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16. Abstract

Currently, Texas urban areas face congestion problems that diminish personal mobility and freight-transport productivity. The prospect of rural congestion in some highway corridors appears imminent, according to a recent Texas Department of Transportation study. An increasing number of experts suggest that separating freight traffic from passenger traffic makes sense in terms of economics, the environment, and safety. Some experts suggest that freight pipelines are the solution.

The objective of this project is to evaluate the potential benefits and limitations of freight pipelines as a viable mode of cargo transport that can alleviate congestion on Texas highways. Specifically, this research employs theoretical and practical methods in: identifying and evaluating transportation corridors amenable to freight pipeline use; identifying, evaluating, and selecting appropriate freight pipeline systems; evaluating the technical, institutional, and economic feasibility of freight pipelines on selected corridors; and estimating environmental, energy, and safety benefits.

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CHAPTER 1

INTRODUCTION

This chapter introduces the relevant framework behind this project. It comprises five sections numbered 1.1 through 1.5:

1.1 Background and significance of project;

1.2 Problem facing TxDOT;

1.3 Project objectives and potential benefits;

1.4 Research approach; and

1.5 Organization of report.

1.1 BACKGROUND AND SIGNIFICANCE OF PROJECT

The economic vitality of this nation relies on the movement of both people and goods. As former U.S. Secretary of Transportation Samuel K. Skinner said (U.S. Dept. of Transportation, 1990):

"No industry in the Nation is more important to the U.S. economic growth and international competitiveness than transportation."

However, the increasing demands for the U.S. surface transportation system to facilitate the mobility of people and maintain and improve the productivity of freight services have reached crisis conditions in some regions of the nation. Due to restrictions of right-of-way, environmental mandates, and projected shortfalls in highway revenues, the traditional approach of increasing the capacity of existing highways or developing new highways is often neither pragmatic nor possible.

Currently, Texas roadways are facing congestion problems resulting in diminished mobility and freight-transport productivity. The Texas Transportation Institute (Shrank and Lomax, 1996) concluded that four of the seven largest urbanized areas in Texas rank in the upper third of the 50 largest U.S. urbanized areas in terms of congestion (Houston, Dallas, Fort Worth, and Austin). This congestion results in a combined annual delay and fuel cost of almost $4.4 billion in 1996 dollars.

Similarly, the prospect of congestion on rural Texas interstate highways appears imminent. According to TxDOT study 0-1326 (Gonzalez-Ayala et al., 1996a), the projected congestion along rural I-35 from San Antonio to Dallas would increase travel times from about 4.5 hours now to 8 hours between 2005 and 2016. The study estimated that the increased travel time would result in $105 billion to $205 billion in combined user and social costs over the next 50 years. Out-of-pocket costs along this route were estimated to increase by over 150 percent for passenger-car users to over 180 percent for heavy-truck operators.

The congestion and related societal problems facing the nation and Texas appear to be rooted in the dual role of highways, transporting both people and freight. Unfortunately, this dual role causes financial, environmental, and safety difficulties as well. For example, to increase the capacity of congested highways, TxDOT must increase the number of lane-miles. Because heavy-trucks are allowed on these same thoroughfares, however, the thickness of pavement must be increased from three to six times (depending on subsurface conditions and heavy-truck volume) that required for passenger cars alone (i.e., the cost of congestion relief is between 200 and 500 percent more than that needed to reduce congestion). Additionally, the rehabilitation and maintenance expenditures of highways in Texas are approximately 60 percent of highway construction expenditures, and of that amount heavy-trucks account for over 80 percent of these costs (Euritt et al., 1993). Also, the fiscal realities are that:

- Highway freight transportation is heavily subsidized by passenger-car drivers (i.e., in Texas, combination trucks pay only 50 percent of the direct costs they impose); and
- State DOTs, due to the above situation, are constrained to construct highways at sub-optimal conditions.

These two related factors not only combine to increase rehabilitation and maintenance costs but also inevitably increase congestion, since public funding for capacity improvement is no longer sufficient to meet expected demand.

A potential solution to these problems may be freight pipelines. As the John A. Volpe National Transportation Systems Center (1994) points out, the fundamental scientific concepts of freight pipelines are about 200 years old, and freight pipelines have been in operation since the 1850s. Recent advancements, though, in both pipeline technology and computer control systems have greatly enhanced the capability of pipelines to transport solid material (Liu et al., Undated).

Proponents of freight pipelines claim the following social benefits (Ampower, Undated; Vandersteel, 1995; John A. Volpe National Transportation Systems Center, 1994):

- Reduced congestion and roadway damage due to removal of long-haul trucks from highways;
- Increased safety due to removal of long-haul trucks from highways;
- Decreased air pollution due to removal of long-haul trucks from highways, since modern freight pipeline systems use electric or pneumatic power;
- Decreased energy use due to removal of long-haul trucks from highways; and
- Increased transportation productivity due to greater potential for automation and improved scheduling control.

Since most experts believe that freight pipelines will be privately constructed and financed, the potential economic benefits from freight pipelines could be staggering. Using the MTS system as recommended by TxDOT project 0-1326 as an example, at least $715 million can be saved in construction and maintenance costs by eliminating all heavy trucks from this proposed roadway (source; Research Report 1326-2, Table B.5 (McCullough et. al, 1996)).

Additionally, passenger-car users would benefit. According to Table 6.1 in Report 1326-2, passenger car users would save at least 6 cents per km traveled, regardless of level of service (LOS), by eliminating trucks. Along I-35, that would mean an annual savings of $246 million, which has a present value of over $3 billion (calculated at TxDOT’s official discount rate of 8 percent over 50 years).

1.2 PROBLEM FACING TXDOT

As stipulated in the Intermodal Surface Transportation Efficiency Act (ISTEA), mobility in the United States must be maintained, while the increasingly aggravated congestion on U. S. roadways must be relieved without sacrifice to either personal safety or the environment. This stipulation, however, presents TxDOT with the dilemma of shifting its emphasis from constructing new transportation highway corridors to extending the capacity of existing systems.

An increasing number of experts suggest that separating freight traffic from passenger traffic makes sense in terms of economics, the environment, and safety. An integrated transportation system that can provide flexible, convenient, safe, and speedy movement of both people and freight should be developed to satisfy the ever increasing demands for personal mobility on the one hand and cost effective, timely, safe, and secure freight transportation on the other. With the advent of computerization and national information infrastructure, TxDOT can develop a fully automated freight-transport system. Thus, the need to "pump" freight through underground ducts and pipelines has been advocated.

Consequently, in preparation for transportation in the 21st century, TxDOT wants to explore the use of freight pipelines to relieve congestion on Texas highways.

1.3 PROJECT OBJECTIVES AND POTENTIAL BENEFITS

The general objective of this research is to evaluate the potential benefits and limitations of freight pipelines as a viable mode of cargo transport that can alleviate congestion on Texas highways. The specific objectives are:

- Determine the cost of the freight pipeline infrastructure along with the institutional, technological, and economic feasibility of this freight pipeline system;
- Determine the extent of congestion relieved, if proven feasible; and
- Determine the social cost savings due to the freight pipeline system, if proven feasible.

With respect to TxDOT administrators, the potential benefits from this research are:

- A better understanding of the capabilities of a freight pipeline system;
- Flexibility in decision making by providing a new alternative regarding congestion relief; and
- A plan of what needs to be accomplished in order to effect a freight pipeline system in terms of technical, institutional, and economic factors.

1.4 RESEARCH APPROACH

Figure 1.1 presents the research approach used in this project. The key components are the three feasibilities of technical, instructional, and economic. Of these feasibilities, the most critical is economic feasibility, principally because less current research has been performed in this area.

In addition, discussions with this project's TxDOT advisory committee recognized the importance of the economic feasibility assessment. While the committee wanted the research team to address institutional and technical feasibility, it directed the research team to focus on economic feasibility of the freight pipeline system.

