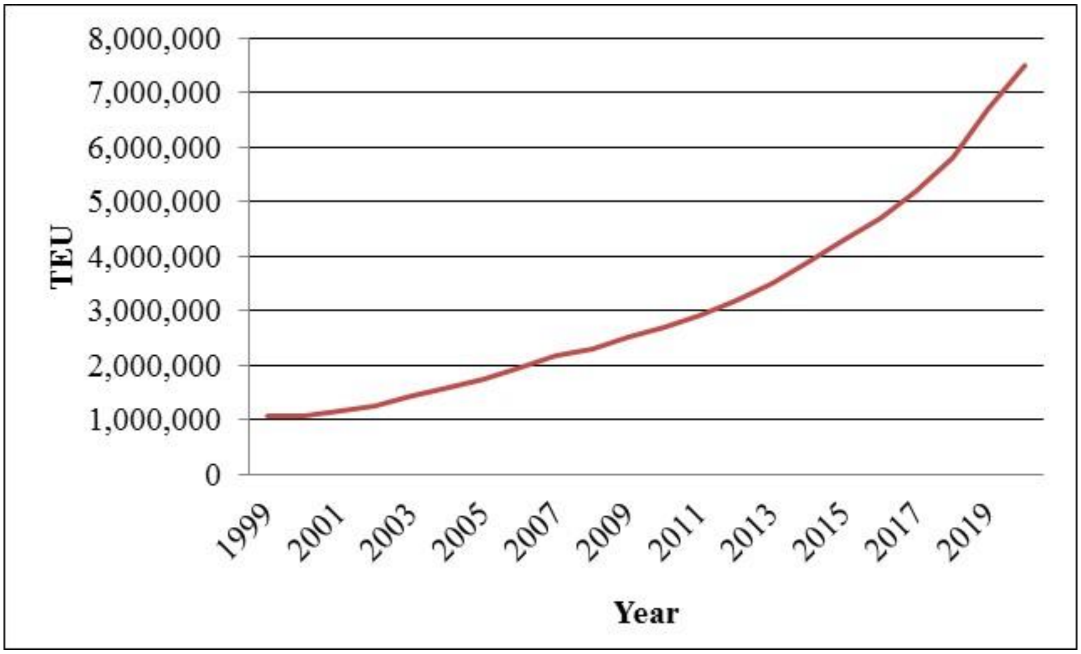


Figure 4-12 Port of Houston's Own Near-Term Estimate of Annual Growth through 2020

4.14.2 Railroad Industry

The Houston rail corridors serving the port are inadequate for Port Terminal Railroad Association (PTRA) traffic and will create bottlenecks in the future when moving more containers out by rail from the Port of Houston terminals (Harrison et al., 2007). Furthermore, railroads will play a major role in the transportation of NAFTA goods through Texas as freight transportation through rail between U.S. and Mexico has grown by 164 percent from 1994 to 2004. As previously mentioned, rail tonnage will increase by 2030. Also, the 2030 estimated number of rail units will grow by 195 percent (TxDOT, 2007). Figure 4-13 shows major Texas NAFTA gateways from 2003 to 2030. Due to the increased rate of container volumes in Texas, it is expected that the UFT system will not have any negative impacts on current truck and railroad freight traffic in Texas. In fact, UFT as an intermodal system will add capacity to freight transportation in the future instead of adding more trucks and rails. In addition, The Port of Galveston is an important and diverse freight handling port in Texas, having handled more than 80,000 TEUs in 2009 (North American Port Container Traffic, 2009). It has been forecast that container volume will double by 2020 (Wickerman, 2005). Therefore, the UFT system is expected to help alleviate the impacts of this dramatic growth in the future, especially on IH-45.

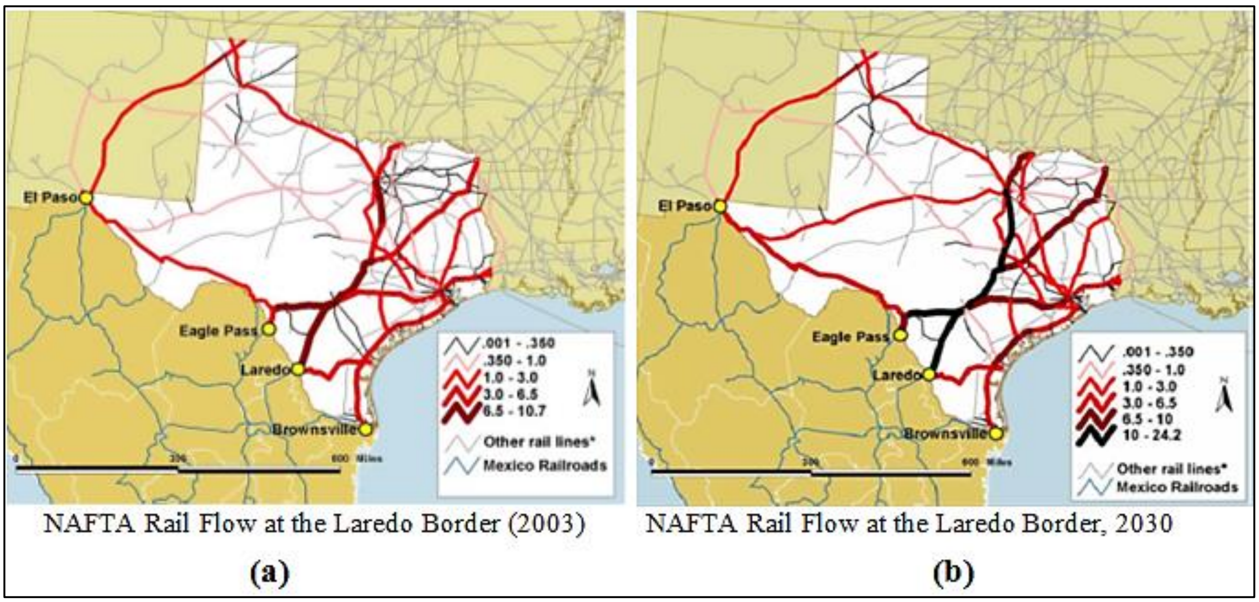


Figure 4-13 Texas NAFTA Gateway Rail Flows (a) 2003 and (b) 2030 (TxDOT, 2007)

4.15 TAX REVENUE LOSS

4.15.1 Fuel Tax Revenue Loss

Every driver that purchases fuel pays an excise tax of 18.3 cents per gallon on gasoline or 24.3 cents per gallon on diesel. Proceeds from these taxes go into the federal Highway Trust Fund (HTF), which is the primary financing mechanism for the nation’s surface transportation system. This fund provides support for a variety of highway and transit programs, including formula based state grants and specific projects and programs as directed by Congress (FHWA, 2014). Tax revenue loss will eventually include tax imposed on fuel, tires, trucks, and trailers, which will be lost by using the UFT system, due to reducing the volume of trucks on highways.

Fuel consumption depends on speed, consumption rate, truck age, condition, maintenance condition, pay-load and road conditions. Moreover, several critical performance parameters are significantly impacted by driver behavior, including speed, idle time, and frequent stops and starts, all of which have the potential to impact fuel economy. Drivers who maintain lower speeds and fewer starts and stops are likely have better fuel economy. Similarly, fuel economy calculated from fuel transactions would be expected to appear higher among drivers who minimize idle time. Additional operational variables include differences in routes and terrain, which may also introduce differences in fuel economy based upon factors such as roadway conditions, speed limits, and changing elevations (Ahanotu, 1999).

As shown in Table 4-10, for calculating the fuel tax, a weight between 70,000 and 80,000 lbs. and average speed of 50 to 60 mph are considered for heavy-duty trucks (Transportation Department of North Central Texas Council of Governments, 2009). Given the average miles per gallon for heavy-duty trucks is approximately 8 miles per gallon (Franzese and Davidson, 2011), Texas should receive 0.138 cents for every mile traveled by trucks.

Table 4-10 Summary of Fuel Tax Results

Required Information	Results
Average mile per gallon for heavy-duty trucks (70,000 lbs. - 80,000 lbs.)	8 mile/gallon
The fuel required for hauling 40 tons (80,000 lbs.) per mile	1/8 gallon or 1/2 quart
The fuel required for hauling one ton per mile	1/320 gallon or 1/80 quarts
Diesel fuel tax in Texas (Retirement Living, 2015)	44.4 cents/gallon (includes all taxes)
Fuel Tax Loss per ton-mile	**0.138 cents**

4.15.2 Tire Tax Revenue Loss

Tire tax revenues are based on tire state and local taxes and the weight of the tire (see Table 4-11 and 4-12). The number of tires consumed is calculated by dividing vehicle miles traveled (VMT) by tire life (FHWA, 2014), for each vehicle class/operating weight cell, multiplied by the number of tires on the vehicle (see Table 4-11). Tires which weigh less than 40 lbs. are not subject to this tax (Federal Highway Administration, 2014).

Table 4-11 Current Federal Tax Rate

Current Tax		Tax Rate
Texas state sales and use tax		6.25%
Local tax		2%
Total maximum		8.25% (Texas comptroller of public accounts, 2014)
Tire tax can be imposed either as a percentage of sales prices or a flat fee, in addition to a general sales tax	Over 40 to 70 lbs.	15 cents/lb. in excess of 40 lbs.
	Over 70 to 90 lbs.	$4.50 plus 30 cents per pound over 70 lbs.
	Over 90 lbs.	$10.50 plus 50 cents per pound over 90 lbs.

Table 4-12 Summary of Required Information

Required Information	Results
Average tire weight	100 lbs. (Tire data guide, 2015)
Average miles of travel	100,000 miles (FHWA No.PL-11-03, 2011)
Average tire life (retread tire)	100,000 miles (Weissmann et al. 2003)
Number of tires	18
Number of tires purchased	18
Tire tax	$10.5 + $5 = $15.5

According to Tables 4-11 and 4-12, tire tax lost revenue per ton-mile for a heavy-duty truck is:

$$\$320\ (Average\ cost\ of\ each\ tire) + \$0.0825\ (Tax) \times \$320) + \$15.5 \sim \$362$$
$$\$362/100{,}000\ (mile)/40\ (ton) = \$0.00009 \text{ per ton} - \text{mile}$$

4.16 ENVIRONMENTAL IMPACT STATEMENT

An Environmental Impact Statement (EIS) describes the impacts on the environment as a result of a proposed action. The National Environmental Policy Act (NEPA) requires federal agencies to prepare environmental impact statements (EIS) for major federal actions that significantly affect the quality of the human and environment. It is required for all projects and should be ready before starting the project. Furthermore, EIS is a decision making tool and linked to project planning and is used by the design team to make sure consequences of the project during the construction and operation are acceptable by NEPA. EIS process is completed in four steps which are as follows (FHWA, 2015):

a) Notice of Intent (NOI)

The NOI is published in the Federal Register by the lead federal agency and signals the initiation of the process, scoping, an open process involving the public and other federal, state and local, agencies. Scoping commences immediately to identify the major and important issues for consideration during the study. Public involvement and agency coordination continues throughout the entire process.

b) Draft EIS

The draft EIS provides a detailed description of the proposal, the purpose and need, reasonable alternatives, and the affected environment; it also presents an analysis of the anticipated beneficial and adverse environmental effects of the alternatives.

c) Final EIS

The final EIS is developed based on formal comment period and receipt of comments from the public and other agencies.

d) Record of Decision (ROD)

The ROD is the final step in the EIS process and identifies the selected alternative, presents the basis for the decision, identifies all the alternatives considered, specifies the "environmentally preferable alternative," and provides information on the adopted means to avoid, minimize and compensate for environmental impacts.

4.16.1 Importance of UFT System

4.16.1.1 Panama Canal Expansion Project

- Route 1- Port of Houston to City of Lancaster (near Dallas)
- Route 3-Port of Houston to an Inland Satellite Distribution Center in Baytown

4.16.1.2 Port of Houston to City of Lancaster (near Dallas)

The Port of Houston is one of the largest ports in terms of TEUs (twenty-foot equivalent units[20]) in 2014. It is also the largest Gulf Coast container port in Texas. This port ranked sixth among U.S. container ports by total TEUs in 2014 and first among U.S. ports in foreign tonnage. It also ranked second among U.S. ports in terms of total foreign freight value.[21] Port of Houston's container operation has grown exponentially over the past 35 years. This has been due to increasing

[20] TEU stands for 20 ft equivalent unit, which can be used to measure a ship's freight carrying capacity. The dimensions of one TEU are equal to that of a standard 20 ft shipping container. 20 ft long × 8 ft tall. Usually 9–11 pallets are able to fit in one TEU. Two TEUs are equal to one FEU (40 ft equivalent unit). http://dedola.com/2011/10/what-is-a-teu/ (Accessed on December 5, 2015).

[21] http://www.portofhouston.com/business-development/trade-development-and-marketing/trade-statistics/ (Accessed on October 5, 2015).

containerization, population growth in Texas and increasing international trade (Harrison et.al, 2007).

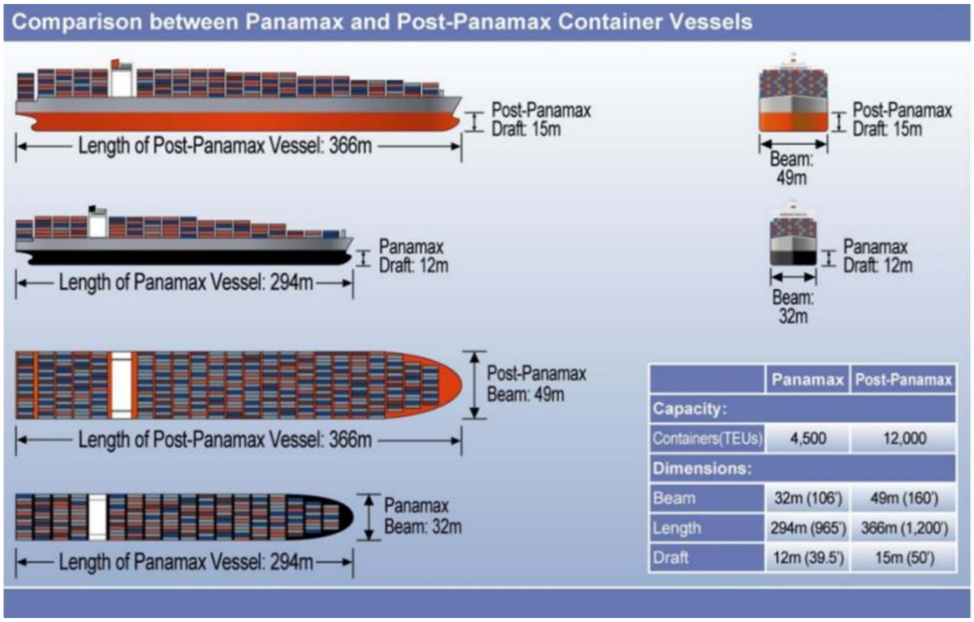


Figure 4-14 Panamax vs. Post-Panamax Container Vessels (American Association of Port Authorities, 2013)

4.16.1.3 Impact of Panama Canal Expansion on Ports

The expansion of the Panama Canal will allow transit by ships of up to 12,600 TEUs compared to the current approximate maximum of around 4,500 TEUs (TranSystems, 2009) as shown in Figure 4-14. The larger size container vessels have many impacts on port operation. Because of lack of land adjacent to the Port of Houston,[22] larger ships must spend more time in the port; hence, demands include more efficient container hauling to avoid delays. Additionally, there will be more traffic congestion in the port due to higher flow of containers between the berth and the yard.[23] For calculating traffic congestion, in this report, specific routes are selected from the Port of Houston to City of Lancaster (near Dallas). It is assumed that traffic congestion from the Port of Houston to City of Lancaster affects these selected routes. Annual truck congestion cost for each route is provided by TxDOT's *100 Congested Roadways* (TxDOT, 2014).[24] After analyzing data, total truck annual congestion cost from the Port of Houston to City of Lancaster is approximately $103,000,000 as shown in Table C-2, and annual benefit of UFT due to decreased congestion is estimated to be up to $24,000,000 as shown in Appendix C).

[22] http://www.marad.dot.gov/wp-content/uploads/pdf/Panama_Canal_Phase_I_Report_-_20Nov2013.pdf (Page 51), (Accessed on November 7, 2015)
[23] http://www.worldshipping.org/industry-issues/transportation-infrastructure/Observations_on_Port_Congestion_Vessel_Size_and_VSA_May_28_2015.pdf (Accessed on December 13, 2015)
[24] http://www.txdot.gov/inside-txdot/projects/100-congested-roadways.html (Accessed on November 5, 2015)

4.16.1.4 NAFTA (The North American Free Trade Agreement) Growth

- Route 2-Border between the U.S. and Mexico in Laredo, TX

According to TxDOT (2007), NAFTA truck tonnage on Texas highways will increase by 207% from 2003 through 2030. Truck tonnage will grow by 251% while rail tonnage is estimated to increase 118%. This data is assumed to change linearly, so truck tonnage will increase by 150% from 2015 through 2030 and rail tonnage will grow 109% (Figure 4-15). The number of trucks carrying NAFTA goods will increase by 158%. NAFTA truck VMT (vehicle miles traveled) will grow by more than 200% from 2015 through 2030 (TxDOT, 2007). Moreover, it is estimated that Texas handles approximately 80% of all NAFTA trade from Mexico. The truck VMT due to NAFTA is projected to more than quadruple by 2030 (TxDOT, 2007). Figure 4-16 shows the future growth of NAFTA truck traffic from 2003 to 2030 over the existing Texas highway corridors (TxDOT, 2007). The NAFTA total truck traffic at the Laredo Border, for example, will go from 2,500 per day in 2003, to more than 15,000 trucks per day by 2030. Figure 4-17 also shows traffic congestion at the Laredo border on the Mexican side. Based on TxDOT's *100 Congested Roadways* (TxDOT, 2014), annual truck congestion cost at the Laredo border is approximately $3,000,000 as shown in Table B-3. The results show that due to the increased rate of tonnage transportation in Texas, there will be great demand for UFT in the future due to its non-obstructive ability to increase capacity of freight transportation. It also will improve traffic congestion especially at the Port of Houston and the Laredo border.

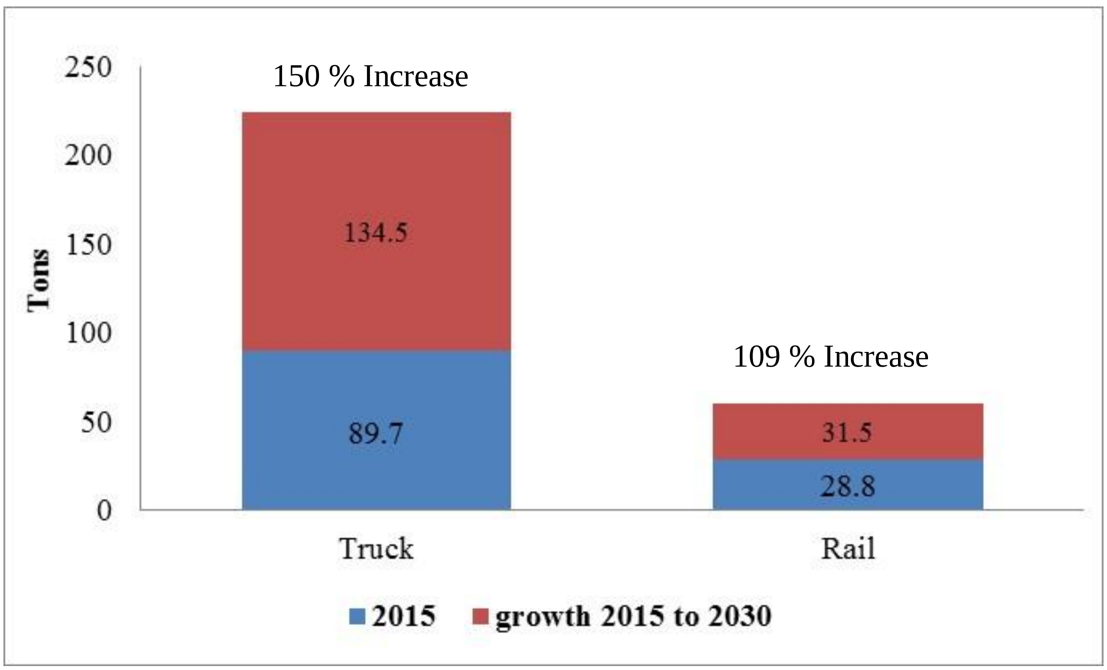


Figure 4-15 NAFTA Growth on Texas Highway and Rail Systems

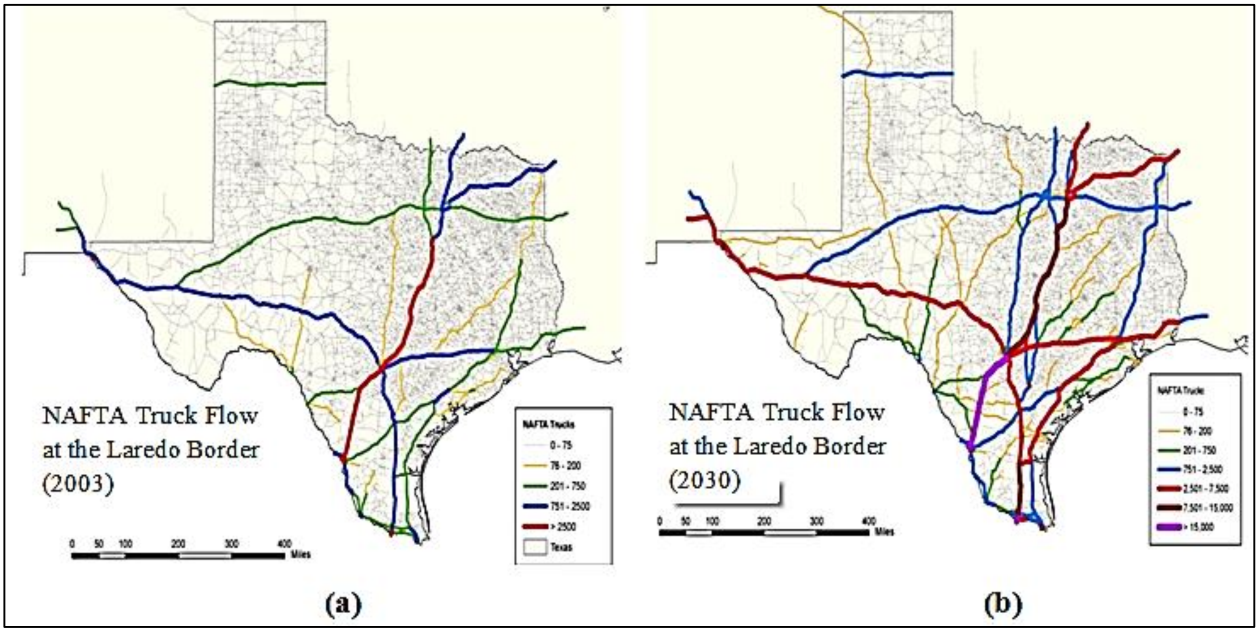


Figure 4-16 NAFTA Truck Traffic Flow on Texas Highways (a) 2003 and (b) 2030 (TxDOT, 2007)

Figure 4-17 Traffic Congestion behind Laredo Border on the Mexico Side (Source: Google Map)

4.16.2 Comparison of Different Alternatives

The Environmental Impact Statement (EIS) describes and summarizes the potential impact of transportation from both an environmental and social point of view. Additionally, it includes funded resources, costs of goods transportation and cost of supporting facilities. The EIS for this project compares the following options:

1. No Build Alternative
2. Build Alternative
3. Proposed Alternative (UFT)

No Build Alternative is do-nothing or No Action, except for minor improvement of existing transportation facilities and services. *Build Alternative* includes widening roads for each direction. *Proposed Alternative* is building the UFT.

Chapter 5 presents some of the EIS requirements such as financing means and life cycle costs of building a UFT. Except for social costs, Appendix C, Table C-1 summarizes the environmental impacts of the No Build Alternative, Build Alternative, and Proposed Alternative along with potential mitigation measures that have been identified for all the routes and all sizes. All the comparisons at this table are for a 250 mile-route between Port of Houston and the Distribution Center in Lancaster, south of Dallas, along highway IH-45, I-610, and SH-225—all of which is based on the assumption that by the year 2030, there will be 15,000 trucks per day and UFT will be operated 24/7 to transport 5,760 containers per day.

4.17 CHAPTER SUMMARY

Social costs of air, water, and noise pollution, and traffic congestion, which are caused by heavy trucks, would be reduced by the use of UFTs; therefore, its use would be considered a social benefit during UFT operation by reducing number of trucks on the road. Government agencies will lose some revenue, which will be the social costs of UFTs. As a part of environmental impact analysis (EIS) of UFT, net impact of pallet and crate size of UFT for a 15-mile Route 3 from the Port of Houston to an inland satellite distribution center in Baytown are estimated at approximately $5,891,694 and $9,784,420, respectively. Tables 4-13 through 4-17 show the summary of UFT's social and environmental impacts in dollar value for shipping container size of UFT. These benefits will be used to calculate the cost/benefit ratio of the UFT in Chapter 5.