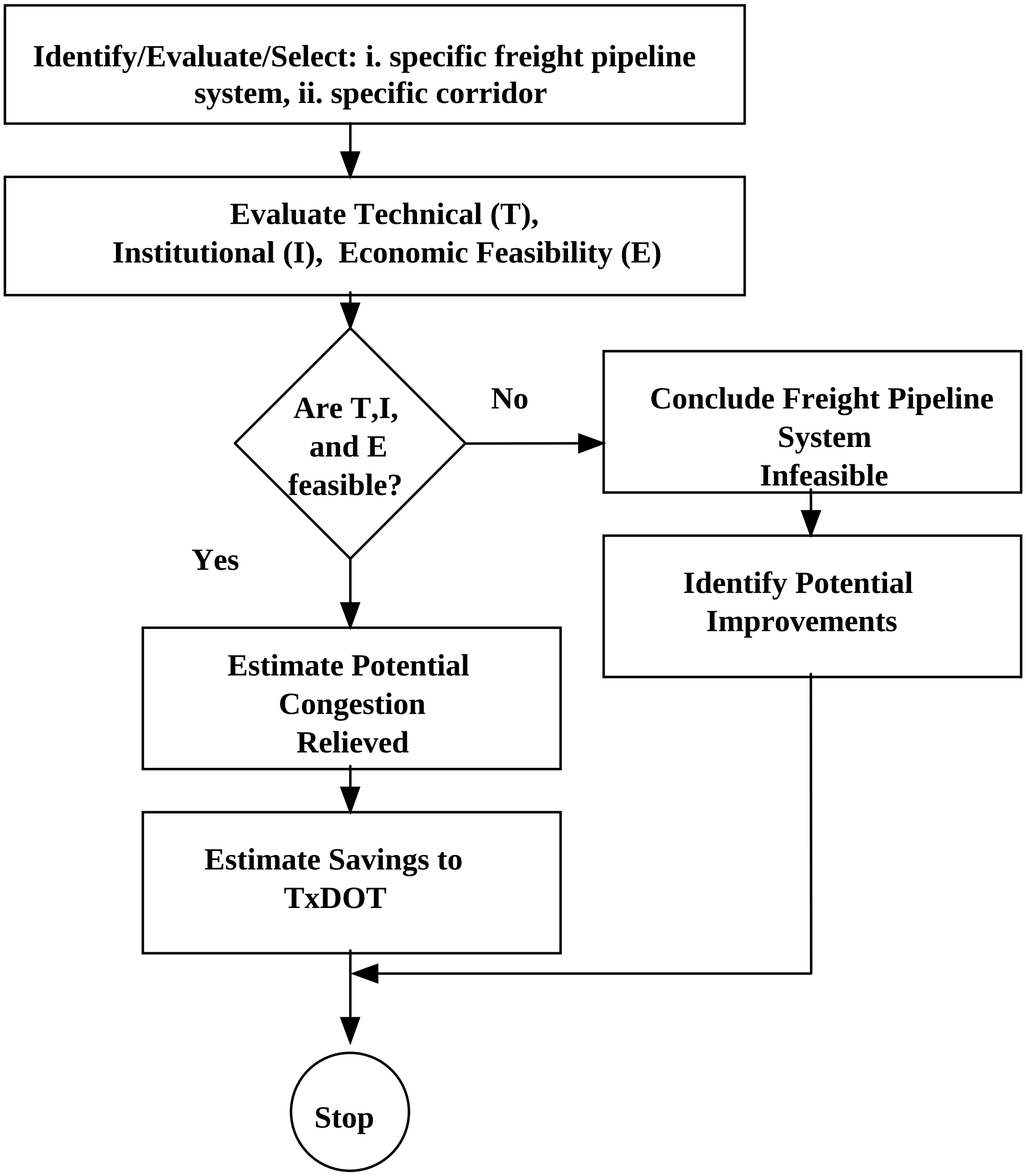

Figure 1.1 Research Approach.

1.5 ORGANIZATION OF REPORT

Four chapters follow this introduction. Chapter 2 addresses freight system selection and qualitative feasibilities (i.e., institutional and technical). Chapter 3 concentrates on infrastructure and freight pipeline system operating expenditures, which are necessary data inputs to Chapter 4, which contains the economic feasibility assessment. Chapter 5 presents a summary along with an identification of potential improvements.

CHAPTER 2

SELECTION PROCESS AND QUALITATIVE FEASIBILITY ANALYSES

The overall approach of this project involved selecting a corridor and a propulsion system for the tube-freight system under study and then conducting institutional, technical, and economic analyses with respect to the aforementioned elements selected. In this chapter, Section 2.1 discusses the selection of the corridor and the propulsion system for the freight pipeline under study. Institutional and technological feasibility evaluation is discussed in Sections 2.2 and 2.3, respectively. Section 2.4 summarizes the chapter.

2.1 THE SELECTION PROCESS

2.1.1 Corridor Selection

The Project 0-1803 Advisory Committee stressed that corridor selection was of minor importance for them, and therefore, not much emphasis should be placed on it. The research team evaluated a set of eight corridors based on advantages and disadvantages. Advantages were limited to the following:

- Desirable existing congestion;
- High potential for a pipeline market (i.e., corridor would have high population and manufacturing growth potential); and
- High conductivity potential.

Disadvantages were limited to estimated pipeline infrastructure installation costs (i.e., the lower the better) and whether or not a change in pipe diameter would require an increase above two meters.

The eight corridor alternatives were:

1. San Antonio–Laredo corridor picks up the North America Free Trade Agreement (NAFTA) trade and provides location for northerly connections;
2. Dallas/Fort Worth (D/FW)–Houston corridor is part of the “Texas triangle” and connects two of the largest urbanized areas in Texas;

3. San Antonio–Houston corridor is part of the “Texas triangle” and has east-west conductivity potential;

4. Houston to Corpus Christi/Brownsville corridor is already heavily traveled and is proposed to be part of an interstate system that would connect Mexico with Chicago;

5. D/FW–Alliance Airport corridor is completely within an urbanized area and offers true intermodal potential. Members of the Texas legislative delegation once proposed the corridor as a test site for freight pipelines.

6. D/FW–El Paso corridor was suggested to the U.S. Secretary of Transportation in 1994 as a link for a pneumatic capsule pipeline carrying general merchandise;

7. Port of Houston–Houston link establishes an intermodal connection to the interior of Texas and has the potential of connecting to the eastern seaboard; and

8. San Antonio–D/FW I-35 link has north-south connectivity and high congestion potential.

Table 2.1 evaluates the above corridors on a 0-4 point scale, with 4 being the highest rating for advantages, and 4 being the best rating for disadvantages (i.e., a 4 rating in the disadvantage category means least disadvantageous). Based on the analysis in Table 2.1, the San Antonio–D/FW - I-35 corridor was selected.

Table 2.1 Corridor Evaluation.

Corridor	Advantage Rating	Disadvantage Rating	Total Points
San Antonio-Laredo	2	2	4
D/FW-Houston	3	2	5
San Antonio-Houston	2	3	5
Houston-Brownsville	2	3	5
D/FW-Alliance	3	2	5
D/FW-El Paso	0	4	4
Port Houston-I-10	4	0	4
San Antonio-D/FW-I-35	4	2	6

2.1.2 Propulsion System Selection

The Task Committee on Freight Pipelines reports that capsule pipelines are the most versatile because they can carry solids, containerized liquids, or other packaged products (Liu et al., Undated). The committee categorizes two types of capsule pipelines as follows:

1. Hydraulic capsule pipelines (HCP) carry capsules suspended in water. These capsules can either be cylindrical containers or cylinders made from material such as coal-logs; and
2. Pneumatic capsule pipelines (PCP) use air/inert fluid to transport; however, the fluid does not have sufficient buoyancy and lift forces to suspend the capsules carrying a heavy cargo and therefore must use wheels affixed to the capsule.

PCP systems have shown operational feasibility. According to the John A. Volpe Transportation Systems Center (1994), the following examples are/were operational, freight-pipeline systems:

- 1971– a 0.92 m diameter, 427 m prototype system built by TRANSCO Energy Corporation of Houston, TX;
- 1971–a Russian system, called TRANSPROGRESS, having 1 m diameter and used for transporting crushed rock;
- 1973–a 0.4 m diameter x 515 m long system, built by TRANSCO and operational for four years, called TUBEXPRESS, that had automated on/off loading capabilities and demonstrated the feasibility of handling dense material;
- 1976–a 0.6 m diameter, 545 m long demonstration capsule pipeline built and operated by British Hydromechanics Research Association (BHRA) (United Kingdom) for four years;
- 1979–a second TRANSPROGRESS (Russian) line having a 1.2 m diameter extending 2.4 km that transported crushed rock;
- 1983–a 1.2 m diameter, 11 km long TRANSPROGRESS (Russian) line constructed in Leningrad for transporting garbage;
- 1983–Sumitomo Cement Co. (Japan) constructed a 1 m diameter, 3.2 km system to move limestone between its mine and cement plant. This system has a 1.8 million metric tons annual capacity;

- 1984–a 1.2 m, 44 km long TRANSPROGRESS (Russian) system transports crushed rock; and

- 1985–a 0.61 m diameter, 1.5 km system based on TUBEXPRESS technology, known as AIRAPID, was built to remove burnt lime from Nippon Steel's Muroran Number 2 steel plant. This system has a capacity of removing over 216,000 metric tons per year.

Two freight pipeline systems are currently proposed at this time. They are the following:

1. SUBTRANS is a freight pipeline concept developed by William Vandersteel, a 50 percent owner of the TUBEXPRESS Corporation. SUBTRANS is a 2 m diameter pipeline that will transport capsules at an average speed of over 90 km/h. The capsules would be propelled by linear electric motors, be totally automated, and would load and unload capsules at speed, with pneumatic pressure providing a buffer between the capsules. The claimed capacity of this system is estimated at over 2,600 Mg per hour at average cargo densities (Ampower Corp., Undated); and

2. The BHRA system (UK) proposes 9 Mg capsules that operate in 1.52 m diameter tubes at speeds of between 32 km/h and 48 km/h, having a capacity of about 1.125 Mg per hour. Pneumatic pressure generated by Rootes-type jet pumps would propel the system (John A. Volpe National Transportation Systems Center, 1994).

Two basic choices exist regarding the propulsion system for the subsurface freight-pipeline systems under study:

- Pneumatic blowers (PB), or

- Linear electric motors.

Linear electric motors can either be linear synchronous motors (LSM) or linear induction motors (LIM). Generally, LSMs are more energy efficient than LIMs, but they are also more expensive, according to researchers Zhao and Lundgren (1996). Aside from cost considerations, these researchers report that LIMs have several other advantages over LSMs:

- LIMs do not require a direct connection with an outside power source;

- LIMs are rugged; and

- LIMs require less maintenance.

For this project, a comparison between LIMs and PBs is made in Table 2.2.

Table 2.2 Comparison between LIM and PB.

Item	LIM	PB	Comments
Hauling range	High	Low	PB hauls fewer km
Noise level	Low	High	per Zhao and Lundgren
Energy efficiency	High	Low	per Zhao and Lundgren
Capsule speed	High	Low	LIM 90 km/h vs. PB@ 48 km/h
Potential freight throughput	High	Low	LIM 2600 Mg/h vs. PB 1125 Mg/h
Braking flexibility	High	Low	See discussion below

For safe operation, the flexibility of the braking system is particularly important. LIMs can be stopped via mechanical devices, aerodynamic drag, and LIM thrust force. Zhao and Lundgren (1996) concluded that the LIM thrust forces could generate:

- Regenerative braking, which occurs when LIM velocity exceeds the synchronous velocity;
- Counter-current braking, which is obtained by reversing the primary winding connection; and
- Dynamic braking which occurs when direct current excites the primary windings immediately after disconnect from the three-phase source.

Therefore, LIMs offer clear and compelling reasons for this project’s propulsion choice.

2.2 INSTITUTIONAL FEASIBILITY

Institutional feasibility for the subsurface tube-freight system was evaluated for environmental effects and availability of personnel. The research team assumed that subsurface tube-freight systems would adhere to the same governmental regulations as oil and gas pipelines. Consequently, governmental regulations should not be an impediment to the construction of a subsurface tube-freight system.

2.2.1 Environmental Effects

Based on information provided by Ingersoll (1998), the environmental effects of LIM powered tube transportation system were compared to the environmental effects of trucks and rail modes. Table 2.3 presents these results.

Table 2.3 Modal Comparison of Environmental Effects.

Rankings: 1 = least environmental impact 2 = moderate impact 3 = most impact

Criteria	Truck	Train	Tube Transportation System (LIM)
Oil leakage/spillage	3	2	1
Other liquid pollution	3	2	1
Soot & dust emissions	3	2	1
Emission of pollutants during construction	3	2	1
Consumption of land	3	2	1
Change in ecology	3	2	1
Energy required–building facility	3	1	2
Change in visual appearance	3	2	1
Nature conservation	3	2	1
Noise pollution	2	2	1
Point source pollution	3	2	1
Total energy used	3	1	2

Among the 12 criteria in Table 2.3, the tube transportation system ranks better (i.e., least environmental effect) than either the truck or train mode in 10 of the criteria and ranks second in only two of the criteria.

2.2.1 Availability of Personnel

Personnel needed for the operation of a tube-freight system can be divided into two groups: technical and non-technical. The following technical personnel would be needed:

- Engineering–civil engineers for the concrete tube, mechanical engineers for the track system, electrical engineers for the LIM and control system, and computer engineers for computerization;
- Inspection–inspectors for tube and track. LIMs and controls could be inspected via sensors;
- Technicians–personnel to perform tube, track, and LIM and control maintenance; and

- Quality assurance and reliability–personnel to minimize defectives and to assure the integration of mechanical, electrical, and concrete systems operates as intended.

Non-technical personnel comprises general, sales, administrative, and labor (GSAL). Specifically, GSAL personnel would include:

- Legal–to comply with federal, state, and local regulations, along with applicable tariffs, contracts, and Securities and Exchange Commission (SEC) regulations;
- Accounting, finance, and record keeping–to develop managerial cost control, financial statement preparation, budget preparation, cash-flow management, credit assessment and collection, debt repayment, dividend decisions, financial forecasting, asset acquisition and disposal, and internal auditing;
- Marketing and sales–to develop market research, strategic planning (in conjunction with accounting, finance, and engineering personnel), advertising, and customer base development;
- Investor relations, employee relations, and public relations–to inform investors and employees, develop personnel, and generate publicity (i.e., to educate potential tube-freight shippers); and
- Consolidation and freight labor–to carry out the physical aspects of moving freight and coordinating shipments.

Personnel would have to acquire new skills because the tube-freight system involves the integration of mechanical, electrical, and concrete components. Also, the successful operation of this system depends on the marketing strategy used. Thus, a competent understanding of the tube-freight market would also be required.

However, the attainment of this new knowledge is foreseeable in the near future. Technical personnel could use visual imaging techniques to determine design flaws and improve the reliability of the system. During the development phase, additional knowledge could be obtained. For example, market knowledge could be obtained by performing market research.

Thus, the availability of trained personnel and requisite new knowledge is likely to be accomplished in the near term (four to six years).

2.2.3 Summary of Institutional Feasibility

The governmental, environmental, and personnel aspects of the proposed tube-freight system are adequate. Any additional expertise and skills can be obtained in the near term. As a result, the research team concludes that the LIM-based tube-freight system is institutionally feasible.

2.3 TECHNOLOGICAL FEASIBILITY

This section examines the technological feasibility of the tube-freight system and its safety and reliability compared to truck and rail modes.

2.3.1 Safety Effects

Table 2.4 compares the safety effects of the truck, rail, and tube-freight system. As a proxy for evaluating the tube-freight system safety, the research team incorporated the findings of the U.S. Department of Transportation (1990) with regard to maglev (magnetic levitation)-type transportation.

Table 2.4 Modal Comparison of Safety Effects.

Rankings: 1 = least environmental impact 2 = moderate impact 3 = most impact

Potential Hazards	Truck	Rail	LIM Tube System
Physical infringement from mode to mode	3	2	1
Electromagnetic-field effects	2	3	1
Transporting hazardous material	3	2	1
Accessibility for inspection	1	2	3
Accessibility for emergencies	1	2	3
Vulnerability to trespass	3	2	1
Inclement weather effects	3	2	1
Earthquake effects	1	2	3
Flood, high water-table effects	2	1	3
Drought, wind erosion effects	1	2	3

If one considers all of the potential hazards as having equal likelihood and severity, the research team observes that all three systems have an average rank of 2. However, the tube-freight system has one tremendous advantage over the other modes—minimal human interaction.