Table 4-13 Summary of EIA for Route 1 from the Port of Houston to City of Lancaster (near Dallas)

Items	Benefit ($/ton-mile)	Cost ($/ton-mile)	Annual Benefit ($)
Air Pollution	0.0177		$372,124,800.00
Noise Pollution	0.00028		$5,886,720.00
Water Pollution	0.000047		$988,128.00
Traffic Congestion	0.0022		$46,252,800.00
Infrastructure Damage Cost Reduction	0.000514		$10,806,336.00
Accident Cost Reduction	0.0029		$60,969,600.00
Electricity Tax Revenue	0.00007		$1,471,680.00
Fuel Tax Loss Revenue		-0.00138	$(29,013,120.00)
Tire Tax Loss Revenue		-0.00009	$(1,892,160.00)
Total	**0.023711**	**-0.00147**	**$467,594,784**

Table 4-14 Summary of EIA for Route 3 From the Port of Houston to an Inland Satellite Distribution Center in Baytown

Items	Benefit ($/ton-mile)	Cost ($/ton-mile)	Annual Benefit ($)
Air Pollution	0.0177		$22,327,488.00
Noise Pollution	0.00028		$353,203.20
Water Pollution	0.000047		$59,287.68
Traffic Congestion	0.0022		$2,775,168.00
Infrastructure Damage Cost Reduction	0.000514		$648,380.16
Accident Cost Reduction	0.0029		$3,658,176.00
Electricity Tax Revenue	0.00007		$88,300.80
Fuel Tax Loss Revenue		-0.00138	$(1,740,787.20)
Tire Tax Loss Revenue		-0.00009	$(113,529.60)
Total	**0.023711**	**-0.00147**	**$28,055,687**

Table 4-15 Summary of EIA for Route 2 Border at Laredo

Items	Benefit ($/ton-mile)	Cost ($/ton-mile)	Annual Benefit ($)
Air Pollution	0.0177		$5,953,996.80
Noise Pollution	0.00028		$94,187.52
Water Pollution	0.000047		$15,810.05
Traffic Congestion	0.00507		$1,705,466.88
Infrastructure Damage Cost Reduction	0.000514		$172,901.38
Accident Cost Reduction	0.0029		$975,513.60
Electricity Tax Revenue	0.00007		$23,546.88
Fuel Tax Loss Revenue		-0.00138	$(464,209.92)
Tire Tax Loss Revenue		-0.00009	$(30,247.56)
Total	**0.026581**	**-0.00147**	**$8,446,938**

Table 4-16 Summary of EIA of Pallet Size UFT for Route 3 from the Port of Houston to Baytown

Items	Benefit ($/ton-mile)	Cost ($/ton-mile)	Annual Benefit ($)
Air Pollution	0.0177		$4,688,772.48
Noise Pollution	0.00028		$74,172.67
Water Pollution	0.000047		$12,450.41
Traffic Congestion	0.0022		$582,785.28
Infrastructure Damage Cost Reduction	0.000514		$136,159.83
Accident Cost Reduction	0.0029		$768,216.96
Electricity Tax Revenue	0.00007		$18,543.17
Fuel Tax Loss Revenue		-0.00138	$(365,565.31)
Tire Tax Loss Revenue		-0.00009	$(23,841.22)
Total	**0.023711**	**-0.00147**	**$5,891,694**

Table 4-17 Summary of EIA of Crate Size UFT for Route 3 from the Port of Houston to Baytown

Items	Benefit ($/ton-mile)	Cost ($/ton-mile)	Annual Benefit ($)
Air Pollution	0.0177		$7,786,711.44
Noise Pollution	0.00028		$123,179.62
Water Pollution	0.000047		$20,676.58
Traffic Congestion	0.0022		$967,839.84
Infrastructure Damage Cost Reduction	0.000514		$226,122.58
Accident Cost Reduction	0.0029		$1,275,788.88
Electricity Tax Revenue	0.00007		$30,794.90
Fuel Tax Loss Revenue		-0.00138	$(607,099.54)
Tire Tax Loss Revenue		-0.00009	$(39,593.45)
Total	**0.023711**	**-0.00147**	**$9,784,420**

CHAPTER 5-FINANCIAL MEANS

5.1 INTRODUCTION

Freight transportation significantly contributes to pavement deterioration. According to the Texas Legislative Budget Board (2015), 60% of goods shipped annually from Texas are carried by trucks and another nine percent are carried by services that use trucks for part of the delivery. Freight vehicle miles traveled are expected to increase 120 percent between 2011 and 2035 (Texas Legislative Budget Board, 2015). The Texas Department of Transportation (TxDOT) estimates a $5.0 billion gap (as of October 2013) between the amount of federal and state revenue anticipated and the amount that is needed annually to maintain the highway network at 2010 levels of congestion and maintenance (TxDOT, 2014). Building new intermodal transportation facilities, such as the Underground Freight Transportation (UFT) system with potentially high benefits and revenues can help the state address highway needs.

As the population grows, the construction and maintenance of transportation infrastructure systems become critical. However, the high initial cost of the highway infrastructure systems has made their financing a national challenge. Financing methods range from traditional federal funding to the more innovative federal loans, state bonding initiatives, and public-private partnerships (Capka, 2006). These financing methods should be accompanied by appropriate project delivery systems to facilitate project success. There is a variety of such feasible project delivery systems. Farely et al. (2014) recently reviewed various feasible transportation project delivery systems, such as design-bid-build (DBB), design-build (DB), operations & maintenance (O&M) contract, design-build-operate-maintain (DBOM), design-build-finance (DBF), design-build-finance-operate-maintain (DBFOM), long-term lease concession, build-transfer-operate (BTO), Lease-Build-Operate (LBO), Build-Operate-Transfer (BOT), build-own-operate-transfer (BOOT), build-own-operate (BOO), private sector owns and operates (PSOO), asset sale, and buy-build-operate (BBO).

Successful financing of large and innovative infrastructure projects, such as UFT requires consideration of a variety of interrelated factors, such as funding sources and project delivery systems. It also requires a rigorous cost and benefit analysis to explicitly show the advantages of UFT projects for public and private stakeholders and investors.

5.1.1 Objectives

The specific objectives of this chapter are to:

- Evaluate and recommend viable funding and financing plans for UFT projects
- Evaluate and recommend proper project delivery systems for UFT projects
- Evaluate costs and benefits of UFT projects

Section 5.2 details our methodology to achieve the objectives. We studied four recent infrastructure project cases in detail to introduce several viable funding and financing sources that can be adopted for UFT projects and to recommend proper delivery methods to support UFT project funding. These case studies are discussed in Section 5.3. Section 5.4 recommends potential funding sources based on the case studies. This section also includes discussions about the eligibility of the funding sources. Section 5.5 presents different common delivery systems suitable for transportation projects based on case studies and proposes the most applicable delivery options for UFT. Section 5.6 presents a summary of costs and benefits as well as benefit-cost analysis of UFT. The conclusions are delivered in Section 5.7.

5.2 METHODOLOGY

5.2.1 Methodology for Evaluating and Recommending Viable Funding and Financing Plans and Project Delivery Systems for UFT Project

Case studies were identified and rigorously evaluated to introduce several viable funding and financing sources that can be adopted for UFT projects, and proper delivery methods to support UFT project funding were recommended. The following criteria were considered in the selection of the case studies:

- Being located in Texas
- Being recently funded
- Having a variety of public and private funding contributions
- Introducing a mechanism, such as toll collection to attract funding during the operation phase

Considering the above criteria and the information availability, we identified and assessed four case studies:

1) NTE (IH-820 and SH-121/183), Tarrant County, Texas
2) NTE 35W (Segment 5 and 6) Project, Tarrant County, Texas
3) Central Texas Turnpike System (CTTS), Travis County, Texas
4) SH-130 (Segments 5-6) Project, Caldwell and Guadalupe Counties, Texas

5.2.2 Methodology and Assumptions for Benefit-Cost Analysis

Potential transportation projects should be rigorously evaluated using proper methods such as benefit-cost analysis to assure that benefits of a project (e.g., improved safety and decreased travel times) are higher than costs (e.g., capital costs). Existing methodologies for evaluating costs and benefits of projects range from benefit-cost analysis to life cycle cost analysis methods (Ozbay et al., 2008). The following methods have been proposed for evaluating costs and benefits of a project:

- Benefit-Cost Analysis (e.g., Akan et al.,1984)
- Life Cycle Cost Analysis (e.g., Gautreau et al., 2009)
- The Scoring Methods (e.g., Avineri, 2000)
- Mathematical Models (e.g., Teng et al., 1996)
- Analytical Hierarchy Process (e.g., Sayers, 2003)

Benefit-cost analysis is the most commonly used method for evaluating costs and benefits of transportation projects. We conducted the benefit-cost analysis for a UFT project, using costs and benefits of the project, which are presented in Chapters 3 and 4, respectively.

The cash inflows and outflows of all the alternatives were created. The initial costs, such as cost of tunneling, cost of terminal land and development, and cost of the LIM system were considered as one-time costs. Other costs and benefits were assumed as constant in the life cycle of UFT. The present values of the benefits and costs of all the proposed alternatives were calculated. The net present value (NPV) and benefit-cost ratio of each designed UFT alternative were calculated based on the present values of benefits and costs. The internal rate of return was also calculated and compared to the market interest rates.

A concise definition of NPV is the difference between the present value of benefits (cash inflows) and their actual cost (cash outflows). Eq. 5-1 presents the general form of NPV.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^n} \qquad \text{(Eq. 5-1)}$$

where B_t is the benefits at time *t*, and C_t is costs at time; *i* is the discount rate, and n is the length of time for the project's benefit and cost streams. For a chosen period, if NPV is positive, the proposed project is considered to be economically feasible. Additionally, in the case of alternative projects, the project with the highest net present value can be selected as the most beneficial. Net present value is the most widely used method as a decision rule for project selection (Kocabaş et al., 2010).

Benefit-cost ratio is computed by dividing present value of benefits by the sum of the discounted costs. Eq. 5-2 presents this ratio.

$$\frac{B}{C} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^n}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^n}} \qquad \text{(Eq. 5-2)}$$

If the ratio is greater than or equal to 1.0, the proposed project is economically feasible. Internal rate of return (IRR) represents the discount rate, which equates NPV to zero. If the rate of return exceeds the market interest rate or any other adopted discount rate, then the project is economically feasible. In case of alternative projects, a project with the higher IRR is most beneficial. Eq. 5-3 should be solved in order to determine IRR:

$$NPV = 0 = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+IRR)^n} \qquad \text{(Eq. 5-3)}$$

The life expectancy of freight vehicles is assumed to be 20 years. Therefore, freight vehicles would be replaced every 20 years, and the salvage value for depreciated vehicles is assumed to be 40% of their original cost. Discounting factors are used to identify the present values of costs and benefits that occur in the coming years. Discount rates recommended by the U.S. Office of Management and Budget (USOMB) in 2016 are presented in Table 5-1 (U.S. Office of Management and Budget, 2016).

Table 5-1 Real Discount Rates for Benefit-Cost Analysis (U.S. Office of Management and Budget, 2016)

	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
Discount Rate	0.3	0.6	0.8	1.0	1.2	1.5

Projects with durations longer than 30 years can use the 30-year interest rate (U.S. Office of Management and Budget, 2016). The overall life expectancy for a UFT is assumed to be 100 years. According to the recommendations provided in OMB Circular No. A-94 Appendix C, a 1.5-percent discount rate is used for the benefit-cost calculations.

5.3 CASE STUDIES

The following information items are provided for each case:

- Project Description
- Cost of the Project
- Sources of Funding
- Project Delivery
- Project Innovations

5.3.1 NTE (IH-820 and SH-121/183)

5.3.1.1 Project Description

TxDOT awarded two Comprehensive Development Agreements (CDAs) in 2009 for the North Tarrant Express (NTE) project (TxDOT, 2015a). These CDAs are equivalent to public-private partnerships. One of the CDAs includes the design, development, construction, finance, maintenance, and operation of 13 miles of highway. This project has two segments. Segment 1 is along Interstate Highway (IH) 820 from IH 35W to SH-121. Segment 2A is along State Highway (SH) 121/SH-183, from north of Fort Worth to just southwest of the Dallas-Fort Worth International Airport. The duration of the concession is 52 years (TxDOT, 2015a). Segments 1 and 2A are illustrated in Figure 5-1.

5.3.1.2 Cost of the Project

The NTE (IH-820 and SH-121/183) project began in October 2010 and was completed nine months ahead of schedule in October 2014. This $2.1 billion (2009 dollars) project added four TEXpress (toll-managed) lanes with frontage roads and auxiliary lanes. It also reconstructed the existing four to six main lanes in order to double the existing capacity (TxDOT, 2015a). The cost of this project in 2016 dollars would be $2.36 billion.

5.3.1.3 Sources of Fund

This public-private partnership used two-thirds private funds with one-third public funds to complete the 13-mile corridor. Table 5-2 and Figure 5-2 summarize the funding sources and the amounts of their contributions to the project (FHWA, 2015a).

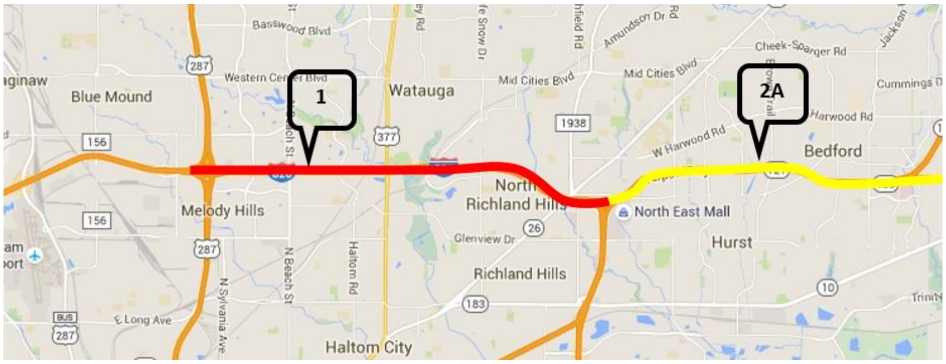


Figure 5-1 The Location of NTE Segments 1 and 2A
(Source: Google Maps)

Table 5-2 Funding Sources and the Amount of Their Contributions to the NTE Segments 1 and 2A

Source of Fund	Amount ($Million)	% of Total
Private Activity Bond Proceeds	398	18.9%
TIFIA Loan	650	30.9%
Public Funds	573	27.3%
Equity Contribution	426	20.3%
TIFIA Draw for Interest	54	2.6%
Total Sources of Funds	2047	100%

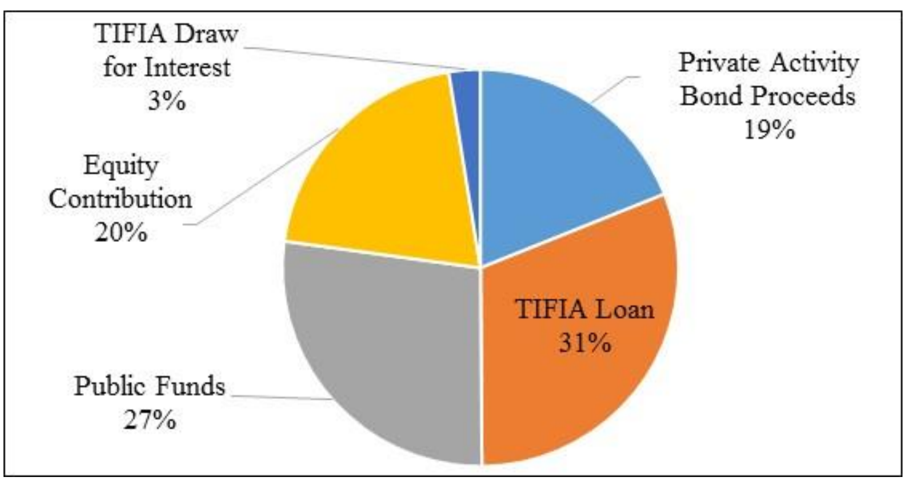


Figure 5-2 Distribution of Funding Sources for NTE Segments 1 and 2A

5.3.1.4 Project Delivery

The delivery method for this project was design, build, finance, operate, and maintain (DBFOM).

5.3.1.5 Project Innovations

The following innovations were introduced in this project (FHWA, 2015a):

- A state-of-the-art electronic toll collection system was introduced in this project. This system has an open architecture to guarantee a free flow operation of the managed lanes.
- An innovative financing package including private activity bonds (PABs) and the Transportation Infrastructure Finance and Innovation Act (TIFIA) credit assistance program was introduced. TIFIA provides opportunities for loans, loan guarantees, and standby lines of credit to finance surface transportation projects of national and regional significance.
- The PABs for this project were the second PAB issuance ever under the $15 billion of authority provided to DOT by SAFETEA-LU.
- This project was the first transportation infrastructure project in the US to reach financial close with direct investment by a pension fund.

5.3.2 NTE 35W Project

5.3.2.1 Project Description

The NTE 35W Project will reconstruct 10.1 miles of IH-35W from downtown to US 287 in Fort Worth (Figure 5-3). The project plan is to reconstruct existing lanes and reduce the congestion by doubling traffic capacity. Construction of this project will include three segments. NTE Mobility Partners Segments 3, LLC (NTEMP3) will construct Segment 3A and TxDOT is responsible for the construction of Segments 3B and 3C. Two TEXpress (toll-managed) lanes in each direction will be added on Segments 3A and 3B and one TEXpress Lane in each direction on Segment 3C will be added as well (North Tarrant Express, 2015). Reconstruction of interchanges and upgrading the existing facilities are in the scope of this project.

According to FHWA (2015a), construction of the Segment 3B (north of IH-820) began in 2013 and is expected to be completed in 2017. Likewise, construction of Segment 3A (south of IH-820) began in 2014 and will be done by 2018.

5.3.2.2 Cost of the Project

According to TxDOT (2015b), the $1.7 billion (2013 dollars) NTE 35W Project will be built in segments. Segment 3A includes construction of two managed lanes in each direction, and reconstruction of interchanges, frontage roads, ramps, bridges and overpasses. It also includes the improvements of approximately 6.5 miles of highway. The total cost for this segment will be $1,377.4 million. Segment 3B will cost $260.2 million and includes construction of two managed lanes in each direction and improvements of approximately 3.6 miles of IH-35W. Construction of this segment also includes frontage road reconstruction, auxiliary lanes, and managed lane direct connectors. The total cost of Segments A and B, according to 2016 dollars, is $1.75 million. Segment 3C will cost $786 million (North Tarrant Express 35W, 2014) and is a 5-mile section of IH-35W from north of US 287 to SH-170. This segment will add three general purpose lanes, two managed/toll lanes, and continuous two-lane frontage roads in each direction.

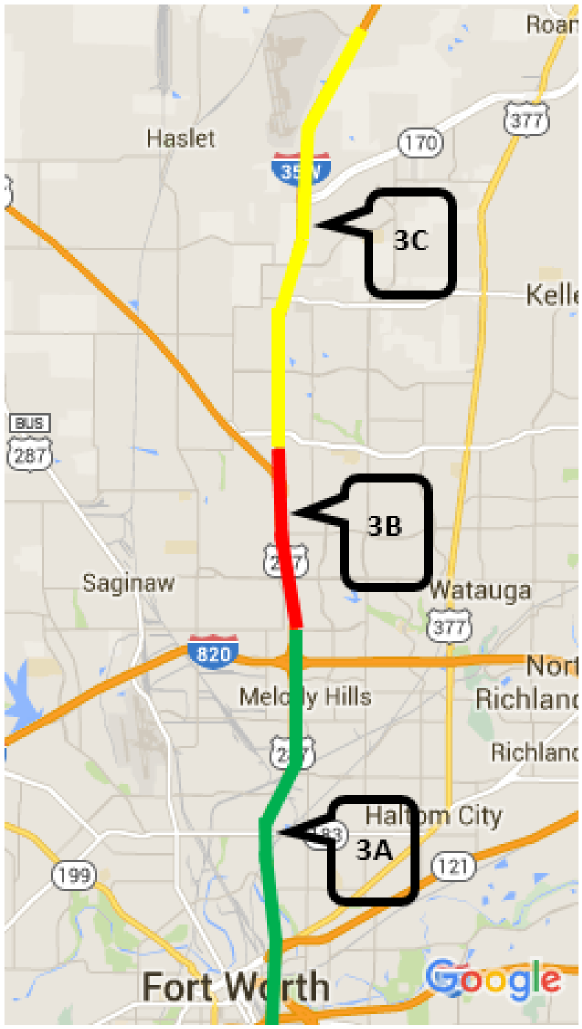


Figure 5-3 The Location of NTE Segments 3A, 3B, and 3C
(Source: Google Maps)

5.3.2.3 Sources of Funding

The consortium proposed a plan that includes a combination of funding sources to optimize the cost of capital and maximize the value offered to TxDOT. Based on FHWA (2015b), Table 5-3 and Figure 5-4 summarize the funding sources and the amounts of their contributions to NTE Segment 3A. Likewise, Table 5-4 and Figure 5-5 summarize the funding sources and the amounts of their contributions to NTE Segment 3B.

Table 5-3 Funding Sources and the Amount of their Contributions to NTE Segment 3A

Source of Fund	Amount ($Million)	% of Total
Private Activity Bond Proceeds	270.6	19.6%
TIFIA Loan	524.4	38.1%
Public Funds	163.8	11.9%
Interest income	5.6	0.4%
Equity	412.9	30%
Total Sources of Funds	1,377.3	100%

Table 5-4 Funding Sources and the Amount of their Contributions to NTE Segment 3B

Source of Fund	Amount ($Million)	% of Total
Proposition 12 Bond Proceeds	100	38.4%
Federal and State Funds	150.2	57.7%
Private Activity Bond Proceeds	3.4	1.3%
TIFIA Loan	6.6	2.5%
Total Sources of Funds	260.2	100%

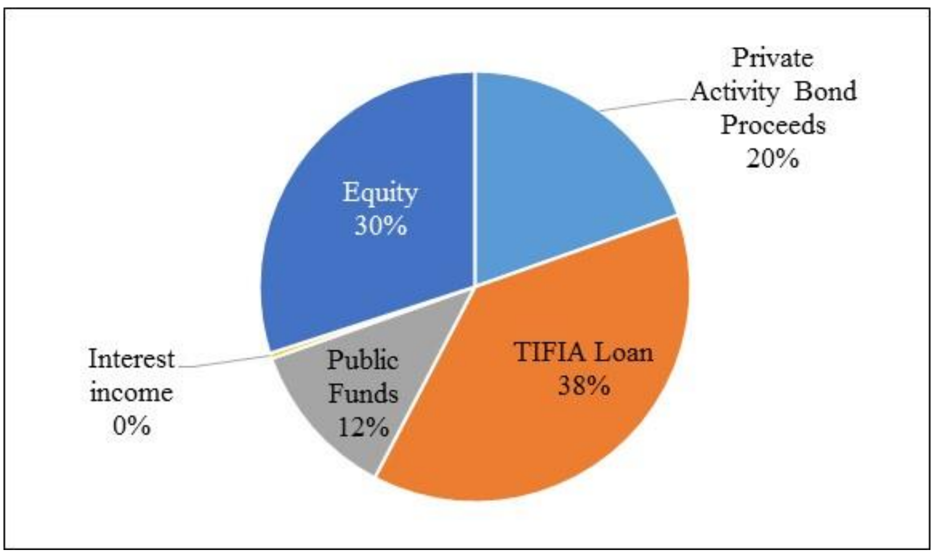


Figure 5-4 Distribution of Funding Sources for NTE Segment 3A

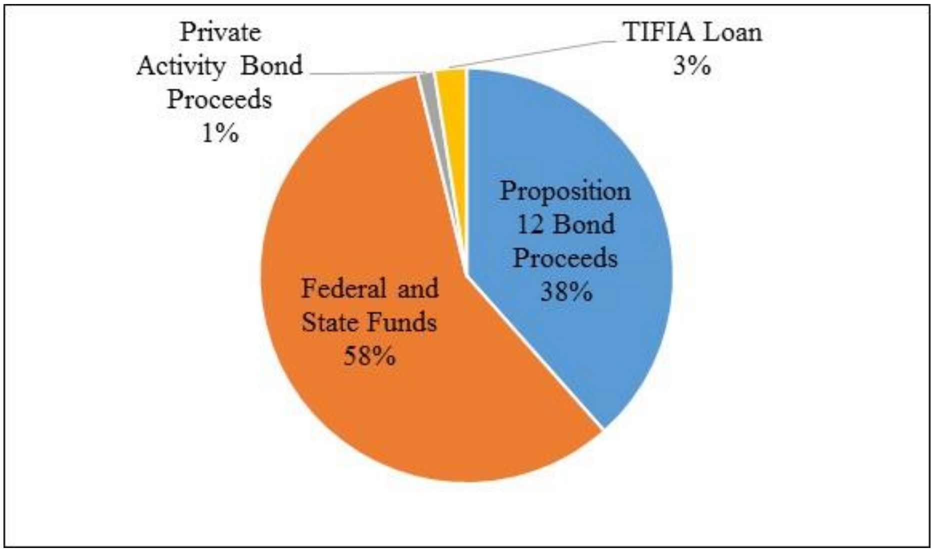


Figure 5-5 Distribution of Funding Sources for NTE Segment 3B

5.3.2.4 Project Delivery

A 52-year concession agreement (effective 2009) between TxDOT and NTE Mobility Partners was executed in 2013. Based on this agreement, NTE Mobility Partners is responsible for the design, construction, financing, operation, and maintenance of Segment 3A and for operating and maintaining Segment 3B. Furthermore, TxDOT will deliver Segment 3B on a design-bid-build basis before turning over operations to NTE Mobility Partners (TxDOT, 2015b).

5.3.2.5 Project Innovations

The following innovations were introduced in this project (FHWA, 2015b):

- This project will make the IH 35W corridor a "Smart Corridor" with an active traffic management technology.
- This project can be considered the third transportation infrastructure project in the United States in terms of reaching financial close with direct investment provided by a pension fund.

5.3.3 Central Texas Turnpike System (CTTS)

5.3.3.1 Project Description

The Central Texas Turnpike System (CTTS) includes three toll highways. It serves the Austin metropolitan region and the Austin-San Antonio corridor (FHWA, 2015c). The first toll highway consists of 13 miles of SH-45 North (four to six lanes) from Ridgeline Boulevard to SH-130. The second toll highway consists of a three-mile northward extension of the existing Loop 1, from Parmer Lane to SH-45 North. The third toll highway consists of 49 miles of SH-130 (Segments 1-4). This four-lane highway is located between Williamson and Travis Counties. Figure 5-6 presents a map of these highways.

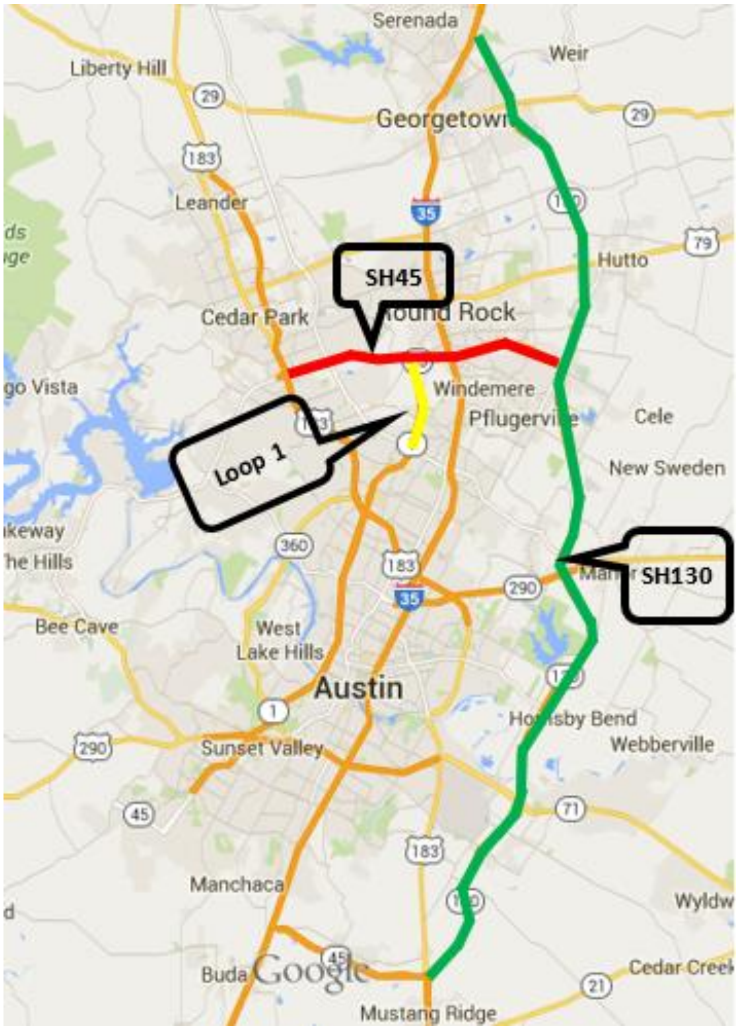


Figure 5-6 Map of Central Texas Turnpike System Project
(Source: Google Maps)

5.3.3.2 Cost of the Project

Total cost of this project was $3.25 billion (2006 dollars) including (FHWA, 2015c):

- Design and Construction: $822.8 million (SH-45 North and Loop 1); $1.282 billion (SH-130 Segments 1-4)
- Right of Way (ROW): $403.4 million
- Interest, insurance, debt issuance costs, and reserve fund: $741.5 million

The total cost of the project would be $5.22 billion in 2016 dollars.

5.3.3.3 Sources of Fund

The funding of this project was provided from several sources. Based on FHWA (2015c) statistics, these funding sources and their contributions to the project are presented in Table 5-5 and Figure 5-7.

Table 5-5 Funding Sources and the Amount of their Contributions to Central Texas Turnpike System (CTTS)

Source of Fund	Amount ($Million)	% of Total
First and Second tier revenue bonds/notes	1,358	41.8%
TIFIA loan	900	27.7%
State funding	520.1	16%
Local contributions/Commission funds	286.5	8.8%
Interest earnings/accrued interest	185.2	5.7%
Total Sources of Funds	3,250	100%

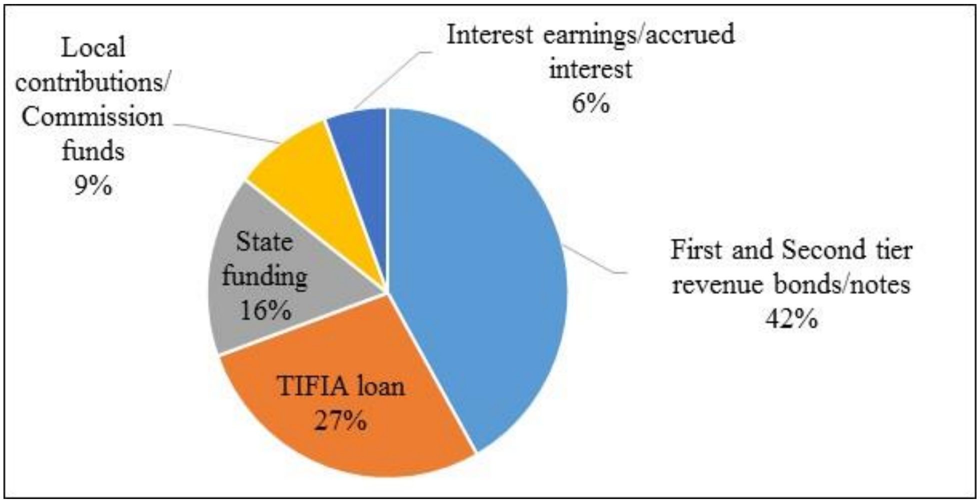


Figure 5-7 Distribution of Funding Sources for Central Texas Turnpike System (CTTS)

5.3.3.4 Project Delivery

Each segment of this project was delivered separately, and their development agreement method was as follows:

- SH-45 North: Design-Bid-Build
- Loop 1: Design-Bid-Build
- SH-130 (Segments 1-4): Design-Build

5.3.3.5 Project Innovations

The following innovations were introduced in this project (FHWA, 2015c):

- The introduction of a fixed-price, lump-sum design-build contract for the SH-130 segment and a variety of funding sources delivered the CTTS components sooner than conventional pay-as-you-go financing.
- The project was delivered ahead of schedule and under budget.

5.3.4 SH-130 (Segments 5-6) Project

5.3.4.1 Project Description

The SH-130 Segment 5 and 6 project is a 40-mile extension of SH-130 along the current US 183 from north of Mustang Ridge to north of Lockhart and continues southwest to IH-10 northeast of Seguin. The location of the project is shown in Figure 5-8. This project started in year 2007 and opened to traffic in 2012 (FHWA, 2015d). Construction of Segments 5 and 6 made State Highway 130 into a four lane, 91-mile toll road that mitigates the congestion of IH-35.

5.3.4.2 Cost of the Project

According to FHWA (2015d), total cost of this project was $1.328 billion (2007 dollars), that is, approximately $1.62 billion in 2016 dollars. This cost includes construction, right-of-way acquisition, utility relocation, and improvements to connecting streets and roads.

5.3.4.3 Sources of Fund

This $1.328 billion project was funded through senior bank loans, a TIFIA loan, private equity and interest income. The funding sources and their contributions to the project are presented in Table 5-6 and Figure 5-9 (Based on FHWA, 2015d).

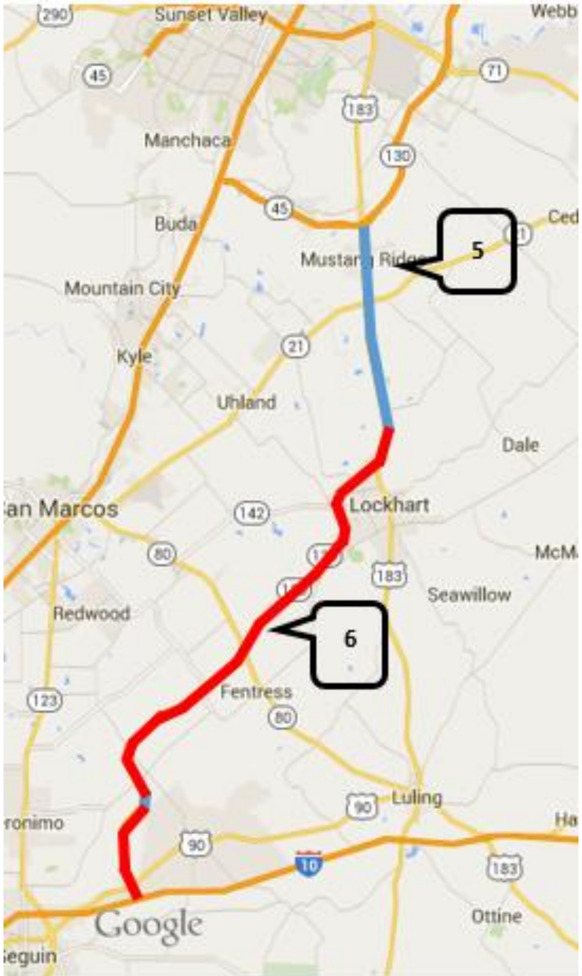


Figure 5-8 Location of SH-130 Segments 5 and 6
(Source: Google Maps)

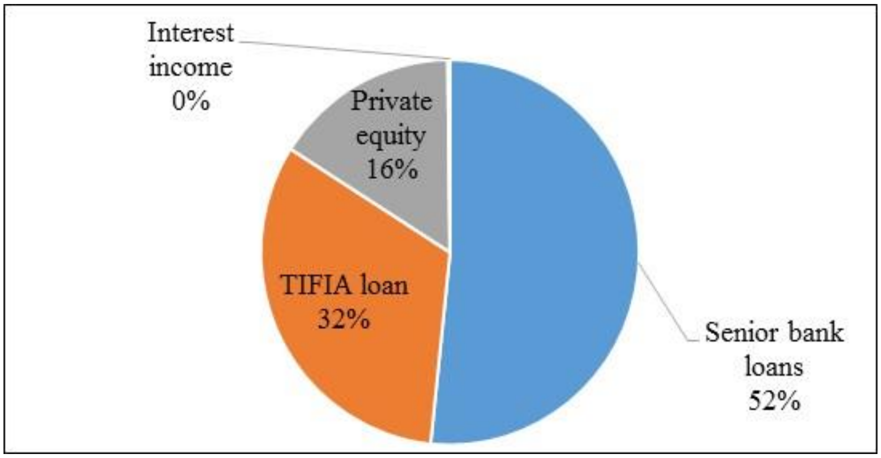


Figure 5-9 Distribution of Funding Sources for SH-130
(Segments 5 and 6) Project

Table 5-6 Funding Sources and the Amount of Their Contributions to (Segments 5 and 6)

Source of Fund	Amount ($Million)	% of Total
Senior bank loans	685.8	51.6%
TIFIA loan	430	32.4%
Private equity	209.8	15.8%
Interest income	2.4	0.2%
Total Sources of Funds	1,328	100%

5.3.4.4 Project Delivery

A 50-year concession agreement (from the opening of the project) was signed between TxDOT and the SH-130 Concession Company to design, build, finance, operate, and maintain (DBFOM) a 40-mile extension of SH-130 (Segments 5 and 6) in 2007. The project opened to traffic in 2012 (FHWA, 2015d).

5.3.4.5 Project Innovations

The following innovations were introduced in SH-130 project:

- SH130 project represents the first open toll road in Texas that is developed and operated privately (FHWA, 2015d).
- The private investment in this project gives the state a share of the toll revenue (FHWA, 2015d).

5.3.5 Summary of Case Studies

Table 5-7 summarizes the information case studies provided in Section 5.3. Based on the information, the following conclusions can be derived:

1. The project delivery methods that were used for these cases studies were Design, Build, Finance, Operate, and Maintain (DBFOM), and Design-Bid-Build.
2. The contributions of both private and public sectors were critical for the success of the major capital-intensive infrastructure projects studied in the case studies.
3. “TIFIA loan” is one of the major funding sources used in the infrastructure projects studied in the case studies.
4. Private equity, bank loan, and bond issuance were among the other significant sources of funding for the major infrastructure projects.
5. The investigation of the case studies shows that the potential for significant private investment in projects, such as UFT, can be as high as two thirds or even all of the project cost.

Table 5-7 Summary of Case Studies

Project	NTE (IH-820 and SH-121/183)	NTE 35W (Segments 3A and 3B) Project	Central Texas Turnpike System	SH-130 (Segments 5 and 6) Project
Year	2010-2014	Segment 3A: 2013-2017 Segment 3B: 2014-2018	2001-2008	2007-2012
Location	Dallas-Fort Worth, Texas	Dallas-Fort Worth, Texas	Austin, Texas	Austin, Texas
Total Cost of the Project (2015)	$2,365 million	$1,750 million	$5,220 million	$1,624 million
Delivery Method	DBFOM	Segment 3A: DBFOM (design, build, finance, operate, and maintain) Segment 3B: Design-bid-build (O&M included as part of concession)	SH-45 North: Design-Bid-Build Loop 1: Design-Bid-Build SH-130 (Segments 1-4): Design-Build	DBFOM
Sources of Fund	• Private Activity Bond Proceeds - $398 million • TIFIA Loan - $650 million • Public Funds - $573 million • Equity Contribution - $426 million • Total does not include TIFIA capitalized interest of $54 million	Segment 3A: • Private Activity Bond Proceeds - $270.6 million • TIFIA Loan - $524.4 million • Public Funds - $163.8 million 1 • Interest income - $5.6 million • Equity - $412.9 million Segment 3B: • Proposition 12 Bond Proceeds - $100.0 million • Federal and State Funds - $150.2 million • Private Activity Bond Proceeds - $3.4 million • TIFIA Loan - $6.6 million	• First tier revenue bonds/notes - $1,358 million • TIFIA loan - $900 million (used to retire Bond Anticipation Notes [BANs] in 2007 and 2008) • State funding - $520.1 million • Local contributions/Commission funds for ROW - $286.5 million • Interest earnings/accrued interest - $185.2 million	• Senior bank loans - $685.8 million • TIFIA loan - $430 million • Private equity - $209.8 million • Interest income - $2.3 million

5.4 FUNDING SOURCES

There are several ways to finance major transportation projects. The traditional financing method is complete or partial federal funding. In this method, the cost of the project is provided by federal funding, and revenues of the project belong to the government as well. However, funding infrastructure projects, such as new highway construction or expansion, is a challenge for public financing, and new transportation systems, such as UFT are not an exception. Therefore, government agencies are looking at new financing tools and techniques to pay for these large undertakings and ways to start the projects sooner. States have started using innovative financing techniques, including federal loans, state bonding initiatives, and public-private partnerships to secure funds (Capka, 2006).

To have a better understanding of several potential funding sources for UFT, four recent and comparable case studies were analyzed and reported in Section 5.3. Figure 5-10 summarizes the amount and contribution of each funding source for these case studies.

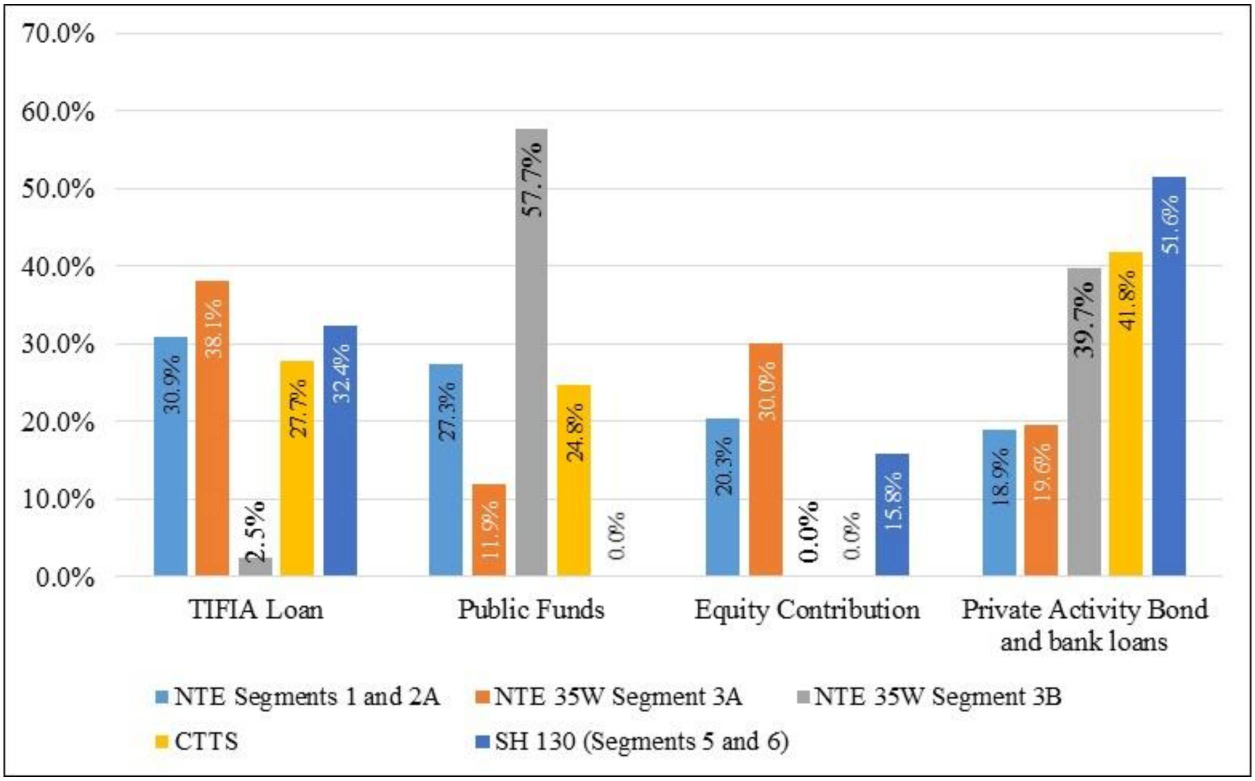


Figure 5-10 Summary of Funding Source Contributions for Case Studies

As shown in Figure 5-10, major funding sources that can be expected to be used in financing UFT are: public funds, TIFIA loan, senior bank loans, revenue bonds, and equity participation.

5.4.1 Public Funds

According to the American Association of State Highway and Transportation Officials (AASHTO), most surface transportation projects in the U.S. are funded from public sources at the federal, state, and local levels. At the federal level, most funding comes from the excise taxes on motor fuels (about 82 percent) (AASHTO, 2015a). In addition, some funding for surface transportation is provided by the General Fund of the U.S. Treasury (AASHTO, 2015b). Motor fuel taxes, as a major funding source, contribute one-third of surface transportation funding.

A continual struggle goes on to find enough funds in federal and state budgets to pay for local transportation projects that can shift the burden to local governments who are going to play an important role in financing of transportation projects. Revenue from local government provides about 36 percent of surface transportation funding in the U.S., and they are expected to play an increasingly critical role as declining federal and state budgets require local governments to spend more of their budget on their roads and streets (AASHTO, 2015c). Most local transportation funding is provided by property taxes and general fund appropriations, as well as toll booths and fares for mass transit. At the state level, motor fuel taxes are significant, but motor vehicle taxes and fees and bond proceeds also play important roles (AASHTO, 2015a).

5.4.2 TIFIA Loan

The Transportation Infrastructure Finance and Innovation Act (TIFIA) is a program that offers credit assistance for qualified projects of regional and national importance. TIFIA was initially authorized in 1998 under the Transportation Equity Act for the 21st Century (TEA-21) and revised in 2005 by the Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU) (USDOT, 2015). This program provides federal credit assistance in three forms (direct loans, loan guarantees, and standby lines of credit) to finance surface transportation projects (FHWA, 2015e). Large-scale surface transportation projects, such as highway, railroad, intermodal freight, and port access may be eligible to utilize this loan (USDOT, 2015). However, this loan is limited to 33 percent of total eligible project costs that are reasonably predicted. According to the USDOT Website, TIFIA loans have been used in ten projects in the State of Texas. The interest rate for this loan is 3.04% as of November 2015 (FHWA, 2015f).

5.4.3 Senior Bank Loan

A senior bank loan is a debt financing obligation. It is issued by a bank or similar financial institution to a company or individual. As for any other bank loan, this loan has priority over all the other claims against the borrower.

5.4.4 Revenue Bonds

Revenue bonds can be used to fund transportation projects. These bonds may be issued by a state or local government or even directly by a transit agency (FTA, 2015). These bonds are used for constructing new transportation projects or maintaining and operating the ongoing facilities. Also, revenue bonds are means to finance larger-scale capital investment transportation projects.

There are several revenue sources to support revenue bonds, such as motor vehicle registrations, sales taxes, property taxes, fare box revenues and anticipated grant receipts (FHWA, 2015g).

5.4.5 Equity Participation

Equity participation is a good funding instrument specifically for new and innovative infrastructure projects, such as UFT that will generate a lot of revenue during its life cycle. Federal-aid highway funds for individual programs are apportioned by a formula that utilizes factors relevant to the particular program and equity considerations (FHWA, 2005). In SAFETEA-LU (see Section 5.2.2), this provision is called the Equity Bonus (replaces TEA-21's Minimum Guarantee). An open-ended authorization guarantees that sufficient funds exist for the Equity Bonus (FHWA, 2005a). Private parties can invest and buy equity bonds or shares.

5.4.6 Innovative Funding Method

The Office of Innovative Program Delivery (IPD) supports the new funding sources that bypass traditional taxes and fees (FHWA, 2015g). SAFETEA-LU encourages the private sector to take part in highway infrastructure projects by offering new ideas and resources. One possibility would be for one or more private parties to invest in a UFT project and receive a share from the profit of moving containers with UFT (FHWA, 2005a). Another scenario could be leasing the facility to a private investor and receiving a fixed monthly or yearly amount of money. In this case, the investor collects the revenue of freight transportation and gives a fixed amount to the public entity originally responsible for the facility's operation. Several innovative and creative funding mechanisms can be formulated to share risks and attract private funding sources.

5.4.7 UFT Funding Sources

Conducting case study analyses on comparable transportation projects funded in Texas resulted in identifying major potential funding sources to finance UFT. The potential funding sources are: federal and state funds, a TIFIA loan, senior bank loans, revenue bonds, and equity participation. The following subsections discuss the eligibility of identified funding sources from both public and private sources as well as a recent funding source (The Fixing America's Surface Transportation (FAST) Act). All of the following sources were evaluated for constructing UFT.

5.4.7.1 Public Funds

Public funding sources can be divided into federal, state, and local funds. There are recent appropriation and authorization bills, different public programs, loans and bonds that authorize public funds to be used for new and innovative transportation projects. TIFIA Loan and the FAST Act are two examples of appropriate public funding sources used to construct and operate UFT. Detailed reviews of federal, state, and location funds, a TIFIA loan, and the FAST Act are provided in the following subsections.

Federal, State, and Local Funds. Many surface transportation projects in the U.S. are funded from public sources at the federal, state, and local levels. Each year, up to $200 billion is invested in surface transportation that is mostly provided by various taxes and fees (AASHTO, 2015a). Federal funds, state revenues, and local funds contribute 21%, 43%, and 36% of total surface transportation funding in the United States, respectively (AASHTO, 2016a).

Each fiscal year the House and Senate introduce “appropriations bills” to outline the amount of funds to be appropriated to each agency and state. The Fiscal Year (FY) 2016–17 general appropriations bills include $23.1 billion in funding for the TxDOT. Likewise, every 5–6 years, Congress reauthorizes the existing statute for funding highway, transit, safety, and rail programs by passing new “authorization bills.” These bills establish the terms and conditions under which a federal agency operates. They authorize the enactment of appropriations and specify how appropriated funds are to be used (The U.S. Senate, 2016).

The most recently passed bill is the Fixing America’s Surface Transportation (FAST) Act. This Act authorizes Federal highway, highway safety, transit, and rail programs for five fiscal years from 2016 through 2020. The two previous bills authorized by the United States Senate were SAFETEA-LU[25] (2009) and MAP-21[26] (2012).

It is not far surprising that there is no appropriated fund specifically prepared for a new and innovative underground freight transportation system in any of the recent authorization bills. However, construction of UFT can be funded using federal funds by getting it named as a specific project (such as a project with state and national significance) under one of these authorization bills along with determined funding levels over a period of years (Texas Transportation Institute, 2002).

At the state level, the Texas Transportation Commission and TxDOT utilize the Unified Transportation Program (UTP) to lead in the development of needed transportation projects. The UTP is developed annually in accordance with the Texas Administrative Code (TAC §16.105) and approved by the Texas Transportation Commission each year before the end of August (TxDOT, 2016a). Due to the several advantages of UFT, such as mitigating traffic congestion and improving safety, this system could be considered as a project applicable to be funded under TAC §16.105.

Likewise, revenue from local governments plays an important role in transportation finance. General fund appropriations are the largest source of local funding. The use of property taxes makes local transportation funding different from the federal and state governments’ funding (AASHTO, 2015c). Undoubtedly, local authorities can play a significant role in funding the construction of UFT with several programs and funding sources that are available at this level.

TIFIA Loan. In 1998, the Congress introduced the Transportation Infrastructure Finance and Innovation Act (TIFIA). This Act provides credit assistance in three forms (direct loans, loan guarantees, and standby lines of credit) to finance qualified projects of regional and national importance. Since this act has been introduced, TIFIA has provided funding to 55 projects in the United States. Notably, Texas, with 10 projects, is the pioneer in using this loan for its transportation projects (USDOT, 2016a).

Any type of project that is eligible for federal assistance through existing surface transportation programs and several other types of projects including intermodal freight

---

[25] Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users

[26] Moving Ahead for Progress in the 21st Century Act

transportation are eligible for the TIFIA credit program (USDOT, 2016b). Under Title 23 of the U.S. Code (23 U.S.C., 2011), eligible projects are defined as within the scope of a TIFIA loan as follows:

> "Public freight rail facilities, private facilities providing public benefit for highway users by way of direct freight interchange between highway and rail carriers, ***intermodal freight transfer facilities***, *projects that provide access to such facilities, and service improvements (including capital investments for intelligent transportation system*s) at such facilities, **are also eligible for TIFIA credit assistance** (23 U.S.C. §601(a)(12)(D)(i)). In addition, a logical series of such projects with the common objective of improving the flow of goods can be combined (23 U.S.C. §601(a)(12)(D)(i)(V))."
>
> U.S.C. Title 23 states:
>
> "Projects located within the boundary of a port terminal are also eligible to receive TIFIA credit assistance, so long as the project is limited to only such surface transportation infrastructure modifications as are necessary to facilitate direct intermodal interchange, transfer, and access into and out of the port (80 23 U.S.C. §601(a)(12)(D)(iii))."