Of the five potential hazards in which the tube-freight system ranks worst, two of the hazards, inspection access and emergency access, directly relate to the potential safety of humans. The major human activities in the tube-freight system would involve inspection of the track and tube as well as the maintenance and repair of the tube, track, and LIMs.

In inspecting a dark, 2 m tube, the average male would have 0.3 m of clearance to walk through the tube. The average female inspector would have about 0.4 m of clearance. Since maintenance activities would primarily consist of kneeling and bending, over 1 m of clearance would be available. Therefore, the proposed tube-freight systems would have acceptable risk in this area.

Limitation on emergency access may be a problem; however, human presence in the tube would amount to about five days per month. This is approximately 16 percent of the human presence of both truck and rail modes. Due to this low human exposure, the risk regarding emergency access is acceptable.

Potential hazards involving earthquakes, flooding, and drought would affect the integrity of the tube system. Earthquakes would cause misalignment in the tube. In this case, the capsule would break through the concrete shell and intrude into the adjacent tube.

However, earthquakes would be a rare event in Texas. Thus, intrusion into the adjacent tube is considered an unlikely event. Consequently, earthquake hazards associated with tube-freight movement are considered acceptable risks.

Droughts are common in Texas and would also cause misalignment since the soil would separate and move a tube section. However, the problems caused by the droughts can be addressed by system design. Therefore, the risk associated with this particular hazard is acceptable.

Flooding is probable and would result in the tube filling with water, curtailing tube-freight movement. However, this problem can be solved via the design and development process.

For all of these reasons, researchers consider the tube-freight system safe. It can transport hazardous materials more safely than either the truck or rail mode. The negative effects of trespass and inclement weather are low compared to the other two modes. Although the tube-freight system does have comparatively worse rankings in five hazards, only two of these areas involve humans, and the human exposure to these hazards is greatly reduced. The geological hazards, although high compared to the other modes, are either unlikely to occur or can be moderated by better design.

2.3.2 Reliability Assessment

Tube transportation, as proposed in this project, consists of four major systems: propulsion and controls, the tube, the guideway or track, and the human system. On the other hand, the truck mode has three major systems: propulsion, highway, and human.

Based on information contained in a recent University of Texas-San Antonio report (Ingersoll, 1998), a comparison of the reliability between the truck and tube modes can be made. This comparison is presented in Table 2.5, in terms of mean time between failures. A single electric motor has a mean time to failure of 116 years (Ingersoll, 1998) if operated continuously. However, the tube mode would require 32 LIMs per kilometer or about 14,400 LIMs per one-direction 450 km route between San Antonio and Dallas. The reliability of such a massive in-series system would be considerably less than that of a single electric motor operating continuously.

However, the LIMs would be operating for only a small fraction of a year, not continuously. Without extensive reliability analysis, the research team estimates that the mean time to failure is about 67 percent of 116 years to obtain a more reasonable value of 80 years.

Trucks operate in an environment that places a great deal of stress on their diesel engine power trains, such as stopping and accelerating in urban traffic. Because of this stress and the fact that there are numerous mechanical parts in the power train, truck engines typically fail between four and ten years, on average.

Pavements in Texas are typically designed to last an average of 20 years; however, these pavements undergo a tremendous amount of stress from the repetition of the forces emanating from the vehicle wheels. As a result many pavements in Texas, because of unseen growth in wheel repetitions, last less than 20 years. In contrast, the concrete pipe in the tube mode would not undergo forces experienced by the highway pavement. Therefore, the concrete tube would last, on average, around 60 years.

The guideway system estimate of mean time to failure is partially based on studies pertaining to maglev operations. In contrast, the track system in the tube mode would undergo greater forces than that of the maglev. Thus, the track in the tube mode would have a shorter mean time to failure.

A typical track system in the rail mode lasts about 20 years, and it experiences about six times more force than the tube mode. Hence, the mean time to failure of the tube mode lies between the 125-year estimate of the maglev system and the 20-year estimate of the rail system. To be conservative, the research team adds 33 percent of the difference between maglev and regular rail (i.e., 35 years) to the rail mode's 20 years to obtain a mean time to failure of 55 years.

Humans have major hazard exposure in the truck mode, but in the tube mode they have limited exposure. Thus, the research team believes that in the tube mode humans would have a higher mean time to failure than those in the truck mode. Table 2.5 compares the estimated reliability of the two modes.

Table 2.5 Reliability Comparison.

	Estimated Mean Years to Failure	
System	Truck	Tube
Propulsion and controls	4-10	80
Tube/Highway	20	60
Track or Guideway	-	55
Human hazard exposure	Low	High

The research team concludes that the reliability of the tube system appears superior to trucks. The propulsion system should last longer, the concrete tube should last longer than highways, the track system should last almost three times as long as regular train tracks due to fewer forces exerted on it, and humans would perform better due to limited exposure and the fact that their tasks would be easier.

2.4 CHAPTER SUMMARY

The tube transportation system under study follows a 450 km route from San Antonio to Dallas, parallel to I-35. This system uses linear induction motors to propel 7.3 Mg capsules along the route.

The proposed tube transportation system is institutionally feasible with regard to the environmental effects and the availability of personnel. Additionally, this system is technologically feasible as well. It is safe compared to either trucks or rail modes and is demonstrably more reliable than the truck mode.

CHAPTER 3

COST ESTIMATE FOR TUBE TRANSPORTATION

In this chapter the research team estimates the infrastructure and operational costs. Section 3.1 presents the tube transportation infrastructure cost estimates, Section 3.2 provides estimates for the operation of the tube system, and Section 3.3 summarizes this chapter.

Of note are Sections 3.1.10 and 3.2. Section 3.1.10 provides a summary of the estimated one-direction capital costs of this system, and Section 3.2 provides a summary for the estimated one-direction operating expenses for tube transportation.

3.1 INFRASTRUCTURE COSTS

The tube transportation infrastructure in the Dallas–San Antonio corridor is proposed to be along the alignment of the existing Interstate Highway 35. The tube tunnel would be built parallel to the I-35 alignment, from the center of the city of Dallas to the center of the city of San Antonio, as shown in Figure 3.1.

The diameter of the tube tunnel is proposed to be 2 m, to facilitate maintenance and inspection activities. Offloading stations/terminals would be built along the alignment at Waco, Temple, Austin, and San Marcos, in addition to the terminals at Dallas and San Antonio. Building such infrastructure would primarily include the following major cost components:

- Cost of right of way;
- Cost of tunneling/tube installation;
- Cost of LIMs;
- Cost of offloading stations;
- Cost of containers/capsules; and
- Cost of design, project management, and contingencies.

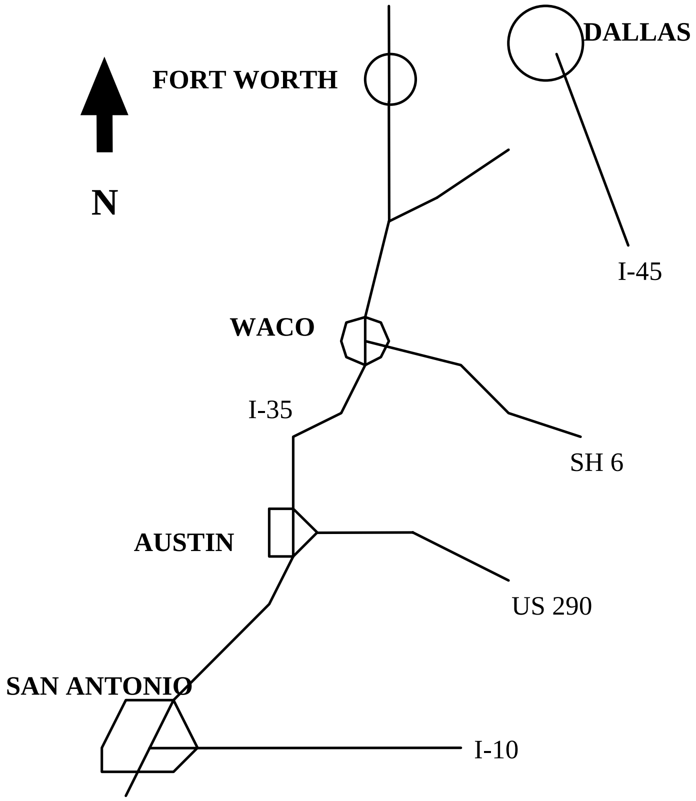

Figure 3.1 I-35 Alignment between Dallas and San Antonio.