As shown explicitly in these two sections, a TIFIA loan can play a significant role in financing UFT as a new innovative, intermodal freight transportation facility.

FAST Act. The Fixing America's Surface Transportation (FAST) Act was signed into law on December 4, 2015. The five-year (through FY 2020) $305-billion bill replaces the Moving Ahead for Progress in the 21st Century (MAP-21) Act. Title VIII of the FAST Act−Multimodal Freight Transportation−focuses on the multimodal freight transportation and its importance as a competitive advantage for the United States in the global economy (USDOT, 2016c). The Act creates a multimodal freight policy and a national multimodal freight strategic plan. It also designates a National Multimodal Freight Network to assist states in using resources and planning freight transportation (USDOT, 2016c).

The FAST Act would create grant programs to fund critical transportation projects with freight movement benefits. These programs will for the first time support freight transportation projects by providing a dedicated source of funding. The FAST Act highlights the necessity of federal supervision to facilitate local government ability to cooperate and assist with freight transportation provider needs (USDOT, 2016d).

5.4.7.2 Private Funds

Although private investment is not a substitute for government funds in providing the U.S. infrastructure, an effective use of both sources can lead us to a better and higher quality infrastructure network. Along with this goal, President Barack Obama announced the Build America Investment Initiative on July 14, 2014. The initiative calls for the Secretaries of the Treasury and Transportation to lead a working group to analyze how to increase the partnership of public and private sectors in developing infrastructure, increase private sector financing contribution in infrastructure, and enhance productivity, efficiency, and resilience (The U.S. Department of the Treasury, 2014).

Private sector investment attracted through public-private partnerships (P3s) is essential in funding transportation projects that cannot be delivered by public funding and expertise. P3s provide the private sector with resources and expertise to handle the challenges of construction and management of the infrastructure assets more efficiently. Under a P3 agreement, a public sector contracts with a private entity to design, finance, construct, operate, and maintain (or combine any of these activities) to develop or provide an infrastructure asset. Risks are managed more effectively when they are transferred to the private sector. Therefore, a P3 could result in a higher quality and reliability in delivering transportation infrastructure projects. It could also save more taxpayer money. Due to the variety of roles that the private sector can play in a P3 project, the risk sharing and repayment arrangements are significantly different from project to project (The U.S. Department of the Treasury, 2014).

Case study analyses of different transportation projects in Texas reported in Section 5.3 led to the identity of several private funding sources for constructing and operating of UFT, such as equity participation and private activity bonds. Useful legislative information on P3s for transportation projects and potential private funds for UFT are discussed in the following sections.

Legislative Information on Private Participation in Transportation Projects. Recent legislation and financing mechanisms have provided an opportunity to use private investments and redistribute project risks. The USDOT supports the construction of transportation projects by administrating several credit programs, such as direct loans and loan guarantees (USDOT, 2016e). Credit programs have enhanced access to a wider range of capital and have expanded limited Federal resources (AASHTO, 2016d). The FHWA P3 website provides comprehensive coverage of P3 legislation for 23 U.S. States (FHWA, 2016a).

The legislation most often associated with public private partnership in Texas is HB 2475, introduced during the 84th Legislative Session (HB 2475, 2016). HB 2475 supports private investment by establishing a new Center for Alternative Finance and Procurement[27] within the Texas Facilities Commission. This center assists governmental entities in the receipt of proposals, negotiation of agreements, and management of qualifying public-private partnerships under Chapter 2267.

---

[27] http://www.tml.org/legis_updates/facilities-commission-establishes-center-for-alternative-finance-and-procurement

Chapter 501 of the Texas Local Government Code supports private investment by expanding the authority of "economic development corporations" to carry out projects for transportation facilities such as airports, hangars, rail and marine ports, rail and freight facilities, and parking located at an airport or rail port facility (Texas Government Code, 2016a). An economic development corporation will also be authorized to own and operate a facility as a "business" (Texas Government Code, 2016a).

Chapter 2267 of the Texas Local Government Code supports private investment by

> "(1) encouraging investment in this state by private entities and other persons; and (2) facilitating bond financing or other similar financing mechanisms, private capital, and other funding sources that support the development or operation of qualifying projects in order to expand and accelerate financing for qualifying projects that improve and add to the convenience of the public" (Texas Government Code, 2016b).

The above assessment of recent legislations clearly shows the eligibility of using private partnership in funding UFT as a new innovative freight transportation project that brings more capacity, safety, and resilience to existing transportation systems.

Equity Participation. Although equity investors accept high risks, they can potentially receive high returns. Subcontractors that perform specific services, such as the construction, operation, and maintenance of a project may contribute as equity participants (FHWA, 2016b). Other potential equity participants include financial institutions, such as investment banks and insurance companies. These institutions may also function as a lender, along with commercial banks and public agencies. As stated by Chapter 370 of the Texas Government Code (subchapter G) (Texas Government Code, 2016c):

> "An authority may authorize the investment of public and private money, including debt and equity participation, to finance a function described by this section."

Further, Section 370.311 emphasizes that:

> "An authority may only enter into a comprehensive development agreement under Section 370.305 with a private equity investor if the project is identified in the department's Unified Transportation Program or is located on a transportation corridor identified in the statewide transportation plan."

Since UFT can be defined as a project under the Unified Transportation Program (UTP), equity participation can be used to attract funding.

Revenue Bonds and Private Activity Bonds. Revenue bonds provide funding for projects that make revenue (e.g., a toll road or bridge). This revenue is used to make principal and interest payments to the bond holders (AASHTO, 2016e). Financing UFT using revenue bonds can be similar to toll roads. Most toll roads are funded by borrowing debt backed by revenues from future tolls. This toll revenue is similar to a fee that UFT can charge each freight car user to transfer freight using the facility. In this method, the public authority (i.e., TxDOT) can issue a bond against anticipated toll revenues to fund the construction of a UFT. When UFT starts to operate, the authority pays back its debt and interest costs using fee revenues collected from each freight car user. The revenue bonds can be very attractive for investors because the interest is exempt from federal and state income taxes.

Similarly, a private partner could finance the project by issuing private activity bonds and repaying the debt from facility revenues. Private activity bonds for these kinds of arrangements can be issued on a tax exempt basis (AASHTO, 2016e). SAFETEA-LU amended Section 142 of the Internal Revenue Code to add highway and freight transfer facilities to the types of privately developed and operated projects for which private activity bonds (PAB) may be issued (AASHTO, 2016f). The private activity bond legislation shows the federal government's interest to enhance private sector investment in the transportation infrastructure (AASHTO, 2016f). Providing private developers and operators with access to tax-exempt interest rates lowers the cost of capital considerably and enhances future investments (AASHTO, 2016f). SAFETEA-LU Section 11143 offers a new tax-free class of private activity bonds with a volume cap of $15 billion. The provision plans to encourage private participation in the delivery, operation and ownership of transportation infrastructure projects including freight transportation projects. The tax exemption could be significant and provides about 15 to 20 percent present value on long-term borrowing (Mercator Advisors LLC, 2007).

5.5 DELIVERY SYSTEMS

Construction of new transportation infrastructure and rehabilitation of old infrastructure (highways and bridges) have been the major construction projects in the United States since the 1990s. The high cost of infrastructure projects and their immediate needs makes them a challenge for the government to finance. Due to the limited budget of an agency, it may take a long time to wait for the necessary funds to become available. This delay in completing a project may lead to deterioration of other infrastructure and public dissatisfaction. In addition, governments do not have all the capacity and expertise needed for executing different projects. Therefore, partnerships of private companies play an important role in these situations. Public-private partnerships (P3s) provide public agencies with access to private equity capital to finance transportation infrastructure projects. P3s can expedite the delivery of projects by helping public agencies raise the funding necessary to construct major transportation infrastructure projects in one single stage, rather than in stages. In some cases, private capital can help develop a project that could not be developed otherwise (FHWA, 2015h). The common element of a P3 delivery method is that public sponsors of transportation projects engage the private sector to a greater degree in the performance of certain functions previously handled by the public sector (FHWA, 2007a).

P3 approaches are established in different forms, including involvement of the private sector in financing, design, construction, operation, maintenance and, in some cases, concessional ownership of major facilities (Li et al. 2005). P3 models are used worldwide in a variety of sectors to close the gap between public service needs and the financial capabilities of governments. The extent and type of projects implemented mainly depend on economic, legal, social, and environmental factors in addition to expectations that can vary according to countries (Gurgun et al., 2014).

Zhang (2005) conducted a survey to identify the relative significance of P3 critical success factors based on worldwide expert opinions and analyzed responses from 42 different organizations/institutions in a number of countries, including Australia, India, Japan, Peru, the Philippines, China, Malaysia, Singapore, South Africa, Thailand, the U.K., and the U.S. The results showed that the five critical success factors in P3 were (1) economic viability, (2) appropriate risk allocation via reliable contractual arrangement, (3) a sound financial package, (4) a reliable concessionaire consortium with strong technical skills, and (5) a favorable investment environment.

FHWA (2007b) reports that the major types of public-private partnership projects used in the U.S. since 1991 are design-build (70%), concession[28] (11%), design-build-finance-operate (5%) and design-build-finance (5%). The remaining portion of all the projects is shared by other types of P3 projects such as build-operate-transfer, design-build-maintain and design-build operate-maintain.

5.5.1 Proper Delivery System

To identify a proper delivery system for UFT, several cases were studied. Reviewing recent transportation projects in Texas showed that mega projects, such as the North Tarrant Express project or the Central Texas Turnpike project were performed under partnerships of private and public parties. This case-study analysis provided valuable insight into the role of both public and private contributions in the success of large projects. The project delivery methods that were used for the studied cases were: design, build, finance, operate, and maintain (DBFOM) and design-bid-build.

5.5.2 Design, Build, Finance, Operate, and Maintain (DBFOM)

Design, construction, finance and operation of a facility are all transferred to private sector partners in the design-build-finance-operate-maintain (DBFOM) approach. In large projects, the public sector often contributes to the financing of the project, by providing right-of-way, different bonds, and loans. Federal financing tools, such as private activity bonds helps the private partners by decreasing the borrowing costs and providing subsidies (FHWA, 2015i). DBFOM concessions have a 30- to 50-year lifetime. These concessions are awarded competitively. DBFOM procurements transfer a lot of the responsibility to private sector partners. In nearly all cases, the public agency sponsoring a project does not give up the ownership of the project (FHWA, 2015i).

5.5.3 Design-Bid-Build (DBB)

This is the traditional form of project delivery where the design and construction of the facility are awarded separately and sequentially to private sector engineering and construction firms. As a result, the DBB process is divided into a two-step delivery process involving separate

[28] A concession gives a private concessionaire responsibility not only for operation and maintenance of the assets but also for financing and managing all required investment, see Public Private Partnership in Infrastructure Resource Center (PPPIRC) available at http://ppp.worldbank.org/public-private-partnership/agreements/concessions-bots-dbos#concessions

phases for design and construction. Under a DBB contract, the project owner takes full responsibility of financing, operation, and maintenance and assumes all design risks (USDOT, 2007). The DBB selection process is based on negotiated terms with the most qualified firm for the design phase while the award of the construction contract is typically based on the lowest responsible bid price (FHWA, 2007b).

5.6 BENEFIT-COST ANALYSIS

Benefit-Cost Analysis (BCA) is a systematic method of comparing benefits and costs of a project to determine the economic competence of UFT. The purpose of this section is to present the benefit-cost analysis of UFT for each design alternative. This analysis includes the calculation of three common economic feasibility measures to compare benefits and costs of the proposed UFTs: Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR).

5.6.1 Benefit-Cost Analysis of Implementing UFT for Five Different Alternatives

Five different alternatives were introduced in Chapter 1. These alternatives are based on using UFT for different routes and freight sizes. Benefits of implementing UFT for each alternative was calculated and monetized in Chapter 4. Chapter 3 provided a cost estimate for constructing, operating, and maintaining a UFT facility for each proposed alternative. Benefit-cost analysis of UFT for each of these alternatives is presented in the following subsections.

5.6.1.1 Benefit-Cost Analysis of Container Size UFT from the Port of Houston to City of Lancaster (near Dallas)

Cash flows of the benefits and costs for having a container size UFT from Port of Houston to a distribution center in Dallas were determined. The present values of the benefits and costs are presented in Tables 5-8 and 5-9, respectively.

Table 5-8 Present Value of the Benefits for a Container Size UFT from the Port of Houston to City of Lancaster (near Dallas)

Costs	Present (2016) Value of Benefits ($Million)
Air Pollution Reduction	$19,499.00
Noise Pollution Reduction	$308.46
Water Pollution Reduction	$51.78
Traffic Congestion Reduction	$2,423.60
Infrastructure Damage Cost Reduction	$566.24
Accident Cost Reduction	$3,194.75
Electricity Tax Revenue	$77.11
Shipment Revenue	$55,081.91
Total	**$81,202.85**

Table 5-9 Present Value of the Costs for a Container Size UFT from the Port of Houston to City of Lancaster (near Dallas)

Costs	Present (2016) Value of Costs ($Million)
Fuel Tax Revenue Loss	$1,520.26
Tire Tax Revenue Loss	$99.15
Maintenance of Tunnel	$6,105.35
LIM Power Consumption	$881.70
LIM Maintenance	$32.75
Tunnel Construction	$11,651.64
Handlers	$8.80
Administrative Cost	$181.08
Freight Vehicles	$1,014.13
LIM	$12.50
Terminal Land	$1.43
Terminal Development	$10.05
Total	**$21,518.84**

Benefit-cost analysis results show that the NPV of the system for this alternative is about $59.7 billion for the 100-year life cycle. The benefit-cost ratio and internal rate of return of the system are about 3.77 and 12.4%, respectively.

5.6.1.2 Benefit-Cost Analysis of Container Size UFT from the Port of Houston To an Inland Satellite Distribution Center in Baytown

Cash flows of the benefits and costs for having a container size UFT from the Port of Houston to a satellite distribution center were determined. The present values of the benefits and costs are presented in Tables 5-10 and 5-11, respectively.

Table 5-10 Present Value of the Benefits for a Container Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Benefits ($Million)
Air Pollution Reduction	$1,169.94
Noise Pollution Reduction	$18.51
Water Pollution Reduction	$3.11
Traffic Congestion Reduction	$145.42
Infrastructure Damage Cost Reduction	$33.97
Accident Cost Reduction	$191.69
Electricity Tax Revenue	$4.63
Shipment Revenue	$3,304.91
Total	**$4,872.17**

Table 5-11 Present Value of the Costs for a Container Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Costs ($Million)
Fuel Tax Revenue Loss	$91.22
Tire Tax Revenue Loss	$5.95
Maintenance of Tunnel	$366.32
LIM Power Consumption	$52.88
LIM Maintenance	$1.96
Tunnel Construction	$699.10
Handlers	$8.80
Administrative Cost	$181.08
Freight Vehicles	$60.82
LIM	$0.75
Terminal Land	$2.22
Terminal Development	$10.05
Total	**$1,481.14**

Benefit-cost analysis results show that the NPV of the system for this alternative is about $3.4 billion for the 100 year's life cycle. The benefit-cost ratio and internal rate of return of the system are about 3.3 and 11.6%, respectively.

5.6.1.3 Benefit-Cost Analysis of Crate Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Cash flows of the benefits and costs for having a crate size UFT from Port of Houston to an inland satellite distribution center were determined. The present values of the benefits and costs are presented in Tables 5-12 and 5-13, respectively.

Table 5-12 Present Value of the Benefits for a Crate-Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Benefits ($Million)
Air Pollution Reduction	$408.02
Noise Pollution Reduction	$6.45
Water Pollution Reduction	$1.08
Traffic Congestion Reduction	$50.71
Infrastructure Damage Cost Reduction	$11.85
Accident Cost Reduction	$66.85
Electricity Tax Revenue	$1.61
Shipment Revenue	$1,660.72
Total	**$2,207.30**

Table 5-13 Present Value of the Costs for a Crate Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Costs ($Million)
Fuel Tax Revenue Loss	$31.81
Tire Tax Revenue Loss	$2.07
Maintenance of Tunnel	$235.93
LIM Power Consumption	$29.86
LIM Maintenance	$1.96
Tunnel Construction	$450.25
Handlers	$4.48
Administrative Cost	$318.74
Freight Vehicles	$43.28
LIM	$0.75
Terminal Land	$2.20
Terminal Development	$6.55
Total	**$1,127.89**

Benefit-cost analysis results show that the NPV of the system for this alternative is about $1.1 billion for the 100-year life cycle. The benefit-cost ratio and internal rate of return of the system are about 1.96 and 6.44%, respectively.

5.6.1.4 Benefit-Cost Analysis of the Pallet Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Cash flows of the benefits and costs for having a pallet size UFT from Port of Houston to a satellite center located inland were determined. The present values of the benefits and costs are presented in Tables 5-14 and 5-15, respectively.

Table 5-14 Present Value of the Benefits for the Pallet Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Benefits ($Million)
Air Pollution Reduction	$245.69
Noise Pollution Reduction	$3.89
Water Pollution Reduction	$0.65
Traffic Congestion Reduction	$30.54
Infrastructure Damage Cost Reduction	$7.13
Accident Cost Reduction	$40.25
Electricity Tax Revenue	$0.97
Shipment Revenue	$743.61
Total	**$1,072.73**

Table 5-15 Present Value of the Costs for the Pallet Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown

Costs	Present (2016) Value of Costs ($Million)
Fuel Tax Revenue Loss	$19.16
Tire Tax Revenue Loss	$1.25
Maintenance of Tunnel	$165.00
LIM Power Consumption	$16.43
LIM Maintenance	$1.96
Tunnel Construction	$314.90
Handlers	$4.48
Administrative Cost	$318.74
Freight Vehicles	$18.55
LIM	$0.75
Terminal Land	$0.90
Terminal Development	$4.64
Total	**$866.75**

Benefit-cost analysis results show that the NPV of the system for this alternative is about $0.2 billion for the 100-year life cycle. The benefit-cost ratio and internal rate of return of the system are about 1.24 and 3%, respectively.

5.6.1.5 Benefit-Cost Analysis of the Container Size UFT for the Border between the U.S. and Mexico in Laredo, TX

Cash flows of the benefits and costs for having a container size UFT for Laredo Border were determined. The present values of the benefits and costs are presented in Tables 5-16 and 5-17, respectively.

Table 5-16 Present Value of the Benefits for the Container Size UFT System for the Border Between the U.S. and Mexico in Laredo, TX

Costs	Present (2016) Value of Benefits ($Million)
Air Pollution Reduction	$311.98
Noise Pollution Reduction	$4.94
Water Pollution Reduction	$0.83
Traffic Congestion Reduction	$89.36
Infrastructure Damage Cost Reduction	$9.06
Accident Cost Reduction	$51.12
Electricity Tax Revenue	$1.23
Shipment Revenue	$881.31
Total	**$1,349.83**

Table 5-17 Present Value of the Costs for the Container Size UFT for the Border Between the U.S. and Mexico in Laredo, TX

Costs	Present (2016) Value of Costs ($Million)
Fuel Tax Revenue Loss	$24.32
Tire Tax Revenue Loss	$1.58
Maintenance of Tunnel	$97.69
LIM Power Consumption	$14.54
LIM Maintenance	$0.52
Tunnel Construction	$186.43
Handlers	$8.80
Administrative Cost	$181.08
Freight Vehicles	$16.72
LIM	$0.20
Terminal Land	$1.59
Terminal Development	$10.05
Total	**$543.53**

Benefit-cost analysis results show that the NPV of the system for this alternative is about $0.8 billion for the 100-year life cycle. The benefit-cost ratio and internal rate of return of the system are about 2.48 and 9.92%, respectively.

5.7 CHAPTER SUMMARY

Table 5-18 summarizes the calculated economic measures for all five UFT alternatives. The values of NPV and benefit-cost ratio of each system along with the comparison of the system internal rate of return with the discount rates clearly show the economic viability of each proposed UFT alternative.

Table 5-18 Summary of Calculated Economic Measuresfor Various Designed UFTs with Discount Rate of 1.5

Alternative	NPV	BC Ratio	IRR
Container Size UFT from Port of Houston to City of Lancaster (near Dallas)	$59.7 billion	3.77	12.44%
Container Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	$3.4 billion	3.3	11.6%
Crate Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	$1.1 billion	1.96	6.44%
Pallet Size UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	$0.2 billion	1.24	3%
Container Size UFT for the Border between the U.S. and Mexico in Laredo, TX	$0.8 billion	2.48	9.92%

This Page is Intentionally Left Blank

CHAPTER 6-STAKEHOLDER COMMITTEE

6.1 INTRODUCTION

A stakeholder committee was formed not only to provide guidance and advice to the project, but also to enable members of the committee to consider using underground freight pipelines in the future for the benefit of their organizations. To fulfill these objectives, two meetings were organized and held at the University of Texas at Arlington to obtain as much input as possible from the participating professionals from related industries.

6.1.1 Objectives

The objectives of this chapter are to present stakeholder committee selections and results of meetings as well as small group discussions. A survey of our stakeholder committee provided input for UFT implementation in Texas.

6.2 METHODOLOGY

6.2.1 Stakeholder Committee

Stakeholder committee members were chosen from any entity, association, organization, company, or affiliate, who could benefit from involvement in a UFT project. Membership came from government agencies (state, regional, and local), port and airport authorities, manufacturers, academia and research institutions, freight companies, professional associations and other organizations with potential benefits from UFT. Of the 124 emailed and mailed invitations sent to potential members of the stakeholder committee for UFT, 47 respondents became members of this organization. Table 6-1 shows the list of Stakeholder Committee members categorized by their organizations.

Table 6-1 List of Stakeholder Committee Members (Categorized by Oganization Type)

Type of Organization	Name	Organization
Agencies	Dennis Abraham	Dallas County
	Steve Boecking	Hillwood, Alliance Texas
	Heath Bozeman	TxDOT
	George Davis	Missouri DOT
	Kelly Davis	Trinity River Authority of Texas
	Chris Glancy	TxDOT
	Jeff Hathcock	NCTCOG
	Dan Lamers	NCTCOG
	Steve Linhart	TxDOT
	Eduardo Mendoza	City of McAllen
	Santos Reyes	City of Laredo
Companies	Abu Abraham	Instituform Technologies , LLC
	Sam Arnaout	Forterra Pressure Pipe
	Josh Beakley	American Concrete Pipe Association
	Stephen Catha	Touchstone Technology
	Walter Chiang	CP&Y, Inc.
	Anthony Cisneros	HEB
	Randel Dobbs	Uni-Bell PVC Pipe Association
	Hassan Elsaad	Salt River Project Company
	Jalal Feghhi	Jumbula
	Glen Jones	Texas Farm Bureau
	Gerhard Lang	Herrenknecht AG
	Eduard Popa	Bombardier
	Richard Mueller	American Concrete Pressure Pipe Association
	Rudy Renda	Oscar Renda Contracting
	Brink Weaver	Pneutrans Systems Ltd.
Freight	Paul Cristina	BNSF Railway
	Richard T. Doarn	J.B. Hunt
	Les Fendeisen	Texas Trucking Association
	Reza Rostami	Pan World Trans
	Rick Wilson	BNSF Railway
Airports and Ports	Donna Eymard	Port of Brownsville
	Bruce Mann	Port of Houston Authority
	Greg J. Royster	DFW International Airport

Type of Organization	Name	Organization
	Olivia Varela	Laredo Development Foundation
	Mark Witte	DFW International Airport
Academic and research	James Bryant	TEAL Transportation
	Yiquan Fan	Shanghai Municipal Engineering Design Institute
	Robert O'Connell	University of Missouri
	Gou Dongjun	Research Center for Underground Space
	Bill Loose	Mole Solutions Ltd.
	Baosong Ma	China-U.S. Joint Center for Trenchless R&D
	Roger Miles	Mole Solutions Ltd.
	Curtis Morgan	Texas A&M Transportation Institute (TTI)
	Jeff Warner	Texas A&M Transportation Institute (TTI)
	Zhu Wenjun	Tsinghua University
	Mark Wilkerson	Consultant

6.2.2 First Stakeholder Committee Meeting

On Thursday, July 30, 2015, the first stakeholder committee meeting was held at the University of Texas at Arlington from 9:00 AM to 12:00 Noon. This meeting included 33 stakeholders attending in person or through the Web conference. Tables 6-2 and 6-3, and Figure 6-1 show the categories of organizations participated at the first stakeholder meeting.