In urban areas, cost of utility relocation can be significant and may have to be added to the components listed above. For example, in a study conducted at the Massachusetts Institute of Technology (MIT), researchers estimated the utility relocation costs for the Boston area to be as high as $331 per meter in 1994 dollars (John A. Volpe National Transportation Systems Center, 1994). The utility relocation costs include the cost of excavation, piping, corrosion protection, trench backfilling, compaction, and surface restoration. The utility relocation costs are considered to be inconsequential, for reasons discussed herein. These factors, as well as the difficulties affecting tube transportation infrastructure cost estimation, are discussed below.

3.1.1 Right of Way

There are no standards for determining right-of-way costs, particularly for an underground facility such as the tube tunnel required for tube transportation. The property acquisition for underground facilities primarily involves a “buried stratified fee,” which accounts for the cylindrical portion of the space underground used by the infrastructure facility. Since the tube transportation infrastructure is proposed along the existing I-35 alignment, it is assumed that no additional costs will be incurred for facilities, which would be built about 6 m beneath the existing 90 to 120 m wide I-35 alignment.

Surface land acquisition would, however, be required to buy the right of way for access shafts, ventilation shafts, and the offloading stations. At this stage, the research team proposes one offloading station every 80 km, on the average, along the alignment. The right of way costs are estimated below for surface land to be acquired. These costs do not include potential cost of damages, loss of access, and other factors that are highly project specific.

At the rate of one shaft per 1.6 km, about 280 access/ventilation shafts are required for the tube tunnel. The total estimated land requirement for all shafts would be 280,000 m^2, each shaft requiring about 1000 m^2 of land acquisition. Statistics indicate approximately 24 percent of this land is in urban areas. This estimate is based on the city limits demarcated in yellow on the Texas Department of Transportation Official Highway Travel Map. Additional land acquisition would also be necessary for the offloading stations/terminals. The research team estimates that six terminals would be built, each terminal requiring about 7500 m^2 of land. Based on the estimated ranges for the cost of land acquisition provided by the Texas Department of Transportation's Right of Way Division, the total cost of right of way is estimated below (Texas Department of Transportation, 1998a):

- Cost of land acquisition in rural areas along I-35: \$2.70 to \$21.50 per m^2; and
- Cost of land acquisition in urban areas along I-35: \$11 to \$270 per m^2.

Assuming average cost of land acquisition in rural areas to be \$12.10 per m^2 and \$140 per m^2 in urban areas, the estimated total cost of land acquisition is given in Table 3.1.

Table 3.1 Land Acquisition Costs for 450 km Facility.

Component	Spacing	Number Required	Size (m^2) Required	Land (m^2) Required	Land Unit Cost/m^2	Total Cost
Access Shafts/ Ventilation ducts						
• Rural Areas	1.6 km	213	1000	213,000	\$ 12	\$ 2,556,000
• Urban Areas	1.6 km	67	1000	67,000	\$ 140	\$ 9,380,000
Offloading stations/terminals	—	6	7500	45,000	\$ 140	\$ 6,300,000

Accurate estimation of the land requirement and the corresponding costs would nevertheless require detailed engineering surveys and negotiations with affected landowners.

3.1.2 Cost of Tunneling/Tube Installation for Transportation Infrastructure

Installation of the subsurface transportation infrastructure is the largest component of the capital cost of a tube transportation infrastructure. The installation can be carried out by the cut and cover technique, by tunneling, or by pipe jacking. The method chosen for installing the tube substantially affects the cost of construction. The cost of construction also varies with the depth at which the tube is to be installed. In the absence of an engineering survey of the subsurface utilities (i.e., oil and gas pipelines) the tube would be installed at a depth slightly greater than six meters in urban areas and within city limits, based on the findings in an interview with a utility specialist from TxDOT (1998b).

In order to make more precise estimates, the "Subsurface Utility Engineering" process, known locally as SUE, would have to be carried out. This process involves detailed investigations of the subsurface ground characteristics and identification of subsurface utilities, pipelines, and other objects. To minimize the cost owing to conflicts with such features, tunneling would have to be used in the zone inside the city limits. This process also minimizes congestion-related problems on the ground, which can impose severe limitations on the construction. Outside the city limits, the depth of tubing can be less than six meters, and the cut and cover technique would be more economical in these zones.

In the absence of field investigations, it is difficult to accurately estimate the portion of the alignment that would fall within city limits and the other portion, which would fall outside the city limits. As in the right-of-way case, the research team estimates 24 percent of the total alignment of 450 km is within city limits. The important cities that the research team accounted for along this alignment include Dallas/Fort Worth, Waco, Temple, Belton, Austin, San Marcos, and San Antonio.

3.1.3 Estimating Tunneling Costs

Two basic methods for estimating tunnel costs are:

1) a simulation of actual construction operations, in which researchers estimate amounts and types of equipment and materials needed, crew productivity rates, the rates of material and labor usage and tunnel advance, and a total estimated cost is computed; and

2) a comparison with similar tunnels, in which the unit costs of major construction components, such as excavation, muck hauling, support and lining, and pumping are determined

and applied with or without adjustments for inflation and other factors to the present tunnel, for which the quantities of each component have been computed (Bennett, 1981).

However, it is extremely difficult to obtain unit costs for similar tunnels, since such data is not readily available. Therefore, the tunnel cost estimates for the tube transportation infrastructure can, at best, be order-of-magnitude estimates. Moreover, considerable variation can be expected from the estimates discussed here.

The U.S. Army Engineer Waterways Experiment Station published a report titled “Tunnel Cost-Estimating Methods” (Bennett, 1981). This study is by far the most extensive of its kind, and it provides case histories of three completed tunnels for which good documentation was available. Of the three, the most detailed information is available for the Nast Tunnel, built between 1970 and 1973 in Pitkin County, Colorado. Nast Tunnel is a 4770 m long, 3 m diameter, circular and horseshoe tunnel, excavated largely through competent granite, porphyry, and some crushed zones. Table 3.2 lists the estimates obtained for the construction of this tunnel and the actual cost per meter.

Table 3.2 Construction Cost Estimates for Nast Tunnel, Pitkin County, Colorado.

No.	Estimator	$/m (1973 cost)	Comments
1	Engineer 1	1,070	• Estimate numbers 1 through 7 are for
2	Contractor 1	1,427	the drill and blast excavation schedule.
3	Contractor 2	1,516	• Estimate numbers 8 through 11 are for
4	Contractor 3	1,709	the mole excavation schedule.
5	Contractor 4	1,673	• COSTUN estimates are for mole
6	Contractor 5	1,752	excavation in good quality rock and
7	Contractor 6	1,755	conventional excavation in poor
8	Contractor 7	1,417	quality rock.
9	Contractor 8	1,378	• Estimate number 12 represents
10	Contractor 9	2,077	estimated costs for most likely
11	Engineer 2	1,076	conditions. Other COSTUN
12	COSTUN program 1	1,486	estimates account for variations in
13	COSTUN program 2	1,578	conditions or for sensitivity analysis.
14	COSTUN program 3	1,391	• As-built cost includes cost of relevant
15	COSTUN program 4	1,732	change orders.
16	COSTUN program 5	1,335	
17	COSTUN program 6	1,375	Highest estimate = $2,077/m
18	COSTUN program 7	1,588	(33% higher than as-built cost)
19	COSTUN program 8	1,568	Lowest estimate = $1,070/m
20	COSTUN program 9	1,486	(32% lower than as-built cost)
	As-Built Cost	1,565	As-Built Cost (1997 dollars) = $3,919/m

Assuming that the trend of the national average construction cost index was not significantly different from the trend of the construction cost index for Pitkin County, Colorado, the as-built cost per meter for the Nast Tunnel would be $3,919 in 1997 (cost index for Denver, Colorado, is used since the index for Pitkin County is not available). This sum translates to $4,210 per meter national average and $3,637 per meter for the 3 m diameter tunnel in the Dallas, Texas, region, based on the location factors of 0.931 and 0.864 specified in the Means Assemblies Cost Data (R.S. Means Company, Inc., 1997). This calculation translates to a construction cost of $2,155 per meter for the proposed Dallas–San Antonio tube system, with size adjusted to a 2 m diameter tunnel using a factor of 1.6875 (based on Figure 3.2).