Table 6-2 Stakeholders Attending the First Stakeholder Committee Meeting In-person

No.	First	Last Name	Organization
1	Dennis	Abraham	Dallas County
2	Sam	Arnaout	Hanson Pressure Pipe
3	Josh	Beakley	American Concrete Pipe Association
4	Steve	Boecking	Hillwood. Alliance Texas
5	Stephen	Catha	Touchstone Technology
6	Kelly	Davis	Trinity River Authority of Texas
7	Richard T.	Doarn	JB Hunt
8	Randel	Dobbs	Uni-Bell PVC Pipe Association
9	Les	Findeisen	Texas Trucking Association
10	Chris	Glancy	TxDOT
11	Glen	Jones	Texas Farm Bureau
12	Bruce	Mann	Port of Houston Authority
13	Richard	Mueller	American Concrete Pressure Pipe Association
14	Robert M.	O’Connell	University of Missouri
15	Greg J.	Royster	DFW International Airport
16	Olivia	Varela	Laredo Development Foundation
17	Mark	Wilkerson	Consultant
18	Rick	Wilson	BNSF Railway
19	Mark	Witte	DFW International Airport

Table 6-3 Stakeholders Attending the First Stakeholder Committee Meeting through Web

No.	First Name	Last Name	Organization	Country
1	Abu	Abraham	Instituform Technologies, LLC	USA
2	Heath	Bozeman	TxDOT	USA
3	George H.	Davis	Missouri DOT	USA
4	Guo	Dongjun	Research Center for Underground Space	China
5	Donna	Eymard	Port of Brownsville	USA
6	Yiqun	Fan	Shanghai Municipal Engineering Design Institute	China
7	Steve	Linhart	TxDOT	USA
8	Bill	Loose	Mole Solutions Ltd.	UK
9	Eduardo J.	Mendoza	City of McAllen	USA
10	Curtis A.	Morgan	Texas A&M Transportation Institute (TTI)	USA
11	Santos	Reyes	City of Laredo	USA
12	Jeff	Warner	Texas A&M Transportation Institute (TTI)	USA
13	Brink	Weaver	Pneutrans Systems Ltd.	Canada
14	Zhu	Wenjun	Tsinghua University	China

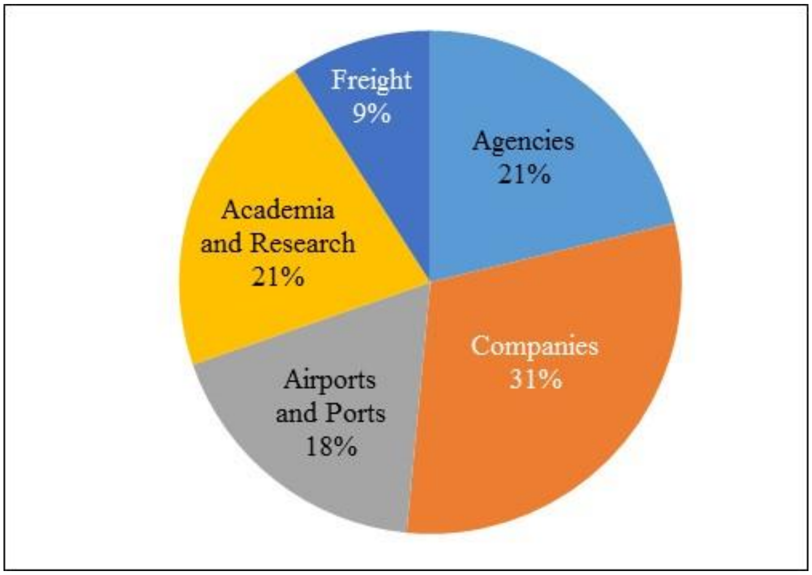


Figure 6-1 Categories of Organizations for the First Stakeholder Meeting

6.2.2.1 Breakout Group

At the first stakeholder meeting, after an introduction to the project's background and objectives by the PI (Dr. Mohammad Najafi) and Co-PI (Dr. Siamak Ardekani), each stakeholder member joined one of four smaller groups based on their organizational type to share their opinions and generate ideas about UFT in general, the proposed routes, size of freight industry, demands, and need to expand, financial means, feasibility of UFT project and project challenges. Below is a summary of the discussions.

Group 1 Discussed Issues:

- Applicability of the project to urban and rural areas.
- Accessing public support, since the cost of land is an important factor.
- Consideration of increase in Texas population and congestion for past 40 years.
- How UFT benefits can best serve all constituencies.
- How UFT can be integrated or incorporated into the existing highway systems.
- How to convince public to follow the project as a way to combine modes of freight transportation without above-ground interference with established routes.
- Need for public education about the potential of UFT.
- Need for more research on possible ways to transport freight using UFT as a way to cut down on a trucker's trip duration and cost of gasoline, and avoidance of congested areas.
- Need for preliminary study on the capacity of containers in port of Houston.
- Ways to network UFT with freight transportation by air, trucks, rails, etc.
- Need for smart system to move small freight automatically (up to 20 tons).
- How UFT can help reduce truck congestion at airports.
- How UFT can benefit freight transportation system at airports.
- Appropriate sizes of containers for different application.

Group 2 Discussed Issues:

Project implementation pros and cons at Laredo border:

- Union Pacific and Kansas City major terminals.
- Freight transportation is growing 10% per year.
- A road between Laredo to ports of Corpus Christi and Houston can be considered.
- Tunnel at border crossing is not beneficial as UFT would transfer the delays from one point to a different point.

Project implementation pros and cons from Port of Houston to Dallas:

- Most likely not cost effective.
- Better potential to connect the port to nearby satellite locations.
- Houston has many underground infrastructures, which makes it very expensive to tunnel.
- Road damage can be considered.

Project implementation pros and cons at DFW Airport to off-site warehouses:

- Possibility for smaller size pallet tunnels
- Most freight terminals such as FedEx, NW: UPS are on the north side of the airport.
- Security of trucks coming to airport is not an issue.

Group 3 Discussed Issues:

- Indicated that the financing of 250 miles is not a good idea at this point
- Considered putting tunnels in urban areas and surface railway in rural areas.
- The size of trucks is big enough to justify the cost of the driver.
- P3 financing method is an appropriate approach towards financing.
- Less than 500 mile-range is covered by long-haul trucks and actually is cheaper than rail.
- Operation benefits can justify UFT investment cost.
- A short haul distance (under 40 miles) is preferred over a long haul distance for UFT implementation. An example of a short haul distance could be the distance between the port of Houston and an intermodal distribution center.
- Indicated the depth of tunnel should be at least 120 ft.
- It is critical to know what kind of freight will be transported through the system (food, medicines, etc.).
- Twin-bore tunnels are preferred over a single-bore twin-track tunnel because of redundancy and constructability.
- 45 MPH speed makes more sense for short hauls.
- Considered tube stations as a way to supplement or support long hauls.

Group 4 Discussed Issues:

- Considered soils and geological concerns (e.g., combinations of groundwater and difficult soil conditions) as important parameters when designing and constructing UFT.
- In some parts we have Austin Chalk Soil—especially around the Lancaster area—which would increase costs of tunnel construction.
- Difficulty of tunnel construction for some isolated areas should be factored into cost considerations, even for short-haul systems.
- Currently, the modern long-freight trains are possible without damaging couplings because of computerized and distributed power.
- Long automobile traffic delays at railroad crossings that are caused by the extremely long trains can be eliminated by building low-cost bridge.
- Trucks may be required for transition between UFT and railroad as well as from railroad terminal to consumers.
- The short-haul is preferred over the long-haul of Houston to Dallas.
- Because of some international political considerations, the Laredo border crossing may not be feasible.
- It was recommended to look further at connections between Barbour's Cut Container Terminal to one or more distribution centers.

- The proposed airport UFT line could be placed mostly within airport grounds due to safety, financing, and right-of-way considerations.
- The airport application, the Alameda Corridor System-as the LAX system-was stated as a possible model.
- Using channels along with tunnels can reduce construction costs.
- UFT system should operate continuously, i.e., 24/7 to be cost effective.
- The significant focus should be given to the airport application.

Following the brainstorming session, all the participants were asked to rank the issues from 0 to 100 with the total number of points not exceed 1,000. Table 6-4 shows the issues and total ranking scores provided by participants based on the instructions provided. The highest ranking issues were determined as the most important for the UFT project. Table 6-5 shows the top ten issues of the first meeting, which provided useful input for the next stakeholder meeting.

Table 6-4 Issues Raised by the Stakeholders

Issue	Title	Ranking Score
1	Look at the needs for the project in 25 years.	1,575
2	Short haul distances are preferred over long hauls.	1,275
3	Potential to connect Port of Houston to nearby satellite locations.	836
4	Safety and security of freight transportation.	836
5	Having two tunnels is better than having a large tunnel due to the redundancy that it creates (If the costs of two options are comparable).	825
6	Private funding should be included as part of project financing.	761
7	Educate public to get their support.	686
8	Freight movement inside DFW Airport.	675
9	The location should be considered in cost estimating because we need to consider prices not just costs.	675
10	Automated use of UFT should be taken in account.	561
11	Port of Houston to Dallas route is most likely not cost effective.	525
12	Consider population increasing.	511
13	Life cycle cost for all modes of transportation should be considered.	500
14	Priorities in application (airport to a distribution center)	461
15	DFW Airport has the possibility for small size pallet tunnels.	425
16	Future congestion should be considered.	386
17	Driverless trucks might be an intermodal system.	361
18	Emphasis on domestic applications over international (Laredo border).	321
19	Tunnels at border are not beneficial as they would transfer the delay from one point to another point.	311
20	Considered road damage.	311
21	Looking at short-haul rail operations, including the I45 corridor.	275
22	Alternative routes to connect Laredo to Port of Corpus and Houston.	236
23	Future land development may not allow any increase in surface transportation.	161
24	Freight growing 10% annually in Laredo.	111
25	Details of various applications (airport to a distribution center 24/7 per day).	111
26	Security of trucks coming to airport.	11

Table 6-5 Top Ten Issues from the First Stakeholder Committee Meeting

Issues	Title
1	Look at the needs for the project in 25 years
2	Short haul distance is preferred over long hauls.
3	Safety and security
4	Potential to connect Port of Houston to nearby satellite locations
5	Having two tunnels is better than having a large tunnel.
6	Private contribution funding for financing the project
7	Educating the public
8	The location should be considered in cost estimating.
9	Freight movement inside DFW Airport
10	Automated use of UFT

6.2.2.2 First Stakeholder Meeting Summary

In their comments and discussions, stakeholders saw the need for the UFT system in 25 years as the most important issue to be considered. Furthermore, they believe that short haul distances are more applicable in terms of productivity and constructability. Members suggested having a meeting at UTA before end of the year, in late October-early November timeframe

6.2.3 Second Stakeholder Committee Meeting

On Wednesday, December 9, 2015, the 2nd Stakeholder Committee meeting of the TxDOT 0-6870 project was held at the University of Texas at Arlington from 9:00 AM to 2:00 PM. Like the previous meeting, 25 stakeholders attended the meeting in-person or through the Web. Figure 6-2 and Tables 6-6 and 6-7 present categories of organizations and a list of stakeholders, who participated at the second stakeholder meeting.

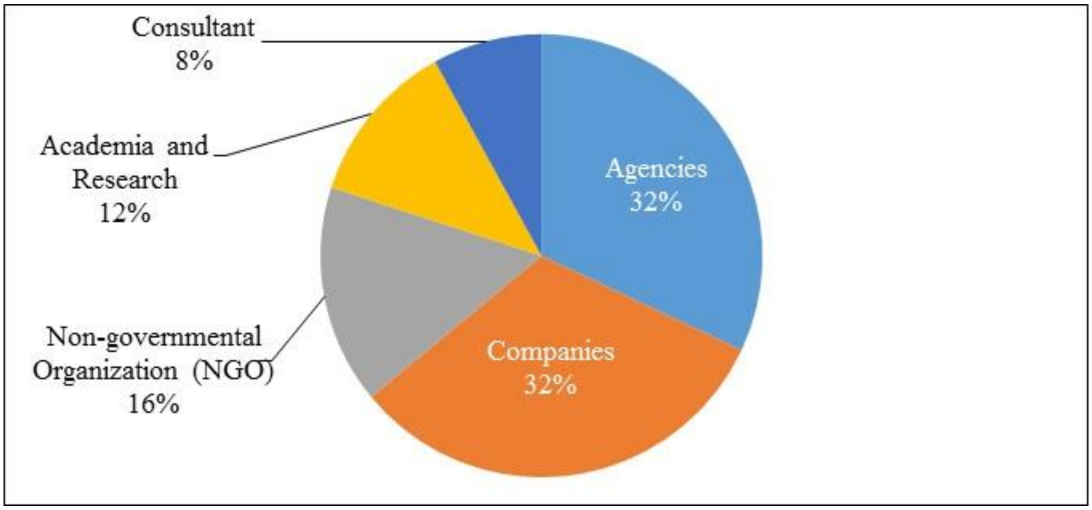


Figure 6-2 Categories of Organizations for the Second Stakeholder Meeting

Table 6-6 Stakeholders Attending The Second Stakeholder Committee Meeting In-person

No.	First Name	Last Name	Organization
1	Abu	Abraham	Insituform Technologies, LLC
2	Dennis	Abraham	Dallas County
4	Josh	Beakley	American Concrete Pipe Association
3	Anthony	Cisneros	HEB
5	Kelly	Davis	Trinity River Authority of Texas
6	Hassan	Elsaad	Salt River Project
7	Jalal	Feghhi	Jumbula
8	Les	Findeisen	Texas Trucking Association
9	Jeff	Hathcock	NCTCOG
10	Glen	Jones	Texas Farm Bureau
11	Dan	Lamers	NCTCOG
12	Reza	Rostami	Pan World Trans
13	Greg J.	Royster	DFW International Airport
14	Mark	Wilkerson	Consultant
15	Mark	Witte	DFW International Airport

Table 6-7 Stakeholders Attending The Second Stakeholder Committee Meeting through Web

No.	First Name	Last Name	Organization	Country
1	Sam	Arnaout	Forterra Pressure Pipe	USA
2	James R.	Bryant	TEAL Transportation	USA
3	Stephen	Catha	Touchstone Technology	USA
4	Dongjun	Guo	Research Center for Underground Space	China
5	Donna	Eymard	Port of Brownsville	USA
6	Yiqun	Fan	Shanghai Municipal Engineering Design Institute	China
7	Roger	Miles	Mole Solutions Ltd.	UK
8	Jeff	Warner	Texas A&M Transportation Institute (TTI)	USA
9	Brink	Weaver	Pneutrans Systems Ltd.	Canada
10	Wenjun	Zhu	Tsinghua University	China

6.2.3.1 Methodology of the 2nd Stakeholder Committee Meeting

The objective of the second stakeholder committee meeting was to obtain as much input as possible from the participants of different organizations. To accomplish this, we asked them to:

- Present and review updates on UFT study progress.
- Complete a brief questionnaire (survey).

Survey. Stakeholders were asked to complete a survey and share their ideas about UFT in general, the proposed routes, size of freight (containers, crates and pallets), financial means (funding opportunities and investment potential), constructability and feasibility of UFT project and project challenges. Face-to-face attendees completed the survey at the meeting and the Web participants were asked to email the survey.

Survey Analysis. The survey included three major types of questions: multiple choice, essay, and ranking. Under each question, a comment box was included so the respondents could provide their feedback. Multiple choice questions were analyzed and presented in a pie chart format. In ranking questions, to be able to make comparison among provided options, weights were assigned to the options based on their degree of desirability. Then weighted average was calculated for each alternative. The option that received the highest weighted average score was determined as the most desirable answer. Stakeholder comments are quoted below with minor editing to preserve the intentions of the committee member. Questions, answers and documentation are as follows:

1. Do you think that UFT will be cost effective and competitive with other modes of freight transportation?

   Total Number of Responses: 15

   Table 6-8 and Figure 6-3 show that the majority of the respondents believe that UFT is cost effective and competitive with other modes of transportation.

Table 6-8 Cost Effectiveness of UFT

Answers	No. of Responses	Percentage (%)
Yes	12	80
Maybe	3	20
No	0	0

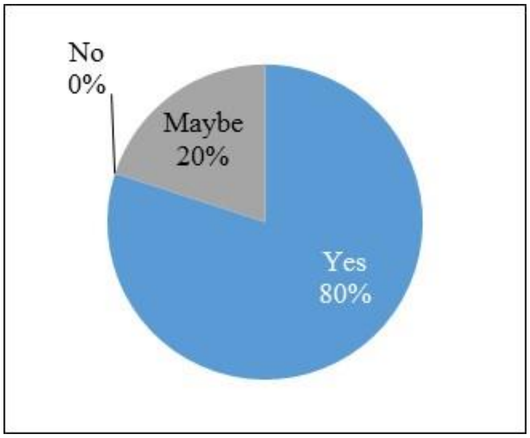


Figure 6-3 Cost Effectiveness of UFT

Comments:

- Dependent upon available capacity of existing system, i.e., railroad. If no available capacity – yes. I feel UFT could be cost effective in long run.
- Initial funding is potentially difficult.
- In the long term, railroad network and operational constraints are insufficient to handle future needs.
- UFT system has the potential to be cost effective. However, private interest needs to be sought.
- It has potential. The long-term must be considered, including pollution and safety concerns that are hard to put a cost on.
- I think there is a market for UFT. Based on your presentations, it seems feasible.

2. Do you foresee UFT to be a part of inter-modal freight transportation in (pick one):

Total Number of Responses: 15

Table 6-9 and Figure 6-4 show that the majority of respondents believed that UFT would be a part of intermodal freight transportation system in less than 20 years.

Table 6-9 UFT Expected Construction Date

Answers	No. of Responses	Percentage (%)
15 Years	5	33
20 Years	5	33
10 Years	3	20
5 Years	1	7
40 Years	1	7

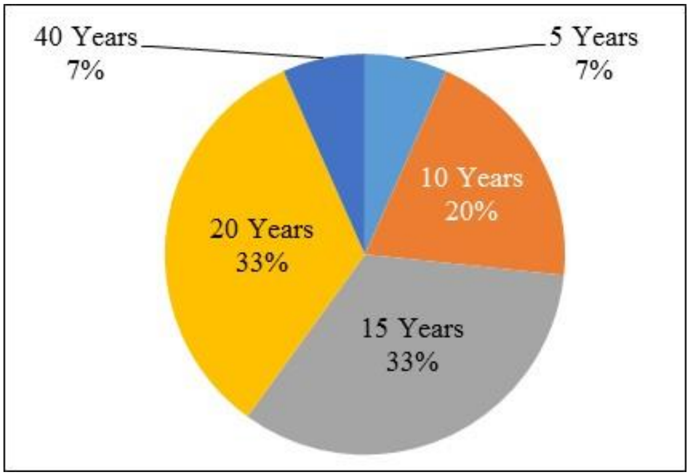


Figure 6-4 UFT Expected Construction Date

Comments:

- Political constraints and financing will be challenges.
- As we become more connected, can see it becoming more feasible.
- On a smaller scale, UFT will be feasible. Large scale (Dallas to Houston) would be further off due to public policy.
- Anticipate land rights acquisition to take additional time for negotiation.
- It should be 5-10 Years.

3. For the following, please rank from 1 to 5, with 1 being the least and 4 being the largest challenge for UFT:

   Total Number of Responses: 15

Table 6-10 and Figure 6-5 show the weighted average score for each factor. Based on the survey results, financing is the most challenging factor which affects UFT with cost of constructing UFT the second challenge.

Table 6-10 UFT Challenges

Answers	Ranking Score	Percentage (%)
Financing	58	27
Cost	52	24
Socio-political	45	21
Constructability	31	15
Operation	28	13

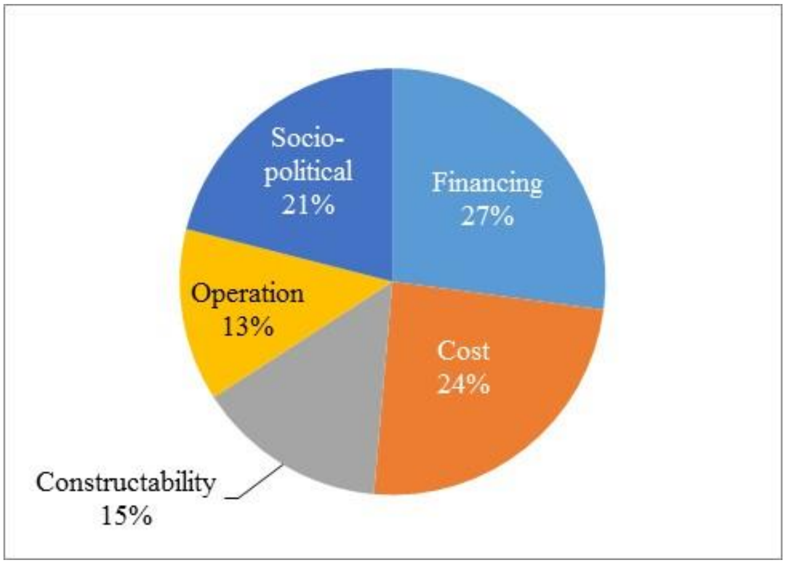


Figure 6-5 UFT Challenges

4. Among the following, please rank your preference from 1 to 9, with 1 being the least and 9 being the most obstacles for construction of UFT:

Total Number of Responses: 13

From Table 6-11 and Figure 6-6 it is concluded that tunnel construction and underground water control are the most important obstacles involved with UFT followed by cut-and-cover construction and existing utility relocation.

Table 6-11 UFT Construction Obstacles

Answers	Ranking Score	Percentage (%)
Tunnel Construction	77	16
Underground Water Control	73	15
Cut-and-cover Construction	56	12
Existing Utility Relocation	55	11
Spoil Removal	54	11
Excavation Support	54	11
Soil Conditions	51	10
Easement Availability	41	8
Access Shaft Construction during Tunnel Construction	33	6

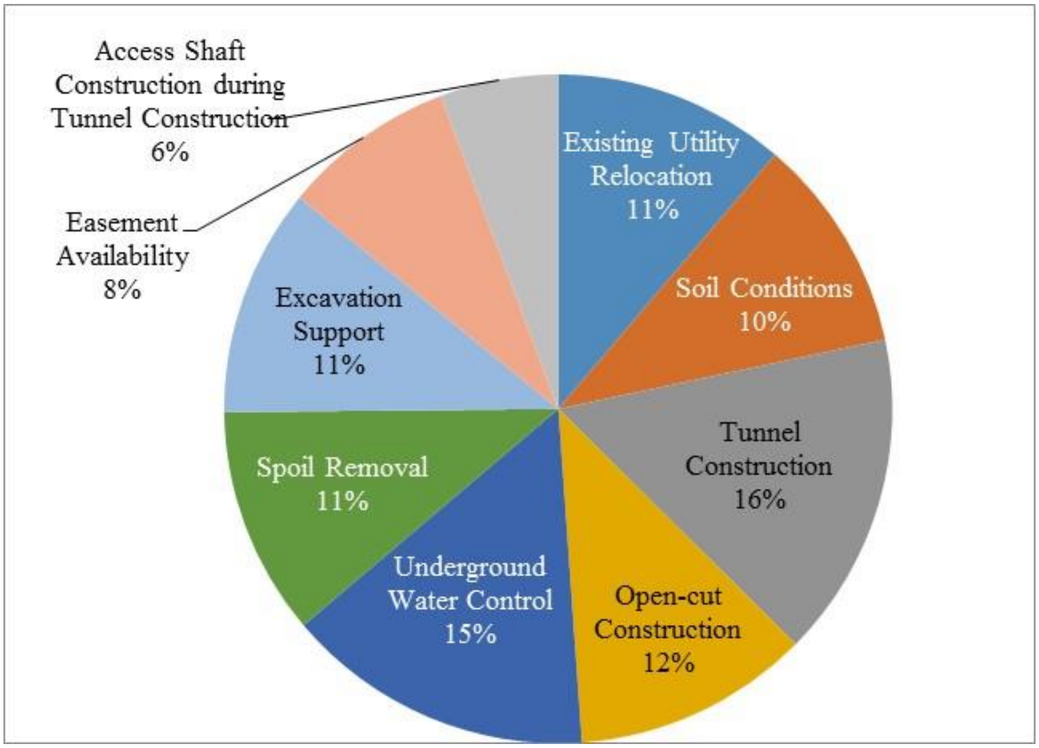


Figure 6-6 UFT Construction Obstacles

5. What size UFT is most effective with choices numbering from 1 to 3, with 1 being the least and 3 being the most:

Total Number of Responses: 13

Table 6-12 and Figure 6-7 show that Large UFT is the most appropriate size for UFT shipments. Medium UFT size was ranked the second most appropriate.

Table 6-12 Applicable UFT Sizes

Answers	Ranking Score	Percentage (%)
Large	31	49
Medium	21	35
Small	10	16

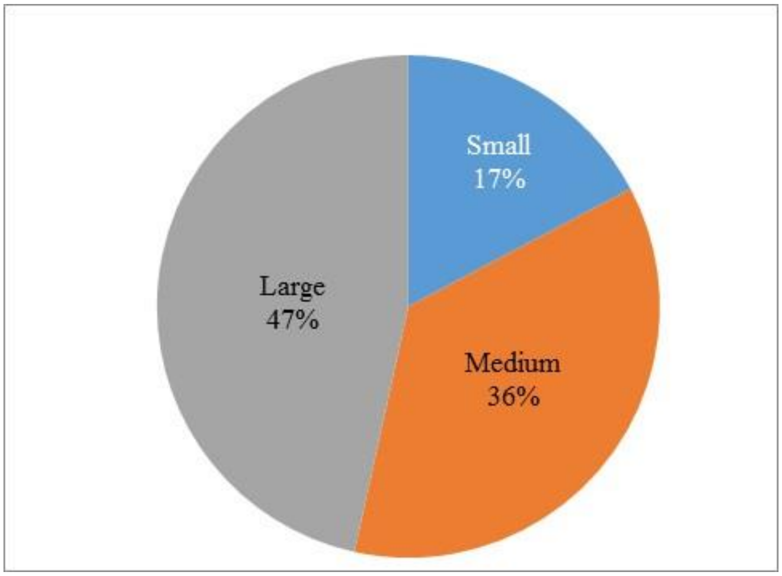


Figure 6-7 Applicable UFT Sizes

Comments:

- It is dependent on route (short or long).
- For UFT to be feasible, container shipment must be accommodated (pallets, containers, crates).
- According to freight type and the needs for UFT.
- Higher value commodities should be the focus.
- Build the large size once and for all purposes.

6. In Texas, what routes might be a suitable candidate for the UFT? Please rank from 1 to 4, with 1 being the least and 4 being the most suitable:

Total Number of Responses: 13

As shown in Table 6-13 and Figure 6-8, the Port of Houston route to a distribution center in Dallas ranked as the most suitable followed by DFW to a distribution center within 10 miles.

Table 6-13 Applicable UFT Routes

Answers	Ranking Score	Percentage (%)
Port of Houston to a Distribution Center in Dallas	42	32
DFW to a Distribution Center within 10 miles	33	25
The Border with Mexico at Laredo	29	23
Port of Houston to a Distribution Center outside of Houston	26	22

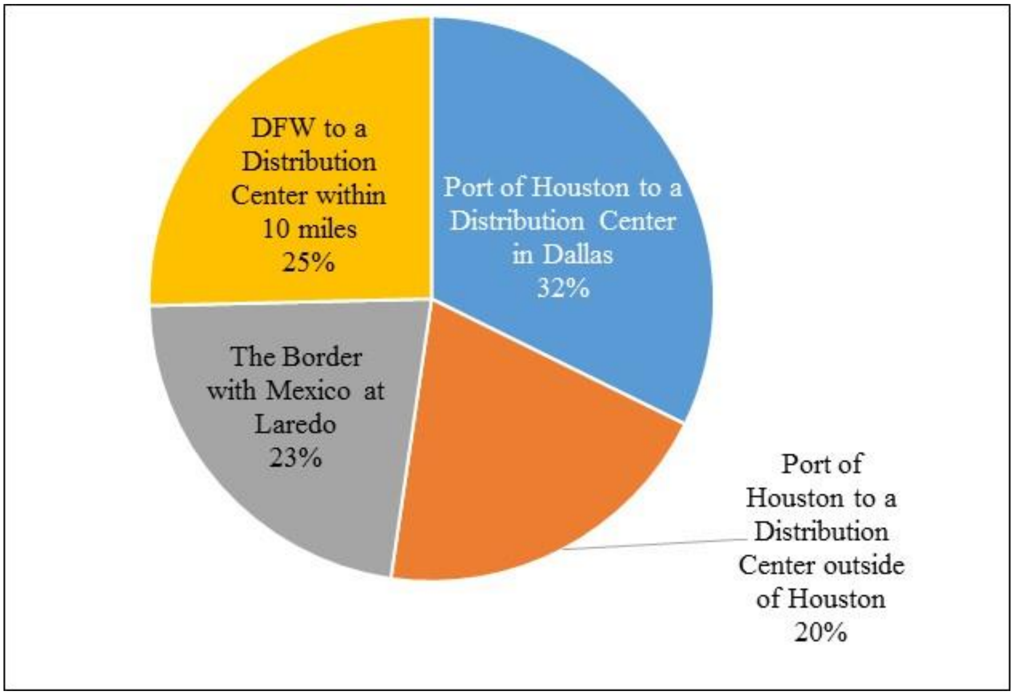


Figure 6-8 Applicable UFT Routes

Comments:

- Do it once and complete the whole project.
- Do not know more about Texas, but I did similar work for Shanghai, China. We think that the first UFT route should be better if it is in small scale.

7. Please give us your suggestions for additional routes that might be a candidate for UFT.

- I like the suggestion for using it internally in the DFW airport.
- Yours look okay.
- IH-35, Laredo to Dallas
- 35 E. Because it is the designated NAFTA corridor.
- Dallas – Laredo- Bonita/Mexico

8. What type of delivery method might be most suitable for constructing and operating the UFT? Please rank from 1 to 4, with 1 lowest and 4 highest.

Total Number of Responses: 14

After analyzing the responses and calculating the weighted average scores for each financing method, as shown in Table 6-14 and Figure 6-9 and, Public Private Partnership (P3) was selected as the most appropriate financing method followed by Public-Public financing method.

Table 6-14 Applicable Financing Methods

Answers	Ranking Score	Percentage (%)
P3	16	39
Public-Public	10	24
Private	8	20
Public	7	17

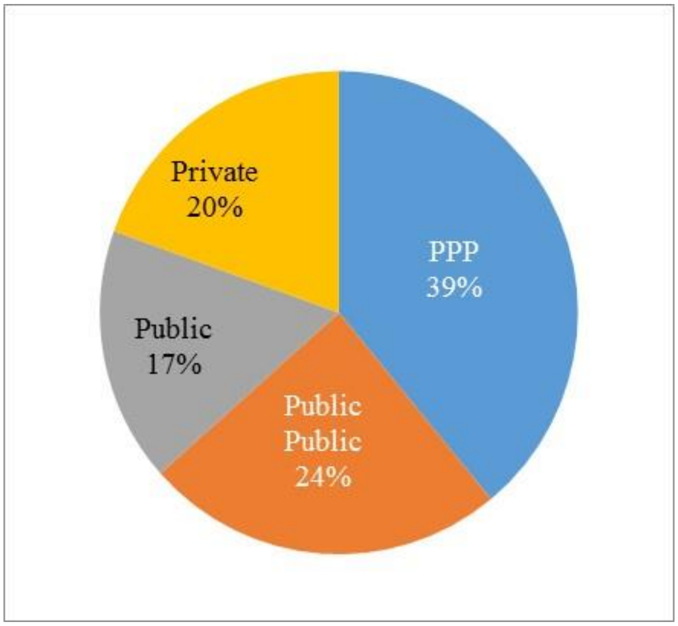


Figure 6-9 Applicable Financing Methods

Comments:

- Amazon (Jeff Bezos) might be interested.
- Public only funds would not be possible.
- Must use all financing tools available. TxDOT is very familiar with multiple means of financing, i.e., LBJ Express, NTE, 35 W.

9. Among the following, what will be the greatest benefits of the UFT? Please rank from 1 to 8, with 1 lowest and 8 highest.

Total Number of Responses: 15

Table 6-15 and Figure 6-10 illustrate the most important benefits of UFT. Reducing traffic congestion, improving freight capacity and enhancing highway safety are the most important benefits of UFT.

Table 6-15 Benefits of UFT

Answers	Ranking Score	Percentage (%)
Reducing Traffic Congestion	94	18
Improving Freight Capacity	82	16
Enhancing Highway Safety	81	15
Reducing Fuel Consumption	62	12
Increasing Reliability	64	12
Improving Safety	62	12
Better Design Life	41	8
Reducing Damage to Pavement	39	7

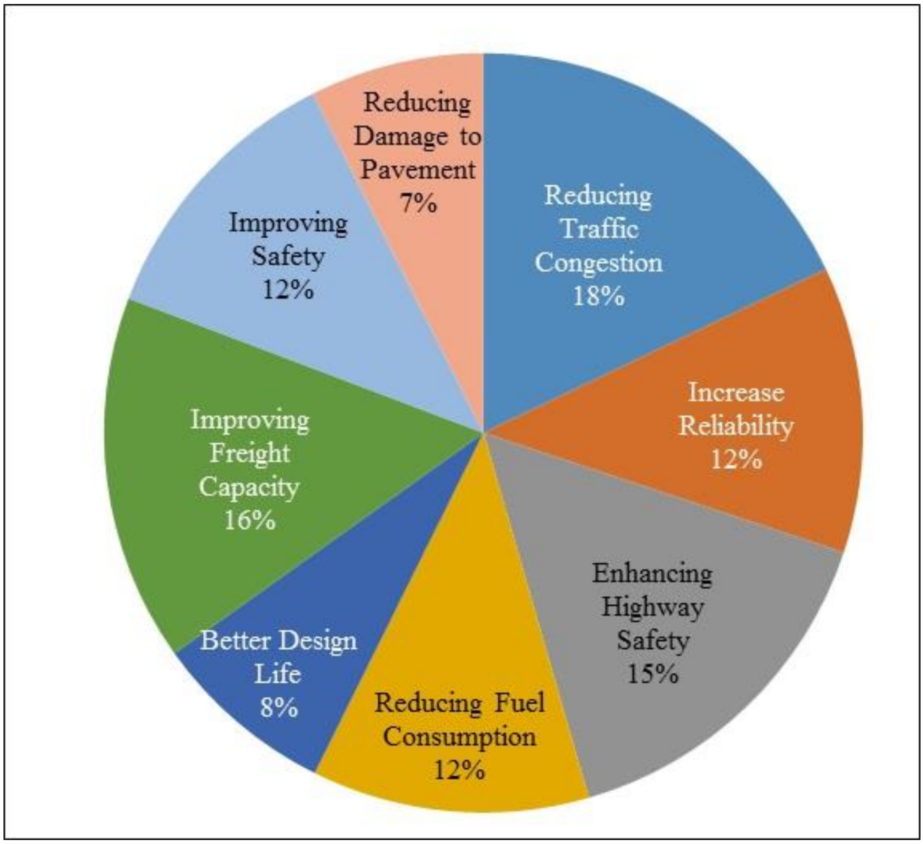


Figure 6-10 Benefits of UFT

10. What delivery method might be most suitable for constructing and operating the UFT? Please rank from 1 to 4, with 1 lowest and 4 highest

Total Number of Responses: 12

Table 6-16 and Figure 6-11 show the applicable delivery methods for construction of UFT. Design-Build-Operate and Maintenance (DBOM) is ranked the most suitable followed by Design-Bid-Build (DBB) and Design-Build (DB).

Table 6-16 Applicable Delivery Methods

Answers	Score	Percentage (%)
Design-Build-Operate-Maintain (DBOM)	12	31
Design-Bid-Build (DBB)	11	28
Design-Build (DB)	10	26
Build-Operate-Transfer (BOT)	6	15

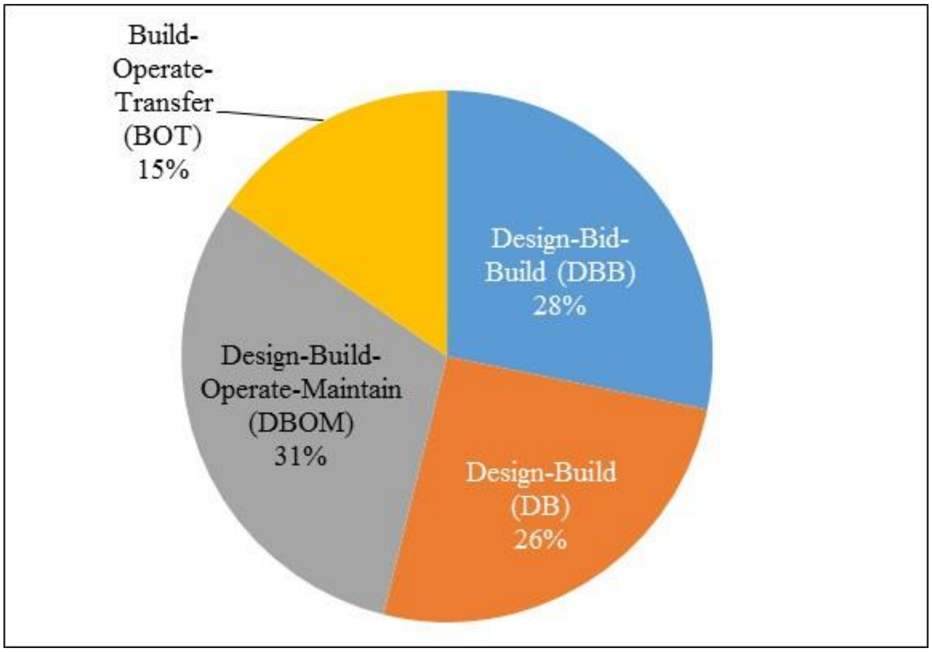


Figure 6-11 Applicable Delivery Methods

Comments:

- If you are going to maintain, you will build it right the first time.

11. Please give your comments and suggestions, including mention of any weakness or strengths, for each of the Project Tasks presented today:

Task 1– Planning and Design:

Strengths	Weaknesses
1. Cost effective @ $10B. 2. Usage of existing ROW 3. TBM Construction 4. Good design. Need to keep in mind expanding capacity. 5. Well-planned 6. Very comprehensive 7. Well thought out design presented.	1. ROW acquisition not anticipated – very ambitious approach. Realistic to include cost and time for some ROW requirements. Relocation of existing utilities in conflict. 2. More focus needs to be placed on problems with equipment/freight 3. Consider alternate designs

Task 2–Construction Methods

Strengths	Weaknesses
1. Thorough discussion 2. Consideration of +/- 100 % tunneling 3. LIM technology- proven, efficient, minimum maintenance requirement.	1. Make a compelling case of using this propulsion system. 2. Maintenance/ power installation constraints along tracks.

Task 3 – Cost Analysis:

Strengths	Weaknesses
1. Thorough analysis 2. Good for this stage of the project 3. Use existing project information for comparison. 4. Great presenting work	1. Unrealistic cost for land in this region. 2. Poor soil condition in Irving affects cost of facility, slab, etc.? 3. Add cost of transporting one ton of material using road/rail/air and UFT. 4. Did not take into account all financial and administrative costs.

Task 4 – Environmental Impacts:

Strengths	Weaknesses
1. Well thought on start	1. No socio-economic analysis presented. 2. Too optimistic on benefit. 3. Effect on trucking system more than listed

Task 5 – Financial Means:

Strengths	Weaknesses
1. Support cost comparisons w/ Texas project. 2. Various delivery systems 3. Good for preliminary results.	1. Utility relocation costs at a minimum where shafts would be required. 2. ROW acquisition costs – too low, even if existing ROW used. 3. Potential conflicts 4. Need to identify real sources of funding and explore what private companies have demonstrated interest. 5. No comparison of different projects delivery/finance options! i.e., P3 vs. Public vs. Private

12. Please include your suggestions and comments for consideration in this project.

- Should compare political, public policy, and economic consequences of replacing freight movement with UFT vs. existing rail/truck. What happens to existing freight carriers?
- It is worthwhile.
- Since tunnel construction $ is the highest project cost:
    - Consider 2-3 tunneling methods that are cost sensitive.
    - Revise cost accordingly.
- Exciting new technology.
- Ambitious approach.
- Curious to see actual time-frame.

6.2.3.2 Second Stakeholder Meeting Summary

Based on the survey analysis, UFT can be an efficient, sustainable, and reliable mode of freight transportation using pipelines and tunnels. Stakeholder members provided valuable comments that will help the project team to continue with this important research. The survey results showed that stakeholders have a positive image of UFT and virtually all agree that UFT will be cost-effective and can be used with other modes of freight transportation (such as, road, rail, air, and sea). Survey results also stated that large UFT from Port of Houston to a distribution center in Dallas and large UFT size were ranked as the most appropriate options. Reducing traffic congestion, improving freight capacity and enhancing highway safety are the most important benefits of UFT.

This Page is Intentionally Left Blank

CHAPTER 7-REFERENCES

2030 Committee. (2009). “Texas Transportation Needs Summary.” Available at: http://texas2030committee.tamu.edu/documents/final_022609_execsummary.pdf (Accessed August 2015).

23 U.S.C. (2011), United States Code, 2011 Edition, Title 23 – HIGHWAYS, <https://www.gpo.gov/fdsys/pkg/USCODE-2011-title23/html/USCODE-2011-title23.htm, (Accessed Feb. 15, 2016).

AAR (2015), Association of American Railroads, https://www.aar.org/Documents/Railroad-Statistics.pdf, (Accessed Dec. 2, 2015).

AASHTO (2015a), http://www.transportation-finance.org/funding_financing/funding/ (Accessed Nov. 10, 2015).

AASHTO (2015b), http://www.transportation-finance.org/funding_financing/funding/federal_funding/, (Accessed Nov. 15, 2015).

AASHTO (2015c), http://www.transportation-finance.org/funding_financing/funding/local_funding/, (Accessed Nov. 18, 2015).

AASHTO (2016a), http://www.transportation-finance.org/funding_financing/funding/state_funding/, (Accessed Jan. 12, 2016).

AASHTO (2016d), http://www.transportation-finance.org/funding_financing/financing/, (Accessed Feb. 20. 2016).

AASHTO (2016e), http://www.transportation finance.org/funding_financing/financing/bonding_debt_instruments/municipal_public_bond_issues/pr vate_activity_bonds.aspx, (Accessed Feb. 12, 2016).

AASHTO (2016f), http://www.transportation-finance.org/funding_financing/financing/bonding_debt_instruments/municipal_public_bond_issues/revenue_bonds.aspx, (Accessed Feb. 12, 2016).

Abbas, S. (2014). “Structural and Durability Performance of Precast Segmental Tunnel Linings.” thesis, presented to The University of Western Ontario, in partial fulfillment of the requirements for the degree in Doctor of Philosophy.

Akan, G.T., Arditi, D., and Imre, M. (1984), “Priority Ranking of Highway Improvement Projects,” Construction Management and Economics, 2(1), pp. 49-55.

American Association of Port Authorities, (2013), http://www.aapa-ports.org/index.cfm (Accessed Dec 8, 2015).

Avineri, E., Prashker, J., and Ceder, A. (2000), “Transportation Projects Selection Process Using Fuzzy Sets Theory, Fuzzy Sets and Systems,” 116, pp. 35-47.

Barták, J. (2007). "Structural behavior of SFRC tunnel segments during TBM operations."

Baumgartner, J.P. (2001), Prices and Costs in the Railway Sector. École Polytechnique Fédérale de Lausanne, Available at: http://litep.epfl.ch/files/content/sites/litep/files/shared/Liens/Downloads/Divers/Baumgartner_Couts_chf_2001_e.pdf, (Accessed Nov. 15, 2015).

Becker, T. and Gerlach, J. (2012). “The True Costs of Automobility: External Costs of Cars Overview on existing estimates in EU-27,” Technische Universitat Dresden, Germany

Bennett, Robert D. (1981). Tunnel Cost-Estimating Methods. Technical Report GL-81-10. Ft. Bellvue, VA: U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory.

Bobylev, N. (2012). “Russia considers sustainable urbanization-TunnelTalk.” RSS, http://www.tunneltalk.com/conferences-jul12-underground-forum-2012-saint-petersburg.php, (Accessed Jun. 10, 2016).

Capka, J. R. (2006), “Financing Megaprojects”, FHWA Public Roads, https://www.fhwa.dot.gov/publications/publicroads/06jan/02.cfm, (Accessed May. 20, 2015).

Chatti, K., Salama, H., and El Mohtar, C. “Effect of Heavy Trucks with Large Axle Groups on Asphalt Pavement Damage.” Michigan State University.

Corporate Headquarters, (2016), Ground Freezing Brochure, http://www.moretrench.com/wp-content/uploads/2014/11/New-Ground-Freezing-Brochure, (Accessed May 8, 2016).

Dallas (2015) http://dallascityhall.com/departments/trinitywatershedmanagement/Pages/default (Accessed Dec. 23, 2015).

Lyons, Morgan (2000). “Southwest’s First Subway Station Takes DART to Another Level, DART news release, https://www.dart.org/news/news.asp?id=178, (Accessed March. 12, 2015).

Dey, K., (2014). “Minimizing Bridge and Pavement Deterioration from Large Trucks: A Policy Analysis for Damage Recovery.” Clemson University.

Donath, M., Murray, D., Short, J., (2005). “Homeland Security and the Trucking Industry,” Intelligent Transportation Systems Institute, Center for Transportation Studies, University of Minnesota.

East Area CSO Tunnels Project Schedule, http://www.cleanwateratlanta.org/csotunnels/east/documents/FactSheet.pdf, (Accessed May 17, 2016).

Eisele, W., Schrank, D., Lomax, T. (2013), “Estimating Urban Freight Congestion Costs: Methodologies, Measures, and Applications,” Transportation Research Board’s 92nd Annual Meeting, January 2013, Washington, D.C.

Ellis, David, “Cost Per Hour and Value of Time Calculations for Passenger Vehicles and Commercial Trucks for Use in the Urban Mobility Report.” Texas Transportation Institute, 2009.

EPA (2008),” Average In-Use Emissions from Heavy-Duty Trucks,” EPA Report 420-f-08-027, http://www.epa.gov/otaq/consumer/42of08027.pdf, (Accessed May, 2015)

EPA (2011), “The 2011 National Emissions Inventory,” EPA Report NEI-2011-V2 GPR, http://www.epa.gov/ttnchie1/net/2011inventory.html, (Accessed May, 2015)

EPA (2012)a, “Noise Pollution,” http://www.epa.gov/air/noise.html, (Accessed June, 2015)

EPA (2012)b, “Reducing Acid Rain,” http://www.epa.gov/acidrain/reducing/, (Accessed June, 2015)

EPA (2015)a, “Inventory of U.S. Greenhouse Gas Emissions and Sinks,” EPA Report 430-R-15-004, Washington, DC.

EPA (2015)b, “The Social Cost of Carbon,” https://www3.epa.gov/otaq/climate/regulations/scc-tsd.pdf, (Accessed July, 2015)

EPA (2015)c, “What is Ozone?” http://www.epa.gov/apti/ozonehealth/what.html, (Accessed May, 2015)

EPAIE (2015), “Environmental Impact Assessment,” Available at http://www.epa.ie/monitoringassessment/assessment/eia/#.VdXs97JVhBc, (Accessed Aug, 2015)

Farely, B., and Norboge, N. (2014), “Public-Private Investment Models for Roadway Infrastructure”, PRC 14-15-F, Texas A&M Transportation Institute.
Federal Highway Administration, (2014), Cost Allocation Study Final Report, “Trends and Forecasts of Highway User Revenues,” Federal Highway Administration, Nov. 2014.
Federal Transit Administration (FTA) (2015), http://www.fta.dot.gov/grants/12863.html, (Accessed Nov. 15, 2015).
FHWA (2005a) “A Summary of Highway Provisions in SAFETEA-LU”, FHWA Office of Legislation and Intergovernmental Affairs, Program Analysis Team, https://www.fhwa.dot.gov/safetealu/summary.htm, (Accessed Nov. 27, 2015).
FHWA (2005b), “FHWA Innovative Finance Quarterly.” Vol 11, https://www.fhwa.dot.gov/ipd/finance/resources/general/if_quarterly/fall_05.aspx, (Accessed Nov. 6, 2015).
FHWA (2007a), “User Guidebook on Implementing Public Private Partnerships for Transportation Infrastructure Projects in the United States”, FHWA, Office of Policy and Governmental Affairs.
FHWA (2007b), “Case studies of transportation public-private partnerships in the United States.” http://www.fhwa.dot.gov/ipd/pdfs/us_ppp_case _studies_final_report_7-7-07.pdf, (Accessed Jul. 16, 2012).
FHWA (2015), “NEPA Documentation,” Available at https://www.environment.fhwa.dot.gov/projdev/docueis.asp, (Visited Aug, 2015)
FHWA (2015a), http://www.fhwa.dot.gov/ipd/project_profiles/tx_north_tarrant.aspx, (Accessed Jul. 15, 2015).
FHWA (2015b), http://www.fhwa.dot.gov/ipd/project_profiles/tx_north_tarrant_3a3b.aspx, (Accessed Jul. 15, 2015).
FHWA (2015c), http://www.fhwa.dot.gov/ipd/project_profiles/tx_central_turnpike.aspx, (Accessed Jul. 15, 2015).
FHWA (2015d), http://www.fhwa.dot.gov/ipd/project_profiles/tx_sh130.asp, (Accessed Jul. 15, 2015).
FHWA (2015e), “Project Finance Primer”, https://www.fhwa.dot.gov/ipd/pdfs/finance/ProjectFinancePrimerREV4.pdf, (Accessed Oct. 16, 2015).
FHWA (2015f), https://www.transportation.gov/tifia, (Accessed Nov. 11, 2015).
FHWA (2015g), https://www.fhwa.dot.gov/ipd/revenue/, (Accessed Nov. 15, 2015).
FHWA (2015h), “Challenges and Opportunities Series: Public Private Partnerships in Transportation Delivery,” FHWA Feedback Forum, https://www.fhwa.dot.gov/ipd/forum/challenges_and_opportunities/financial_considerations.aspx, (Accessed Nov. 15, 2015).
FHWA (2015i), “P3 Toolkit,” http://www.fhwa.dot.gov/ipd/p3/defined/design_build_finance_operate.aspx, (Accessed Sep. 26, 2015).
FHWA (2016a), http://www.fhwa.dot.gov/ipd/p3/default.aspx, (Accessed Feb. 28, 2016).
FHWA (2016b), https://www.fhwa.dot.gov/ipd/forum/challenges_and_opportunities/financial_considerations.aspx, (Accessed Mar. 05, 2016).
FHWA technical report, (2011), “Annual vehicle miles travelled and related data,” No. FHWA-PL-11-031, Washington, DC.

Fiars, R. (2009). “The Virtual Sea Port: Sydney Freight Circle.” Proc. of the 8th International Conference of Associated research Centers for the Urban Underground Space (ACUUS). Shenzhen, China.

Forkenbrock, D. (1999). “External Costs of Intercity Truck Freight Transportation,” Transportation Research Report, No.505-526.

Franzese, O., and Davidson D., (2011), “Effect of weight and roadway grade on the fuel economy of class-8 freight trucks,” Oak Ridge National Laboratory, Managed by UT-Battelle for the department of energy, Tennessee

Fricker, Jon D. and Whitford, Robert K. (2004), Fundamentals of transportation engineering a multimodal systems approach, Prentice Hall.

Frideman, D., Mitchell, C., (2003). “Commercial Truck and Bus Safety Program,” Federal Motor Carrier safety Administration.

Gamarra, J. (2016). “Potential Application of Ultra-High Performance Fiber-Reinforced Concrete with Wet-Mix Shotcrete System in Tunneling.” thesis, presented to The University of Texas at Arlington, TX, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Gautreau, G. P., Zhang, Z., and Wu, Z. (2009), “Accelerated Loading Evaluation of Subbase Layers in Pavement Performance,” No. FHWA/LA. 09/468.