In another significant research project conducted at MIT and initiated by the FHWA and the Volpe National Transportation Systems Center, tunnel construction costs were collected for over 100 projects (Sinfield and Einstein, 1998). Researchers reduced the data set to 52 tunnels by eliminating projects involving multiple tunnel diameters, unusual projects such as caverns and underground storage facilities, and projects that included costs of other structures in the construction cost. The costs for projects with tunnel diameters ranging from 1.8 m to 2.4 m are given in Table 3.3 below.

Table 3.3 Construction Costs for Tunnel Projects.

Project Number	Diameter (m)	Construction Cost (1994 $/m)	Construction Cost (1997 $/m)
34	1.80	1,673	1,809
35	1.80	3,255	3,520
36	1.80	3,727	4,030
37	2.30	2,539	2,745
38	2.40	3,487	3,771
39	2.40	2,438	2,636
40	2.40	4,731	5,116
41	2.40	4,321	4,672

The best-fit relationship between tunnel cost per unit length and the tunnel diameter shown in Figure 3.2 is based on the original data set of 52 tunnel costs. The second order curve indicates that the cost per meter for a 2 m diameter tunnel works out to about $2,625 per meter. Considerable variation is possible in this estimate, depending on factors such as the type of soil, method of tunneling, and other local factors. The authors suggest that for tunneling in rock or mixed-face conditions, the upper-bound relationship should be used instead of the best-fit relationship. The upper bound relationship indicates a $4,757 per meter cost for a 2 m diameter tunnel, as indicated by the approximate upper-bound curve in the figure below.

These costs per meter are the U.S. national average values, and they translate to $2,267 per meter for the best-fit relationship and $4,111 per meter for the upper-bound relationship, based on the location factor for Dallas, Texas.

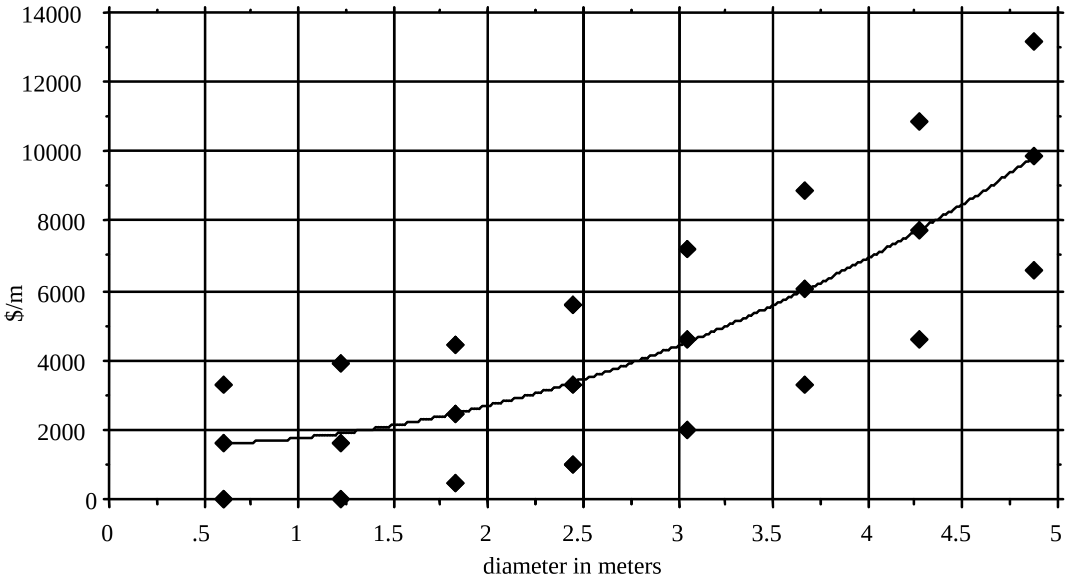

Figure 3.2 Relationship Between Tunnel Cost per Unit Length and Diameter.

3.1.4 Cost of Cut and Cover Construction

Installation of a reinforced concrete liner/tube by the cut and cover method is another approach for building an infrastructure of this nature. The installed cost of reinforced concrete pipes of up to 1.5 m in diameter was estimated in Volume III of the USDOT report entitled "Transport of Solid Commodities via Freight Pipeline" (Zandi et al., 1976). Although this report does not mention the method of installation, it is assumed here that the cut and cover method was used to construct these pipelines, since the cost estimates are consistent with those of other pipelines built with the same method. The cost per meter is extrapolated from 1.5 m to 2.0 m as presented in Table 3.4.

Table 3.4 Installed Cost per Meter of 2.0 m Reinforced Concrete Pipe.

Depth of Cut (meters)	USDOT National Avg Cost (1972 $)	USDOT Dallas Region Cost (1972 $)	USDOT Dallas Region Cost (1997 $)	MEANS Dallas Region Cost (1997 $)	Gifford-Hill American (1997 $)
1.50	274	223	557	-	-
3.60	286	232	581	-	-
4.60	298	242	605	-	-
5.80	310	251	629	-	-
7.00	319	259	647	-	-
-	-	-	-	843	1,148

Average costs from R. S. Means and Gifford-Hill American are provided for comparison. The adjusted MEANS cost per meter for a 2 m reinforced concrete (RCC) pipe in Dallas region is approximately 30 percent higher than the cost based on the USDOT report, and the Gifford-Hill American, Inc. price quote is about 77 percent higher than the cost based on the USDOT report. To be on the conservative side, the Gifford-Hill estimate of $1,148 per meter is considered appropriate for the purpose of the present analysis.

3.1.5 Cost of Track Structure

The absence of detailed engineering design of the tube transportation system at this stage of estimation imposes considerable limitation on the estimation of the cost of railroad construction inside the tube tunnel. The first three estimates given in Table 3.5 date back to the construction of the Arctic Oil and Gas railroads in early to mid-1970s (Ministry of Transport, 1974).

Table 3.5 Cost of Construction of the Track Structure

Project	Construction 1973 Cost /m (Canadian $)	Construction 1997 Cost /m (US $)
Valley Section	120	307
Delta Section	114	291
North Slope Branch	134	342
Kennedy Rail Road	-	367
Average	-	327

Although the ground conditions and other variables were different on these projects, it is assumed that the cost of construction of the track structure, excluding other elements such as the grading, culverts, and ballast, would be relevant. The fourth estimate is from the reported cost of construction for the Kennedy Rail Road (Logan, 1998).

The costs of construction on the Arctic Oil and Gas railroads are translated into U.S. dollars by first using a conversion factor of 0.98 from Canadian dollars to U.S. dollars in 1973 (Laidler, 1990). The construction cost index of 2.504, based on *Engineering News Record’s* (1998) indexes, is then applied to the 1973 cost in U.S. dollars. It is important to note that the construction cost indices published by the *Engineering News Record* are a composite index based on a certain proportion of steel, cement, and lumber used. The authors use the same index here in the absence of a better estimation parameter.

3.1.6 Summary of the Cost of Tube Installation and Track Construction

In order to account for the various cost estimates discussed above, an average of the three tunnel cost estimates per meter is worked out as follows:

• Size and location adjusted estimate for Nast Tunnel:	$2,155;
• Best-fit estimate from MIT research on past projects:	$2,267;
• Approximate estimate of Houston-based contractor *:	$3,937; and
• Average per meter cost (Low+4[Most Likely]+High)/6	$2,527.

*This estimate is consistent with the upper bound estimate from the MIT research on past projects.

Based on the tunneling and pipeline construction data discussed above and the assumption that the cut and cover method will be used over 76 percent (based on city limits shown in the Texas Department of Transportation Official Highway Travel Map) of the 450 km alignment, the cost of installing the reinforced concrete tube will be as shown in Table 3.6.

Table 3.6 Summary of Tube Construction Cost.