Goff, Z. A., Patil, S., & Shih, C. S. (2000). Feasibility of Freight Pipelines to Relieve Highway Congestion (No. FHWA/TX-00/1803-1,); Sinfield, Joseph V., and Herbert H. Einstein (1998). Tunnel Construction Costs for Tube Transportation Systems. Journal of Construction Engineering and Management, 124(1), 48-57;

Grant-Muller S., and Laird J., (2007), “International literature review of the costs of road traffic Congestion,” Scottish Executive, www.scotland.gov.uk/Publications/2006/11/01103351/0 (Accessed July.10, 2015)

Gruebl, F., (2012) “Tunneling and Underground Space for a Global Society,” *Proceeding of World Tunnel Congress* 2012, Bangkok, Thailand.

Guo, D. J., Yu, M. J. and Chen, Z. L. (2008). “The Preliminary Study on Underground Container Transportation System (UCTC) for Yangshan Port in Shanghai.” Proc. of the 5th International Symposium on Underground Freight Transportation (ISUFT). Arlington, TX.

Gurgun, A. P., and Touran, A. (2014), “Public-Private Partnership Experience in the International Arena: Case of Turkey”, ASCE Journal of Management in Engineering, 30(6): 04014029.

Harrison, R., Hutson, N., Siegesmund, P., Blaze, J., West, J., (2007). “Planning for Container Growth along the Houston Ship Channel and Other Texas Seaports,” Texas Department of Transportation, Center for Transportation Research at the University of Texas at Austin.

Hatch Mott MacDonald Earth Tech, Inc. (2008). “Circumferential Transportation Improvements in the Urban Ring Corridor. Technical Tunnel Alternatives Summary Report.” https://www.massdot.state.ma.us/theurbanring/downloads/TunnelTechnicalReport.pdf (Accessed Jun. 5, 2016).

HB 2475 (2016), http://www.legis.state.tx.us/billlookup/text.aspx?LegSess=84R and Bill=HB2475 (Accessed Feb. 20, 2016)

HDR Engineering, Inc. (2012), Baseline Assumptions for the Program of Projects Study-Final, Available at: http://ww.corridorsofopportunity.org/, (Accessed April 16, 2016).

Hegar, G., (2015), Texas, comptroller of public accounts, http://comptroller.texas.gov/taxinfo/local/ (Accessed July 3, 2016)

Houston Transtar website, (2015), http://traffic.houstontranstar.org/layers/, (Accessed Aug. 10, 2015)

Houston-Galveston Area Council, (2014), http://www.h-gac.com/home/residents.aspx, (Accessed Aug.15, 2015)

IAIA (1999), "Principles of Environmental Impact Assessment Best Practice," International Association for Impact Assessment. Fargo, ND, USA.

Kalmar (2016). Available at: https://www.kalmarglobal.com, (Accessed April, 2016).

Kocabaş, G., and Kopurlu, B. S. (2010), "An Ex-Post Cost - Benefit Analysis of Bolu Mountain Tunnel Project1", Edge Academic Review, 10(4), pp. 1279 – 1287.

Kosugi, S. (1999). "Pneumatic Capsule Pipelines in Japan and Future Developments." Proc. of the 1st International Symposium on Underground Freight Transportation, Columbia, Missouri, PP. 61-73.

Kurer, R. (1991). "International Symposium on Theory and Practice in Transport Economics." Berlin, Germany.

Lachel Felice & Associates, Inc. (2006). "IH-635 Managed Lanes Project Geotechnical Interpretive Report for the Reference Schematic - Segment A". Dallas, Texas.

Li, B., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005), "Critical success factors for

Liu, H., and Lenau, C. W. (2005). "An Electromagnetic Pneumo Capsule System for Conveying Minerals and Mine Wastes." Final Report, U.S. Department of Energy Project No. DE-FG26-03NT41928.

Lomex, Tim, (2011), "TTI's 2011 Congested Corridors Report Powered by INRIX Traffic Data—Methodology."

McFarland, W.F., M. Chui. "The Value of Travel Tim: New Estimates Developed Using a Speed Choice Model." Transportation Research Record No. 1116.Transportation Research Board, Washington, D.C., 1987

McKinnon, A. and Piecyk, M. (2011). "Measuring and Managing CO2 Emissions of European Chemical Transport," Edinburgh, UK.

Mercator Advisors LLC (2007), "National Surface Transportation Policy and Revenue Study Commission Briefing Paper 5A-14," http://transportationfortomorrow.com/final_report/pdf/volume_3/technical_issue_papers/paper5a_14.pdf, (Feb. 20, 2016).

Minnesota Department of Transportation (MnDOT), (2015), "Benefit-Cost Analysis for Transportation Projects", http://www.dot.state.mn.us/planning/program/benefitcost.html, (Accessed Oct. 16, 2015).

Najafi, M. and Gokhale, S. (2005). "Trenchless Technology, Pipeline and Utility Design, Construction, and Renewal," McGraw-Hill, New York, NY.

Nelson, P. (1989). "Geology and geotechnical considerations of the SSC site in Texas: tunneling and construction at the Dallas-Ft. worth SSC site." http://lss.fnal.gov/archive/other/ssc/ssc-n-620.pdf (Accessed Nov. 5, 2015).

Nemati, K. M. (2007). "Site Improvement and Deep Foundations, Earth-Retaining Structures." http://courses.washington.edu/cm510/Foundation.pdf (Accessed Dec. 1, 2015).

North American Port Container Traffic, (2009), Available at http://aapa.files.cms-plus.com/Statistics/NORTHAMERICANPORTCONTAINERTRAFFIC2009.pdf, (Accessed December 28, 2015).

North Tarrant Express (2015), http://www.northtarrantexpress.com/AboutNTENew.asp, (Accessed Jul. 15, 2015).

O' Conner, J. and Syed, O. (2001). "Planning for the I-635 HOV/TOLL Tunnels. A Report to the Texas Department of Transportation," Dallas, Texas.
Ozbay, K., Yanmaz-Tuzel O., Mudigonda S., and Bartin, B. (2008), "Quantification of Possible Impacts of Capacity Expansion Projects on Transportation Costs via Trip-based full marginal Cost Estimation Methodology," Proceeding of Transportation Research Board's 87th annual meeting, Washington, D.C.
Parker, F., J. Elton, D., E. Whitbeck, J., (1997), Tieback Wall Design and Construction, Alabama Highway Research Center, Auburn University.
Parry, I., (2006), "How heavy-duty trucks should be taxed?" Resources for the future, Washington, DC.
PPP/PFI projects in the UK construction industry," Construction Management and Economics, 23(5), 459–471.
Pratt, D., (2011), Fundamentals of construction estimating, Delmar Cengage Learning, New York.
Quandel Consultants, LLC (2011), Cost Estimating Methodology for High-Speed Rail on Shared Right of-Way.
Realtor (2016), Available at: http://www.realtor.com/realestateandhomes-search/Lancaster_TX/type-land/acre-20, (Accessed March. 15, 2016).
Regin, F.J., Damaso, R.A., and Bilugan R.V. (2005). "Assessment of Traffic Inputs to Pavement Design and Rehabilitation." Pipeline Engineering Journal, 2005. Vol 26, No.2:1-12
Retirement living information system, (2015), http://www.retirementliving.com/taxes-by-state, (Accessed July, 5)
RICARDO-AEA (2014), "Update of the Handbook on External Costs of Transport," DG MOVE Report Ricardo-AEA/R/ED57769, Available at http://ec.europa.eu/transport/themes/sustainable/studies/doc/2014-handbook-external-costs-transport.pdf , (Accessed June, 2015).
Roop, S. S., Olson, L., Warner, J., Morgan, C., and Rediniotis, O. (2000). The Technical and Economic Feasibility of a Freight Pipeline System in Texas – Year 1 Report." Report 1519-1, TxDOT Project No. 9-1519, Texas A&M Transportation Institute.
RSMeans (2016), RSMeans Heavy Construction Cost Data, 2016.
RSMeans Construction Cost Indexes (2016), http://rsmeansonline.com/, (Accessed March 14, 2016).
RSMeans Heavy Construction Cost Data. (2016). http://rsmeansonline.com/, (Accessed June 14, 2016). Soldier Pile Walls as Retaining Systems for Deep Excavations, Available at http://www.deepexcavation.com/en/retaining-systems-soldierpile, (Accessed March 12, 2016).
Sayers, T. M., Jessop, A.T., and Hills, P. J. (2003), "Multi-criteria Evaluation of Transport Options- Flexible, Transparent and User-Friendly?" Transport Policy, Vol. 10, pp. 95-105.
Schrank, D., Eisele, B., Lomax, T., (2012), "Urban Mobility Report." Texas Transportation Institute, The Texas A&M University System, http://mobility.tamu.edu, (Accessed July. 30, 2015)
Sinfield, Joseph V., and Herbert H. Einstein (1998). Tunnel Construction Costs for Tube Transportation Systems. Journal of Construction Engineering and Management, 124(1), 48-57.
Teng, J. Y., and Tzeng, G. H. (1996), "Fuzzy Multi-criteria Ranking of Urban Transportation Investment Alternatives," Transportation Planning Technologies, 20(1), pp.15-31.

Texas Department of Transportation, (2007). “Texas NAFTA Study Update,” Cambridge Systematics, Inc.
Texas Department of Transportation, (2014), available at http://www.txdot.gov/inside-txdot/projects/100-congested-roadways.html (Accessed October 15, 2015).
Texas Department of Transportation, (2015), “Proposition 1 Funding,” available at http://www.txdot.gov/government/legislative/state-affairs/ballot-proposition.html (Accessed June 15, 2016).
Texas Government Code (2016a), http://www.statutes.legis.state.tx.us/Docs/LG/htm/LG.501.htm, (Accessed Feb. 20, 2016)
Texas Government Code (2016b), http://www.statutes.legis.state.tx.us/Docs/GV/htm/GV.2267.htm, (Accessed Feb. 21, 2016)
Texas Government Code (2016c), http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.370.htm (Accessed Feb. 27, 2016)
Texas Legislative Budget Board (2015), “Transportation Funding Options, Legislative Policy Report,” Submitted To the 84th Texas Legislature, February 2015.
Texas Small Land Sales Report (2015), Available at: https://www.texasrealestate.com/uploads/files/general-files/2014SmallLandSalesReportTAR.pdf, (Accessed Dec. 5, 2015).
Texas Transportation Institute (2002),”Year 3 Report on the Technical and Economic Feasibility of a Freight Pipeline System in Texas,” Report 1519-3, Project Number 0-1519, Research Project Title: Freight Pipeline Feasibility Study.
Texas Transportation Institute, (2008), “Preliminary Review of Data Sources To Identify Portion of Heavy-Duty Vehicle Activity in Texas Metropolitan Areas from Long-Haul Pass-Through Trucks,” Texas Transportation Institute, The Texas A&M University System, College Station, Texas.
The Robbins Company (2015). “Project Results.” http://www.therobbinscompany.com/en/project-results/ (Accessed Dec. 1, 2015).
The U.S. Department of the Treasury (2014), Expanding our Nation’s Infrastructure through Innovative Financing, U.S. Department of the Treasury Office of Economic Policy, September 2014 https://www.treasury.gov/press-center/press-releases/Documents/Expanding%20our%20Nation’s%20Infrastructure%20through%20Innovative%2ofinancing.pdf (Accessed Jan. 15, 2015)
The U.S. Senate, (2016), http://www.senate.gov/reference/glossary_term/authorizations_act.htm, (Accessed Feb. 4, 2016).
Tire data guide (2015), Commercial vehicle tires to fit your needs, Available at: www.continental-truck.com 2015, (Accessed July, 20).
TranSystem, (2009), “IIPOD Competitive Assessment and Opportunities Study,” Office of Economic Development City of Dallas.
TRIP (A National Transportation Research Group). (2013). “Texas Top 100 Transportation Challenges and Improvements Needed to Address Them.” Washington, DC.
Tunneling and TBM Method. (2008). “Tunneling and TBM Method,” http://www.p3planningengineer.com/productivity/tunneling/tunneling.htm (Accessed Jul. 1, 2016).
TxDOT (2014), “Transportation Funding; Understanding Transportation Funding in Texas,” Statewide Funding Brochure, 2014-2015 Edition.

TxDOT (2015a), http://www.txdot.gov/government/partnerships/current-cda/north-tarrant-express.html, (Accessed Jul. 15, 2015).
TxDOT (2015b), http://www.txdot.gov/inside-txdot/projects/studies/fort-worth/north-tarrant-express/nte-cda.html, (Accessed Jul.15, 2015).
TxDOT, (2016a), http://www.txdot.gov/government/programs/utp.html, (Accessed Feb. 6, 2016).
U.S. Bureau of Labor Statistics (2016), http://www.bls.gov/, (Accessed March 10, 2016).
U.S. Energy Information Administration (2015), Available at: https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a, (Accessed Dec. 2, 2015).
U.S. Office of Management and Budget (2015), https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c, (Accessed May 27, 2016).
Underground space: the 4th dimension of metropolises, Proceedings of the 33rd ITA- AITES World Tunnel Congress (2007), Prague, Czech Republic, 1461-1467.
United States environmental protection agency (EPA), (2008), "Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks," Office of Transportation and Air Quality.
Urbanohio, 2015, Available at: http://www.urbanohio.com/forum2/index.php?topic=19910.0 (Accessed Oct. 18, 2015)
USDOT (2015), https://www.transportation.gov/tifia/overview (Accessed Oct. 23, 2015).
USDOT (2016a), https://www.transportation.gov/tifia, (Accessed Feb. 4, 2016).
USDOT (2016b), https://www.transportation.gov/tifia/overview, (Accessed Feb. 4, 2016).
USDOT (2016c), http://transportation.house.gov/fast-act/, (Accessed Feb. 16, 2016).
USDOT (2016d), https://www.transportation.gov/fastact#sthash.2SGKn8uS.dpuf, (Accessed Feb. 16, 2016).
USDOT (2016e), https://www.transportation.gov/budget/innovative-financing#sthash.QeVcfNg4.dpuf, (Accessed Jan. 29, 2016).
Vance, L. L. (1999). "The Technical and Economic Feasibility of Tube Freight Transportation Systems." Proc. of the 1st International Symposium on Underground Freight Transportation, Columbia, Missouri.
Vickerman, M., (2005), "Planning for Future Transportation Technological Change," 2005 Executive Management Conference, Norfolk, Virginia
Weissman, Sh., Sackman, J., Gillen, D., (2003), "Extending the Lifespan of Tires: Final Report," Institute for Transportation Studies, University of California at Berkeley.
Whitehouse (2010), "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis," Under Executive Order 12866, Available at https://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf (Accessed June, 2015)
Zandi, I. (1976). Transport of Solid Commodities via Freight Pipeline (Vol.2, Freight Pipeline Technology
Zhang X. Q. (2005), "Critical success factors for public-private partnerships in infrastructure development," ASCE Journal of Construction Engineering and Management, 131, 3-14.
Zhang, Y., Novick, D., Hadavi, A., and Krizek, R. J. (2005), Life cycle cost analysis of bridges and tunnels, Construction Research Congress Proceedings, ASCE, San Diego, California.

APPENDIX A

This Page is Intentionally Left Blank

Table A-1 GIS Database of Port of Houston to City of Lancaster (near Dallas) Route

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
1	4	192	20	80	40	0	0	336	7	2	0
2	4	140	20	40	40	28	28	300	0	0	0
3	4	140	20	40	40	28	28	300	3	2	0
4	4	140	20	40	40	28	28	300	2	4	0
5	4	196	20	60	60	0	0	342	2	1	0
6	6	196	20	20	20	19	19	300	5	2	0
7	6	196	20	20	0	29	29	300	1	2	0
8	6	144	24	40	40	24	24	300	4	1	0
9	4	120	24	40	40	36	36	300	5	2	0
10	4	120	20	40	40	37	37	300	3	2	0
11	6	120	20	40	40	74	74	370	12	7	0
12	2	120	20	50	50	64	64	370	10	6	0
13	2	136	22	50	50	55	55	370	2	4	0
14	2	136	20	40	40	66	66	370	5	5	0
15	2	96	20	60	60	22	22	300	13	6	0
16	20	164	0	57	57	0	0	300	3	3	0
17	22	162	20	80	80	0	0	345	7	6	0
18	3	162	0	67	67	1	1	301	2	1	0
19	3	162	0	67	67	1	1	301	3	2	0
20	3	136	20	40	40	22	22	300	9	7	0
21	20	136	20	50	50	12	12	300	6	4	0
22	20	136	20	60	60	2	2	300	5	4	0
23	20	136	20	50	50	12	12	300	7	4	0
24	20	136	20	50	50	12	12	300	8	4	0
25	20	136	20	50	50	12	12	300	16	8	0
26	20	136	20	20	20	42	42	300	14	6	0
27	20	136	20	20	20	42	42	300	2	4	0
28	20	140	20	20	20	37	37	300	10	7	1
29	26	140	20	20	20	37	37	300	15	6	0
30	26	116	20	20	20	27	27	256	4	4	0
31	26	116	20	20	20	27	27	256	0	3	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
32	26	116	20	20	20	27	27	256	1	6	0
33	26	192	20	20	20	10	10	300	1	1	1
34	28	192	20	20	30	5	5	300	8	3	0
35	28	192	20	20	20	10	10	300	3	4	2
36	28	192	20	20	20	10	10	300	4	4	5
37	28	192	20	20	20	10	10	300	14	7	5
38	28	140	20	20	20	40	40	300	9	4	0
39	20	192	20	30	30	4	4	300	4	4	2
40	20	192	36	40	40	0	0	328	2	0	0
41	20	192	36	40	40	0	0	328	2	0	1
42	20	192	36	40	40	0	0	328	0	3	0
43	20	165	36	40	40	0	0	306	5	10	0
44	25	140	36	30	30	20	20	300	5	6	0
45	25	180	36	80	20	5	5	351	2	5	0
46	25	180	36	40	40	15	15	351	2	5	2
47	25	140	36	40	30	37	37	350	4	3	3
48	30	140	20	40	40	0	0	270	1	2	1
49	30	140	20	40	40	0	0	270	6	1	1
50	30	160	20	30	30	30	30	322	2	9	1
51	22	160	20	40	40	20	20	322	0	7	3
52	22	160	20	30	10	40	40	322	2	4	1
53	22	140	20	30	40	35	35	322	1	4	0
54	22	140	20	30	30	41	41	322	2	2	2
55	20	140	20	40	40	36	36	322	1	3	0
56	10	140	20	40	40	36	36	322	2	3	0
57	10	140	20	40	40	31	31	322	1	0	0
58	20	140	20	40	40	31	31	322	6	2	0
59	20	140	40	30	50	26	26	322	3	1	0
60	10	140	20	40	40	36	36	322	2	1	1
61	10	80	20	20	20	65	65	300	1	3	4
62	30	80	20	20	20	65	65	300	1	3	0
63	30	80	20	20	20	65	65	300	6	5	0
64	30	80	20	20	20	65	65	300	1	3	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
65	30	92	20	20	20	61	61	300	1	2	0
66	26	92	20	20	20	61	61	300	1	2	0
67	26	92	26	30	20	16	16	300	1	2	0
68	100	96	26	30	20	14	14	300	2	0	0
69	100	96	32	30	20	11	11	320	1	2	0
70	120	96	0	52	52	0	0	320	0	0	0
71	120	80	32	50	50	34	34	320	1	0	0
72	40	80	32	50	50	34	34	320	1	0	2
73	40	80	30	50	50	35	35	320	1	2	0
74	40	80	40	30	30	50	50	320	1	2	0
75	40	80	32	30	30	54	54	320	1	3	0
76	40	80	32	30	30	54	54	320	0	0	1
77	40	80	32	30	30	54	54	320	1	1	0
78	40	76	22	20	70	125	125	480	1	2	1
79	43	76	22	80	120	5	5	350	2	2	0
80	43	76	22	80	100	72	72	465	2	2	0
81	43	76	22	0	120	67	67	395	0	0	0
82	43	76	22	0	120	67	67	395	0	0	0
83	43	76	22	0	120	102	102	465	2	0	0
84	43	76	22	0	120	72	72	405	0	0	0
85	43	76	22	0	120	72	72	405	0	0	0
86	43	76	22	0	120	72	72	405	1	2	0
87	43	76	24	0	120	71	71	405	0	1	0
88	43	76	24	70	70	61	61	405	0	1	0
89	43	84	24	70	70	54	54	401	1	1	0
90	45	84	24	100	100	24	24	401	1	1	0
91	45	84	24	100	100	24	24	401	1	4	0
92	45	84	24	70	70	54	54	401	2	3	0
93	45	84	24	70	70	29	29	351	1	3	0
94	45	84	24	70	70	29	29	351	1	2	0
95	45	80	20	70	0	108	108	426	1	2	1
96	40	80	20	70	70	71	71	425	0	0	0
97	43	80	20	0	70	106	106	425	0	0	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
98	43	80	22	0	70	105	105	425	2	0	0
99	43	80	22	70	0	105	105	425	1	2	0
100	43	80	20	70	0	106	106	425	0	0	0
101	43	80	20	70	0	106	106	425	0	0	0
102	43	80	20	50	0	116	116	425	0	0	1
103	43	80	20	70	0	106	106	425	0	1	0
104	43	80	20	70	0	106	106	425	1	0	0
105	43	80	20	70	0	106	106	425	0	0	0
106	43	80	20	120	0	81	81	425	1	0	0
107	43	80	20	120	0	81	81	425	3	0	0
108	43	80	24	120	0	79	79	425	0	0	0
109	43	80	0	128	128	1	1	381	1	2	0
110	43	80	0	148	148	1	1	421	2	0	0
111	43	80	24	80	0	80	80	420	0	0	1
112	76	80	24	80	0	80	80	420	0	0	0
113	76	80	24	80	0	60	60	380	1	0	0
114	76	80	24	80	0	60	60	380	0	0	0
115	76	80	24	80	0	60	60	380	0	0	3
116	76	80	24	80	0	60	60	380	1	0	0
117	76	80	24	30	30	84	84	380	0	1	0
118	48	80	24	50	50	44	44	340	1	2	1
119	48	74	24	50	50	47	47	340	0	0	0
120	48	74	24	50	50	47	47	340	0	2	0
121	48	74	24	50	50	67	67	380	0	1	1
122	48	76	24	50	50	31	31	310	1	3	0
123	48	76	24	0	50	75	75	348	0	0	0
124	48	80	24	0	50	62	62	326	0	0	0
125	48	80	24	0	50	62	62	326	1	2	0
126	48	80	24	0	50	62	62	326	1	0	1
127	48	80	24	0	50	48	48	326	1	2	0
128	76	80	24	0	50	62	62	326	3	2	0
129	48	78	24	0	50	73	73	346	1	0	0
130	48	78	24	50	50	48	48	346	1	0	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
131	48	78	24	50	50	48	48	346	2	2	0
132	48	78	20	0	70	65	65	346	0	0	0
133	48	78	20	0	70	65	65	346	2	1	0
134	48	78	20	0	70	65	65	346	1	0	0
135	48	78	20	0	70	65	65	346	2	0	0
136	48	78	20	0	70	65	65	346	1	0	0
137	48	78	20	0	70	65	65	346	0	0	3
138	48	78	20	0	70	65	65	346	0	2	0
139	48	78	20	0	70	65	65	346	1	1	0
140	48	78	20	0	70	65	65	346	1	2	0
141	48	78	20	50	50	50	50	346	0	1	1
142	48	78	20	0	70	65	65	346	0	0	0
143	48	78	20	0	70	65	65	346	0	0	0
144	48	78	20	0	70	65	65	346	1	0	1
145	48	80	20	0	70	64	64	346	0	0	0
146	48	80	20	0	100	49	49	346	0	0	1
147	48	80	20	0	100	49	49	346	0	2	1
148	48	80	20	0	100	49	49	346	0	1	0
149	48	80	20	0	100	49	49	346	0	1	1
150	48	80	20	100	100	0	0	348	1	2	1
151	48	80	20	100	100	0	0	348	0	1	1
152	48	80	20	100	100	0	0	348	1	0	2
153	48	80	20	0	100	49	49	346	1	0	1
154	48	80	20	0	100	49	49	346	1	1	0
155	48	80	20	0	100	49	49	345	2	2	0
156	48	80	20	200	200	0	0	548	1	4	0
157	48	80	28	200	200	0	0	556	1	0	0
158	48	76	28	0	100	60	60	401	1	1	0
159	77	76	28	0	100	60	60	401	1	0	0
160	77	76	28	0	150	35	35	401	0	0	5
161	77	76	28	0	150	35	35	401	0	1	0
162	77	76	28	0	150	35	35	401	0	0	1
163	77	76	28	0	150	35	35	401	1	0	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
164	77	76	28	120	120	0	0	421	0	0	0
165	77	76	28	120	120	0	0	421	1	2	4
166	77	76	28	100	100	10	10	401	1	2	0
167	77	76	28	100	100	10	10	401	0	0	1
168	77	76	28	100	100	10	10	401	1	0	0
169	77	76	28	0	100	60	60	401	1	2	2
170	77	76	28	0	100	60	60	401	0	0	4
171	77	76	28	0	100	60	60	401	0	0	3
172	77	76	28	0	100	60	60	401	0	1	3
173	77	76	28	0	100	60	60	401	1	1	0
174	77	76	28	0	100	60	60	401	1	2	0
175	77	76	28	100	100	30	30	441	1	2	3
176	77	76	28	100	100	30	30	441	0	0	3
177	77	76	28	0	100	80	80	441	1	2	4
178	77	76	24	100	100	33	33	441	0	3	0
179	75	76	20	100	100	35	35	441	1	2	0
180	75	76	20	0	100	85	85	441	0	0	0
181	75	76	20	0	100	85	85	441	0	1	0
182	75	76	22	0	100	84	84	441	1	2	2
183	75	76	22	0	100	84	84	441	1	1	0
184	75	76	22	0	100	84	84	441	1	2	1
185	75	76	20	0	100	85	85	441	0	1	3
186	75	76	0	144	144	1	1	441	3	0	0
187	75	78	18	0	100	59	59	360	0	0	0
188	46	78	0	117	117	1	1	360	2	4	0
189	46	78	0	117	117	1	1	360	1	0	1
190	46	114	0	78	78	0	0	310	1	2	1
191	40	76	24	60	80	10	10	300	1	0	1
192	40	76	24	80	80	0	0	300	1	2	1
193	40	76	24	80	80	0	0	300	1	0	1
194	40	76	24	80	80	0	0	300	2	0	1
195	40	76	24	50	50	30	30	300	1	2	0
196	40	92	24	50	50	27	27	310	3	0	0

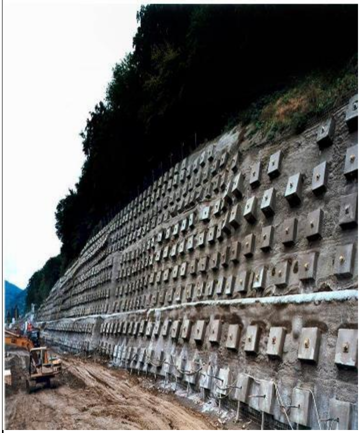
DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
197	40	72	24	50	50	37	37	310	2	0	1
198	40	92	26	50	50	21	21	300	1	1	0
199	40	92	26	50	50	21	21	300	0	1	1
200	40	92	26	50	50	21	21	300	0	1	0
201	40	76	26	50	50	29	29	300	0	1	1
202	40	76	26	50	50	29	29	300	1	0	0
203	40	76	26	50	50	29	29	300	0	1	1
204	40	76	26	50	50	29	29	300	2	0	1
205	40	76	26	30	30	49	49	300	2	1	3
206	40	76	0	92	92	0	0	300	1	2	1
207	40	76	0	92	92	0	0	300	3	1	1
208	40	76	26	70	70	9	9	300	2	4	0
209	40	76	18	70	70	16	16	306	2	2	0
210	40	76	0	75	75	0	0	300	2	2	0
211	74	76	0	75	75	0	0	300	1	0	0
212	74	72	24	0	60	7	7	300	3	2	0
213	130	88	24	40	40	34	34	300	1	0	0
214	40	88	24	40	40	34	34	300	1	0	2
215	40	72	26	40	40	41	41	300	1	2	0
216	40	72	26	40	40	41	41	300	1	1	0
217	40	72	26	40	40	41	41	300	0	0	0
218	40	72	26	40	40	41	41	300	1	0	0
219	40	72	26	40	40	41	41	300	1	0	0
220	40	72	26	40	40	41	41	300	1	2	0
221	40	104	22	40	40	27	27	300	0	0	0
222	40	104	22	40	40	27	27	300	1	0	0
223	40	104	22	40	40	27	27	300	2	1	0
224	40	104	36	80	40	18	18	300	2	0	0
225	4	104	36	40	40	38	38	300	0	1	1
226	4	104	22	30	30	55	55	300	1	2	1
227	4	104	20	20	20	50	50	300	0	0	0
228	36	104	20	30	30	40	40	300	2	2	0
229	36	104	20	30	30	40	40	300	1	2	0

DFO	Median Width (ft)	Lane Width (ft)	Frntg Width (ft)	Apron Width Right (ft)	Apron Width Left (ft)	Sideslope width Right (ft)	Sideslope width Left (ft)	Tot ROW Width (ft)	Major Obstr	Minor Obstr	Pipe Xing ROW
230	36	104	20	30	30	40	40	300	2	1	0
231	36	104	20	30	30	40	40	300	2	4	0
232	36	114	20	30	30	35	35	300	0	0	1
233	36	114	20	50	50	15	15	300	1	1	0
234	36	114	20	30	30	35	35	300	2	1	0
235	36	114	20	30	30	35	35	300	2	2	0
236	36	114	20	30	30	35	35	300	1	1	0
237	36	114	20	80	80	0	0	330	4	1	1
238	36	114	22	60	60	4	4	300	1	2	2
239	36	106	20	40	40	32	32	300	1	3	2
240	30	108	20	30	30	41	41	300	2	2	0
241	30	108	20	60	60	11	11	300	2	3	0
242	30	108	20	40	40	31	31	300	1	2	0
243	30	108	20	40	40	31	31	300	2	1	0
244	30	108	20	40	40	41	41	320	5	2	0
245	30	108	20	40	40	41	41	320	0	1	0
246	30	112	60	40	40	23	23	301	1	2	0
247	3	112	60	40	40	23	23	301	2	5	0
248	3	112	60	40	40	23	23	301	1	2	0
249	3	112	60	40	40	23	23	301	1	1	0
250	3	112	60	40	40	23	23	301	1	2	0
251	3	112	60	40	40	23	23	301	1	2	0

APPENDIX B

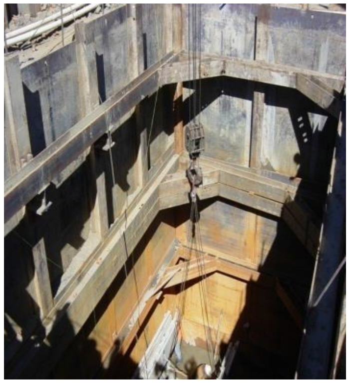
This Page is Intentionally Left Blank

Table B-1 Shaft Construction Methods

Method	Advantages	Limitations	Figure[29]
Soil Nailing	1. Smaller ROW need compared to ground anchors. 2. Less disruptive to traffic and less environmental impact compared to other shaft construction methods. 3. Less congested work area. 4. Relatively rapid installation. 5. Nail location, inclination, and lengths can be adjusted easily when obstructions (cobbles or boulders, piles or underground utilities) are encountered.	1. It may not be appropriate for structures and utilities located behind the shaft wall. 2. Existing utilities may place restrictions on the location, inclination, and length of soil nails. 3. Not well-suited where large amounts of groundwater seeps into the excavation. 4. Soil nail walls require permanent, underground easements. 5. Not very useful in areas near bridges and foundations. 6. It is not a water barrier so it is not suitable for below watertable. 7. It cannot be constructed in saturated clayey soils. Watertable should be lowered before construction.	

[29] Photos by Dr. Glenn Boyce, presented at CUIRE School, February 2016.

Method	Advantages	Limitations	Figure
Secant Pile Wall	1. Increased construction alignment flexibility. 2. Increased wall stiffness compared to sheet piles. 3. Can be installed in difficult ground (cobbles/boulders). 4. Less noise during construction.	1. Verticality tolerances may be hard to achieve for deep piles. 2. Total waterproofing is very difficult to obtain in joints. 3. Increased cost compared to sheet pile walls. 4. It cannot be constructed in saturated clayey soils. So, watertable should be lowered before construction.	
Sheet Pile	1. High resistance to drive stresses. 2. Light weight. 3. Can be reused on several projects. 4. Long service life above or below water with modest protection. 5. Pile length potentially can be increased by either welding or bolting. 6. Sheet pile joints are resistant to deformation during driving.	1. Sections rarely used as part of the permanent structure. 2. Difficult Installation of sheet piles is in soils with boulders or cobbles. 3. Excavation shapes are dictated by the sheet pile section and interlocking elements. 4. Settlements in adjacent properties due to installation vibrations. 5. Installation vibration makes the construction difficult in urban areas. 6. It requires large space for material storage.	

Method	Advantages	Limitations	Figure
Soldier Pile and Lagging Beam (Soldier Pile Walls, 2016)	1. Fast to construct. 2. Very cost effective. 3. Easy to install, adjustments can be made to accommodate changes. 4. Lagging construction can be very quick. 5. Construction of soldier pile and lagging walls does not require very advanced construction techniques. 6. They are primarily limited to temporary construction.	1. Cannot be used in high watertable conditions without extensive dewatering. 2. Poor backfilling and associated ground losses can result in significant surface settlements. 3. They are not as stiff as other retaining systems. It provides water barrier for the shaft so it is suitable in areas with high watertable. 4. It doesn't require lowering the watertable before construction. 5. Suitable for up to 24-ft deep shaft.	
Ground Freezing (Ground Freezing Brochure, 2016)	1. Implemented through the difficult geologies such as soil/rock interface. 2. A frozen wall resists the loads imposed by full groundwater and soil pressures.	1. Highly energy intensive process. 2. Requires plenty of monitoring. 3. Volume expansion of water during freezing, leading to soil heaves and thaw settlement. 4. Most expensive method. Around 50% to 100% higher cost than other methods. 5. It requires large space for material storage.	

This Page is Intentionally Left Blank

APPENDIX C

This Page is Intentionally Left Blank

Table C-1 Comparison of Different Alternatives for EIS

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Land Use	• No Impact	• At least 2,500 acres land required. • There is no available land in urban area.	• No required land due to constructing UFT under available ROW, except in terminal area.
Neighborhood and community facilities and services	• Increased traffic congestion, accidents, and air and noise pollution will affect the quality of neighborhoods and communities.	• Build Alternative will have temporary impact during construction. • Greater access and mobility is anticipated to support the existing neighborhood functions without changing the overall neighborhoods.	• Reducing the number of trucks will have a positive impact on quality of neighborhoods and communities due to traffic congestion, air and noise pollution, and accident rate reduction.
Displacement and Relocation	• No Impact	• Property acquisition will occur after the Record of Decision. • Property owners would be paid fair market value for property acquired. • Relocations will be accomplished either by providing compensation for moving residences and businesses back from the proposed ROW (where possible), or by providing assistance to locate and acquire available properties elsewhere.	• Property acquisition may occur after the Record of Decision. • Relocations may be accomplished either by providing compensation for moving residences and businesses, or by providing assistance to locate and acquire available properties elsewhere.

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Economic	• Reduced freight transportation performance due to traffic congestion increase. • Possible increase of driver's wage. • Increased cost of transportation.	• Increase job opportunity during construction. • Possible increased property values along the highway; therefore, increased property tax revenue.	• Increase freight transportation performance. • Possible decrease in job opportunities for truck drivers. • Reduced cost of transportation. • Higher benefit/cost ratio compared with other alternatives.
Historic, Architectural, and Archeological Resources	• Increased possibility of impact due to increase emitted particulate matter and acid rain.	• Increase possibility of impact due to increased emitted particulate matter and acid rain.	• No Impact.
Air Quality	• Increased air pollution due to increase number of trucks, and traffic congestion. • Annual social cost of air pollution by 15,000 trucks is approximately $970,000,000 (2015- dollars). At this calculation, social cost of air pollution by trucks in traffic congestion is not considered.	• Increased air pollution due to increased number of trucks. • Annual social cost of air pollution by 15,000 trucks is approximately $970,000,000 (2015- dollars).	• By UFT, social and other agencies' benefits will be up to $372,000,000 per year due to air pollution reduction (2016- dollars).
Visual and Aesthetic Resources	• No Impact	• Minimal impact depends on design of bridges.	• Minimal impact depends on terminal designs and fencing around terminals.

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Noise and Vibration	• Increased noise pollution due to increased number of tracks, and traffic congestion. • Annual social cost of noise pollution by 15,000 trucks is approximately $15,000,000 (2016- dollars).	• Increased noise pollution due to increased number of trucks. • Possible impact by noise pollution and vibration during construction. • Annual social cost of noise pollution by 15000 trucks is approximately $15,000,000 (2016- dollars).	• Possible impact of noise pollution and vibration during construction. • Social benefits of UFT will be up to $5,800,000 per year (2016 dollars).
Ecosystem	• Potential impact on vegetation due to increased air pollution.	• Potential impact on vegetation due to increased air pollution. • High impact due to cutting trees and wood along highways. • Potential impact to median's landscape.	• Possible impact due to cutting trees and wood at shaft locations and along cut-and-cover construction. • Possible impact to median's landscape.
Water Resources	• Potential impact due to increased amount of acid rain. • Annual social cost of water pollution by acid rain is approximately $2,500,000 (2016- dollars).	• Potential impact due to increased amount of acid rain. • Annual social cost of water pollution by acid rain is approximately $2,500,000 (2016- dollars). • Potential runoff due to increased rigid surface.	• Further study needed to investigate impact of UFT construction to aquifer in Houston area. • Use best management construction practice to avoid seepage of contaminants into ground water. • Social benefits of UFT will be up to $1,000,000 per year due to decreased water pollution.
Energy	• Loss of more energy due to traffic congestion and increased number of trucks.	• Loss of more energy due to increased number of trucks.	• The UFT system consumes energy 7.5 times less than trucking system. • Energy saving due to LIM efficiency.

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Geology and soils	• No Impact	• Geotechnical investigation could be performed to develop site specific design criteria, selection of construction method.	• Geotechnical investigation could be performed to develop site specific design criteria, selection of construction method, and other impacts.
Safety and Security	• Decreased safety and security due to increased number of trucks. • Increase accident rate. • Potential conflict between trucks and pedestrians and passenger vehicles in urban area.	• Decreased safety and security due to increased number of trucks.	• Increased safety and security due to decreased number of trucks from highways. • Increased security due to limited access to freight during transportation. • Increased passengers and passenger vehicle safety.
Traffic Congestion	• Potential heavy traffic congestion due to increased number of trucks. • Annual social cost of traffic congestion is approximately $120,500,000 (2016-dollars). • Most of this cost is because of traffic congestion in Houston area.	• High potential of traffic congestion in urban area. • Annual social cost of traffic congestion is estimated to be up to $100,000,000 (2016-dollars).	• Social benefit of UFT will be approximately $46,250,000 per year due to decreased traffic congestion (2016- dollars). • Possible impact at UFT terminal area.

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Accident Rate	• High potential of increasing accident rate. • Social cost of accidents is estimated to be more than $160,000,000 per year.	• High potential of increasing accident rate in urban areas. • Decrease accident rate in rural areas. • Possible increased accident rate during construction. • Social cost of accidents will decrease compared with No Build Alternative.	• Decreased accident rate due to decreased number of trucks on highways. • Precautions planned to prevent accidents during construction. • Social benefit of UFT will be up to $61,000,000 per year due to decrease accident rate (2016- dollars).
Tax Revenue	• It is estimated to earn $80,500,000 per year from part and fuel tax by government agencies.	• It is estimated to earn $80,500,000 per year from part and fuel tax by government agencies.	• It is estimated to earn up to $1,500,000 per year from electricity tax.
Life Cycle Design	• 30 years	• 50 years	• 100 years
Construction	• Minor maintenance is needed to increase quality of surface. • Increased traffic congestion and vehicular detours during maintenance.	• Increased traffic congestion and vehicular detours. • Temporary limits on parking and short term blockages of driveways. • Interrupted access to businesses. • Short-term disruption of utilities. • Airborne dust and possible mud on roadways.	• Increased traffic congestion and vehicular detours wherever UFT construction method is cut-and-cover (Rural Area). • Possible temporary limits on parking and short term blockages of driveways at shaft construction area. • Possible interrupted access to business at urban area near shaft construction.

Subject Area	No Build Alternative	Build Alternative	Proposed Action
Construction		• Noise and vibration from construction equipment and vehicles. • Removal of or damage to vegetation (e.g., trees, shrubs, grass). • Short term use of vacant land for staging, and storage of equipment. • Spillage of petrochemicals (fuels and lubricants) during operation, servicing, and maintenance of equipment. • Water quality degradation from storm water runoff is expected to be minimal. • Potential removal or disturbance of contaminated soils. • Implement maintenance of traffic.	• Minimal short-term disruption of utilities. • Noise and vibration from construction equipment and vehicles, wherever UFT construction method is cut-and-cover (Rural Area). • Possible damage to vegetation in median. • Short term use of vacant land for backfill material and pipe/segment manufacture. • Removal and disposal of tunnel spoils. • Possible damage to frontage road. • Lower amount of dust, air pollution, noise pollution, and water pollution wherever construction method is used. • Possible traffic congestion in rural area. • Increased traffic congestion in urban area during haul spoil removal.

Table C-2 Cost of Traffic Congestion in Portion of Houston (Year 2014)

Truck Rank	Roadway	From	To	Annual Hours of Truck Delay per Mile	Annual Truck Congestion Cost (Million)	AADTT	Cost (Truck/Year) (2016 dollars)
14	IH-45	IH-610	IH-10/ US- 90	35,570	$11.08	15,922	$695.89
18	IH-45	SL-8	IH-610	32,377	$24.40	16,518	$1,477.18
21	IH-45	IH-10/ U.S.-90	IH-610	29,264	$16.39	12,863	$1,274.20
27	SH-288	IH-45	IH-610	24,284	$9.25	8,959	$1,032.48
35	IH-10/ U.S. 90	IH-45	US-59	22,279	$5.13	7,197	$712.80
29	IH-45	IH-610	SL[30]-8	23,268	$14.24	12,576	$1,132.32
59	IH-45	Lake Front Cir	Spring Cypress Rd/ FM 2920	13,994	$7.06	13,710	$514.95
65	IH-45	FM 2920	SL-8	13,136	$8.23	14,730	$558.72
67	US-59	IH-610	IH-10/ US-90	12,930	$2.69	10,526	$255.56
52	IH-10/ US-90	US-59	IH-610	15,226	$4.92	16,965	$290.01
Total				**222,328**	**$103.39**		**$7,944.10**

[30] Sam Houston Tollway

Table C-3 Cost of Traffic Congestion at Laredo Border (Year 2014)

Truck Rank	Roadway	From	To	Annual Hours of Truck Delay per Mile	Annual Truck Congestion Cost (Million)	AADTT	Cost (Truck/Year) (2016 dollars)
28	IH-35	U.S. 59	Hidalgo St.	23,334	\$3.25	8,804	\$369.15

C-1 Traffic Congestion Cost from Houston to Dallas based on TxDOT Data

Average cost of traffic congestion for each truck in PHA area: \$7,944.10 (Table C-2)

$$Total\ annual\ social\ benefit\ of\ UFT\ with\ 3000\ containers\ per\ day = 7{,}944.10 \times 3000 \sim \$24{,}000{,}000$$

$$Annual\ benefit\ (\$/ton-mile) = \$24{,}000{,}000/\ 3000\ (\#\ of\ containers)/365\ days/40\ tons/250\ mile \sim \$0.0022\ (\$/ton-mile)$$

C-2 Annual Cost of Pavement and Bridge Maintenance in IH-45 Parallel to UFT Route

Cost of maintenance per lane-mile-year = \$10,536
Average Number of Lanes = 8 ea.
Distance between Port of Houston to Distribution Center in Dallas = 250 miles (assumed)

$$Annual\ Cost\ of\ Maintenance = \$10{,}536 \times 8 \times 250\ miles = \$21{,}072{,}000$$

C-3 Cost of Infrastructure Maintenance per ton-mile

AADTT = 10,470 Trucks (TxDOT Statewide Planning, 2014)

ATT = 365 × 10,470 = 3,821,550 Trucks

$$Maintenance\ Cost\ Caused\ by\ each\ Truck = \frac{\$21{,}072{,}000\ Annual\ Cost\ of\ Maintenance}{3{,}821{,}550\ Trucks\ per\ year} = \$5.514\ per\ Truck-Trip$$

$$Cost\ of\ Maintenance\ per\ ton-mile = \frac{\$5.514\ per\ Truck-Trip}{40\ ton\ \times 250\ miles} = \$0.000514$$

C-4 Total Annual Benefit of UFT by Reducing Infrastructure Maintenance Cost

Cost of maintenance per ton-mile = \$0.000514
Number of daily containers = 3,000/day
Distance = 250 miles
Weight of each container = 40 ton/container

$$Annual\ Benefits = \$0.000514/ton - mile \times 3000\ containers/day. \times 250\ miles \times 40\ ton/container \times 365\frac{days}{year} = \$5{,}628{,}300/year$$

C-5 Cost of Accidents in Texas

Table C-4 Cost of Accidents in Texas from 2003 to 2014

Year	Deaths	VMT (Millions)	Cost of Accidents (2016 dollars) (Billion)	Cost of Accidents per mile Traveled (2016 dollars)	Cost of Accidents per ton-mile (2016 dollars)
2003	3,822	218,209	\$20.70	\$0.095	\$0.0024
2004	3,700	229,345	\$19.40	\$0.085	\$0.0021
2005	3,558	234,231	\$19.20	\$0.082	\$0.0021
2006	3,521	236,486	\$20.40	\$0.086	\$0.0022
2007	3,462	241,746	\$20.60	\$0.085	\$0.0021
2008	3,479	234,593	\$22.90	\$0.098	\$0.0025
2009	3,122	231,976	\$21.30	\$0.092	\$0.0023
2010	3,060	234,261	\$22.30	\$0.095	\$0.0024
2011	3,067	237,443	\$23.40	\$0.099	\$0.0025
2012	3,417	237,821	\$26.00	\$0.109	\$0.0027
2013	3,408	244,536	\$27.80	\$0.114	\$0.0029
2014	3,534	248,824	\$28.80	\$0.116	\$0.0029

C-6 Annual Accident Cost Reduction

$$Annual\ accident\ cost\ reduction = Cost\ of\ Accident\ \times No.of\ Container \times Weight\ of\ Container\ (ton) \times Distance \times 365\ \frac{days}{year}$$

(Eq. C-1)

Cost of accident = \$0.0029 per ton-mile
Number of container = 3,000 containers
Weight of container = 40 tons
Distance = 250 miles (assumed)

$$Annual\ Accident\ Cost\ Reduction$$
$$= \$0.0029/ton - mile \times 3{,}000\ containers/day \times 40\,\frac{tons}{container} \times 365\ days/year \times 250\ miles = \$31{,}755{,}000/year$$

C-7 Annual Benefit of Electricity Tax Revenue

$$Required\ Electricity\ per\ ton - mile = \frac{Required\ electricity\ per\ hour}{Average\ Speed \times Weight}$$

(Eq. C-2)

Required electricity for each vehicle per hour = 30 kW
Average speed of each vehicle = 45 mile per hour
Weight of each vehicle = 40 ton

$$Required\ Electricity = \frac{30\ kWh}{45\ mph\ \times 40\ ton} = 0.0167\ kW\ per\ ton - mile$$

$$Electricity\ Tax\ Revenue\ per\ ton - mile = \\ = Required\ Energy\ per\ ton - mile \times Cost\ of\ Electricity \times State\ Tax$$

(Eq. C-3)

Required electricity per ton-mile = 0.0167 per ton-mile
Cost of electricity = \$0.0533 per kWh
State Tax = 8.25%

$$Electricity\ Tax\ Revenue\ per\ ton - mile \\ = 0.0167\ kW\ per\ ton - mile \times \$0.0533\ per\ kWh \times 8.25\% \\ = \$0.00007\ per\ ton - mile$$

$$Annual\ benefit\ of\ tax\ revenue \\ = distance \times weight \times no.of\ container \times tax\ revenue\ benefit \times 365\,\frac{days}{year}$$

(Eq. C-4)

Distance = 250 miles (assumed)
Weight of Container = 40 ton
Tax Revenue = \$0.00007 per ton-mile
Number of containers = 3,000 per day

$$Annual\ Benefit\ of\ Tax\ Revenue = 250\ miles \times 40\ ton/container \times 3{,}000\ containers/day \times \$0.00007/ton - mile \times 365\frac{days}{year} \cong \$802{,}500\ per\ year$$

C-8 Energy Efficiency

$$Required\ energy\ to\ move\ 40 - \text{ton}\ container\ by\ truck\ for\ one\ mile = Required\ Fuel\ \times Coefficient\ Factor$$ (Eq. C-5)

Fuel consumption of truck = 8 mpg
Required gallon to move 40-ton container for one mile = 0.125 gallon
Coefficient of gallon of diesel to BTU = 138,874.158

$$Required\ energy\ to\ move\ 40 - ton\ container\ by\ Truck\ for\ One\ mile = 0.125\ gallon \times 138{,}874.158\frac{BTU}{Gallon} = 17{,}360\ BTU$$

$$Required\ Energy\ to\ Move\ 40 - ton\ Container\ by\ UFT\ for\ One\ mile = Required\ Electricity\ \times Coefficient\ Factor$$
(Eq. C-6)

Required electricity to move 40-ton container for one mile = 0.667 kWh
Coefficient of kWh electricity to BTU = 3,412.141

$$Required\ Energy\ to\ Move\ 40\ ton\ Container\ by\ UFT\ for\ One\ mile = 0.667\ kWh \times 3{,}412.141\frac{BTU}{kWh} = 2{,}276\ BTU$$

The Texas transportation system is critical to the United States economy. According to a report prepared for TxDOT, NAFTA tonnage on Texas highways and railroads is expected to increase by nearly 207 percent from 2003 to 2030. Truck tonnage will grow by 251 percent while rail tonnage is forecasted to increase 118 percent. The number of trucks carrying NAFTA goods will increase by 263 percent and the number of rail units will grow by 195 percent. This will have a profound impact on the Texas highway and rail systems. Additionally, larger ships will arrive in the Port of Houston due to Panama Canal expansion. Therefore, increasing the capacity of the freight transportation system in Texas is a must, but increased land development and population growth make the possibility of building new roads, widening existing roads, and building new railroad tracks very difficult if not impossible. Underground freight transportation (UFT) is a class of automated transportation systems in which vehicles carry freight through pipelines and tunnels between terminals Being able to use a part of the underground space of the existing highways, will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs. By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the stakeholder committee input, this project examines the use of UFT in three proposed routes in Texas, specifically, the Port of Houston to City of Lancaster (near Dallas), Port of Houston to a distribution center within 15 miles of the Port's point of origin, and the border crossing with Mexico in Laredo. This project has shown that underground freight transportation is financially viable, feasible, greener, cost-effective, and can become an important part of intermodal freight mobility in Texas.

CUIRE

UNIVERSITY OF TEXAS ARLINGTON

DEPARTMENT OF CIVIL ENGINEERING

Texas Department of Transportation