Component	Cost per meter (1997 $)	Total Cost
Tube tunnel installation inside city limits (24% of length) using tunneling (0.24 x 450 = 108 kilometers)	2,527	$272,916,000
Tube tunnel installation outside city limits (76% of length) using cut and cover (0.76 x 450 = 342 kilometers)	1,148	$392,616,000
Track structure material and construction (450 kilometers)	327	$147,150,000
Total Cost:	—	$812,682,000

The cost estimates used in Table 3.6 are deduced from data on completed project or estimates provided by contractors. The scope of the work involved in all of these projects was far less than the scope of work in the present analysis. This difference in scope will certainly have some impact on the actual cost of construction, as will other variables such as ground conditions. In the absence of more detailed engineering investigations, the research team considers this estimate for the feasibility analysis.

3.1.7 Linear Induction Motors

Table 3.7 presents estimates of the cost and installation of the LIM and controls.

Table 3.7 LIM and Control Estimates.

	$ per km (1997 $)		
Source	Low Estimate	High Estimate	Comments
Vandersteel		659,500	Similarly powered electric motors; vested interest in tube-freight
Mueller	160,000	460,000	Vested interest in tube-freight
Foster	400,000	600,000	
		Highest Estimate (H)	659,500
		Lowest Estimate (L)	160,000
		Most Likely Estimate (M)	500,000
		*Wtd. Avg. (H+4M+L)/6	470,000

* rounded to 2 significant digits

The estimates for the LIM and control system were obtained from the following sources:

- William Vandersteel–chief executive officer and president of AMPOWER, Inc. and patent holder of the SUBTRANS tube-freight system;
- Richard Mueller–vice president of marketing at Gifford-Hill American, Dallas, Texas; and,
- John Foster–chief engineer at Force Engineering Ltd., Leicesteshire, England, an international engineering firm that specializes in LIM design, production, and installation.

Since Vandersteel and Mueller have a vested interest in tube-freight systems, their estimates were weighted by a factor of 0.1667, while the median estimate of Foster was weighted by a factor of 0.6667. This results in an estimated LIM and control cost of $470,000 per kilometer.

3.1.8 Offloading Stations

The offloading stations for tube transportation infrastructure will require specific features for lifting, switching, storage, and maintenance of the capsules. The FHWA report on tube transportation and a quote from Gifford-Hill American, Inc., are consistent in their estimates for the cost of constructing offloading stations. Both these reports place the cost of one offloading station per 80 kilometer segment to be $25 million.

3.1.9 Containers/Capsules

The Linear Tube Transportation System (LTTS) built and tested by NKK Corporation in Japan is perhaps the only working system that operates on linear induction motors. No cost data is available however for the capsules used by NKK Corporation in the LTTS. The cash flow analysis provided by Gifford-Hill American estimates 1542 capsules over 160 km of tube at a cost of $7,000 per capsule. The FHWA report estimates the cost of each capsule to be $12,000, with 3.75 capsules assumed for every kilometer of the tube. Using the median value, the research team estimates that the cost of the capsule is $9,500, with 1.875 capsules per kilometer (50 percent capacity of the tube-freight system).

3.1.10 Summary of Capital Costs

All the base estimates given are order of magnitude estimates of the cost of construction. Hence, it is imperative to add an allowance that would account for design, project management, and contingencies. The contingencies account for factors such as:

1) the assumed cost indices may not truly represent the real price fluctuations;
2) differences in the scope of work on previous projects and the one under consideration;
3) potential variations in estimated unit costs as well as the scope of work; and
4) unforeseen conditions that may influence the project costs.

Results of the estimation are summarized in Table 3.8.

Table 3.8 Summary of Capital Costs.

Component	1997 $/450 km one-way
Cost of Right of Way	$18,282,880
Cost of tube installation & track	$812,682,000
Cost of linear induction motors	$211,500,000
Cost of offloading stations (6 stations)	$150,000,000
Cost of capsules (3.75 /km)	$8,015,625
Sub-total	$1,200,480,505
Cost of design, project management and contingencies (25 percent)	$300,120,126
Total:	$1,500,600,631
per one-way km	$3,334,668

The total estimated cost of approximately $1.5 billion translates to a unit cost of $3,334,668 per one-way kilometer for the Dallas–San Antonio corridor. In the absence of more detailed engineering investigations and analysis, this estimate can be considered reasonable for the purpose of feasibility analysis.

3.2 ANNUAL OPERATIONAL EXPENSES (1997 DOLLARS)

Annual operational expenses for the proposed tube-freight system consist of the following three items:

1. GSA–a fixed cost composed of general, sales, administrative, and legal expenses;
2. Energy expense–a variable cost; and
3. Maintenance expenses–a fixed cost.

3.2.1 GSA Expense Estimation

The research team used publicly held gas pipeline transmission companies and water works companies as models for estimating GSA expenses. These companies provide the same basic service as would tube-freight systems—pump fluids from terminus to terminus. The only difference is that tube-freight systems pump solid fluid (i.e., capsules).

As a proxy for estimating GSA expenses, the research team estimated the fraction, p, of net fixed assets (NFA) that gas pipeline transmission companies and water works companies possess (i.e., $p = GSA/NFA$). The value p is then multiplied by the initial cost of the tube-freight infrastructure to arrive at a dollar figure. Annual reports from 19 gas pipeline transmission companies and 9 water works companies were analyzed.

The estimation process involved the following steps:

Step 1. Regress NFA onto GSA using the linear statistical regression model

$$\begin{aligned} GSA_i &= b_{0i} + b_{1i}(\mathrm{NFA}),\ \mathrm{i}= 1, 2 \\ \textit{where}\ i &= 1 \text{ refers to gas pipeline transmission companies} \\ i &= 2 \text{ refers to water works companies.} \end{aligned} \tag{3.1}$$

Thus, the research team has two regression estimates, b_{11} and b_{12}.

Step 2. Calculate p according to

$$p = 0.5\bullet b_{11} + 0.5\bullet b_{12}.$$

Figure 3.3 shows the linear regression for gas pipeline transmission companies, while Figure 3.4 depicts the linear regression for water works companies.

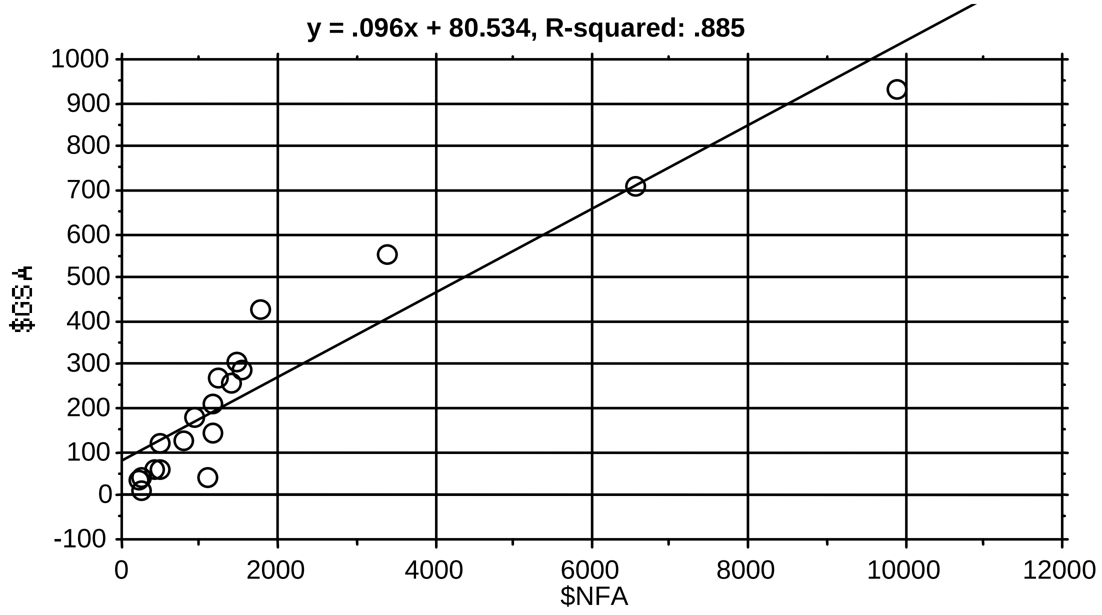

Figure 3.3 Regression for Gas Pipeline Transmission Companies, in $ Millions.

The regression estimates (b_{11} and b_{12}) demonstrate a high degree of "goodness-of fit," as evaluated by the coefficient of determination, R-square (i.e., R-square = 0.88 and 0.98, while 1.0 is a perfect fit).

Thus, the estimate for p is

$$\begin{aligned} p &= (0.5 \bullet 0.096 = 0.5 \bullet 0.145) \\ &= 0.12. \end{aligned}$$

On the average and under ceteris paribus conditions, the estimated annual GSA expenses are 12 cents of every dollar of NFA for the tube transportation system.

From Table 3.8, the research team concludes that the cost of the tube-freight infrastructure is $3,334,668 per kilometer and, therefore, the annual GSA expense would be $401,160 per kilometer.

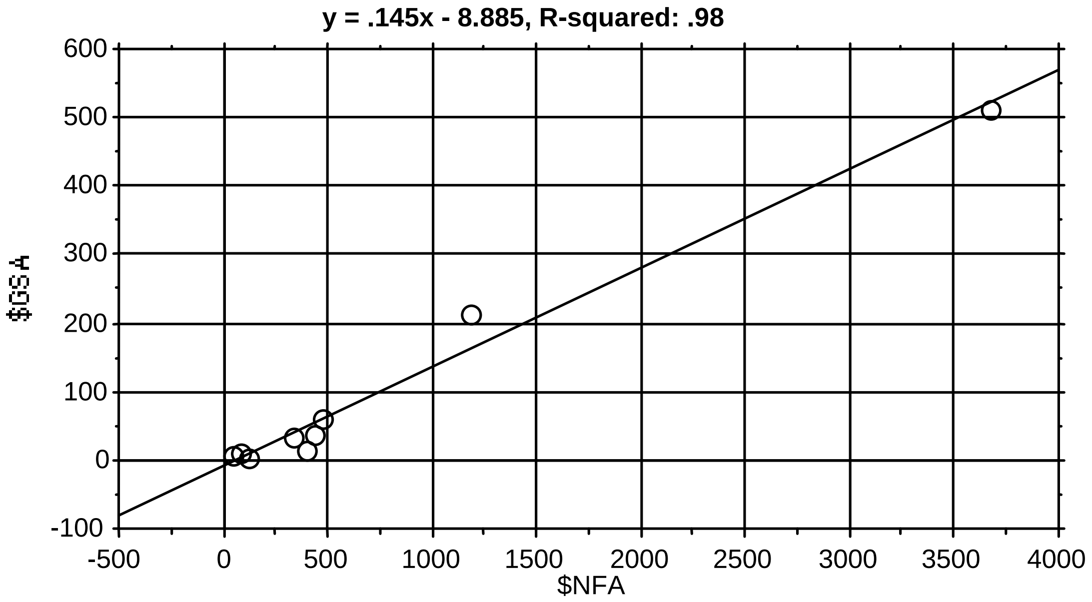

Figure 3.4 Regression for Water Works Companies, in $ Millions.

3.2.2 Annual Energy Expenditures

Energy expenses are variable costs. Three estimates are provided: two by Vandersteel and one by TTI. Vandersteel derived his estimates from estimating energy expenses from similarly powered electric motors, while the TTI estimate is based on the actual characteristics of a LIM.

Since a single capsule travels 27 m/s, the TTI energy estimate for dollars per minute is:

$$\begin{aligned}\$\text{ per min} &= \frac{32\text{ LIMs}}{1\text{ km}} \times \frac{1.609\text{ km}}{1\text{ min}} \times \frac{575\text{ kw}}{\text{LIM}} \times 9.11\text{E-}5\text{ h} \times \frac{\$0.053}{\text{kwh}} \\ &= \$0.143/\text{min.}\end{aligned}$$

A single capsule carries 7.526 Mg over 1.609 km, yielding 11.67 Mg-km/min. Therefore, the TTI energy cost is estimated to be $0.012 per Mg-km ([0.143$/min]/[11.67 Mg=km/min]).

The two estimates provided by Vandersteel were $0.025 per Mg-km and $0.016 per Mg-km. It appears that the higher estimate does not comport with either the latter Vandersteel estimate or the TTI estimate. Thus, this estimate is thrown out, and the research team uses the average of the $0.016 per Mg-km and $0.012 per Mg-km, $0.014 per Mg-km for this project.

3.2.3 Annual Maintenance and Repair Expenses

Because the GSA estimate includes the maintenance and repair of the concrete pipeline system, this section estimates the maintenance and repair expenses for the track/guideway system, the LIMs, the capsules, and stations. Table 3.9 displays the estimate for these annual expenses.

Table 3.9 Estimating Annual Maintenance and Repair (M&R) Expenses.

Component	Initial Cost (IC) per km	Fraction of IC Estimated as M&R	Estimated Annual M&R Cost per km
Track	$ 408,500	0.0100	$ 4,085
LIMs	$ 587,500	0.0075	$ 4,406
Capsules	$ 22,266	0.0050	$ 111
Stations	$ 416,667	0.0075	$ 3,125
Total	-	-	$11,728

All of the fraction estimates, except the track estimate, were based on engineering judgment. They are ballpark estimates; however, Dunn and Bradstreet (1990) report that the average repairs, as a percentage of sales, range from 1.33 percent to 2.31 percent. Since the ratio of net fixed assets to sales is between 0.6 and 1.0, it is surmised that for transportation industries maintenance and repair expenses from 0.8 percent to 2.3 percent of net fixed assets are reasonable. Table 3.10 presents a summary of the estimated annual operating expenses of the LIM-powered tube transportation system.

Table 3.10 Summary of Annual Operating Expenses.

Expense Category	Fixed expense amount per km	Variable expense per Mg-km
GSA (Section 3.2.1)	$401,160	-
Energy expense (Section 3.2.2)	-	$0.014
Maintenance expenses (Table 3.9)	$11,728	-

3.3 CHAPTER SUMMARY

Infrastructure costs of the proposed LIM-powered tube transportation system are estimated to be over $1.5 billion for a one-way 450 km route from San Antonio to Dallas. This is over $3.3 million per kilometer.

The annual operating expenses for this system consist of general, sales, and administrative expenses (fixed expenses), energy expenses (variable expense), and maintenance and repair expenses (fixed expenses). The total fixed costs amount to over $185 million for the one-way 450 km route or over $410,000 per kilometer. The total variable expenses are $0.014 per Mg-km.

CHAPTER 4

ECONOMIC FEASIBILITY OF TUBE-FREIGHT TRANSPORTATION

This chapter sets forth the methodology and evaluation of economic feasibility for the tube transportation system under study. Section 4.1 presents the methodological approach and Section 4.2 estimates the volume, in Mg-km, that capital-market suppliers would require to satisfy their economic demands. Section 4.3 estimates the market volume for tube transportation. Section 4.4 evaluates the economic feasibility of the tube transportation system, in terms of near, intermediate, and long-term feasibility. Finally, Section 4.5 presents a summary of this chapter.

If not stated explicitly, all costs in this chapter are for a one-direction tube transportation system on a per kilometer basis.

4.1 METHODOLOGY

Since this project assumes that the private sector will finance the tube-freight system, the determination of the economic feasibility of a tube-freight system is performed with respect to the requirements of capital-market suppliers. Figure 4.1 provides an overview of the paradigm used to determine economic feasibility.

The paradigm depicts that the volume required to compensate capital suppliers (VRCS), consistent with their required risk-return preferences, must be less than the tube-freight market volume (TM) to be economically feasible.

4.2 ESTIMATING VRCS

The value of VRCS can be determined by

$$VRCS = \frac{\left[\dfrac{RCF - t(I+D) + IVS}{(1-t)}\right] + E}{c} \tag{4.1}$$

where $VRCS$ = *as defined in Figure 4.2*
RCF = *discounted cash flow required by capital-market suppliers*
I = *interest payments*
D = *depreciation*
E = *all expenses before interest, depreciation, and federal taxes*
IVS = *investments to renew infrastructure*
t = *federal corporate tax rate*
c = *contribution margin in terms of dollars per Mg-km.*

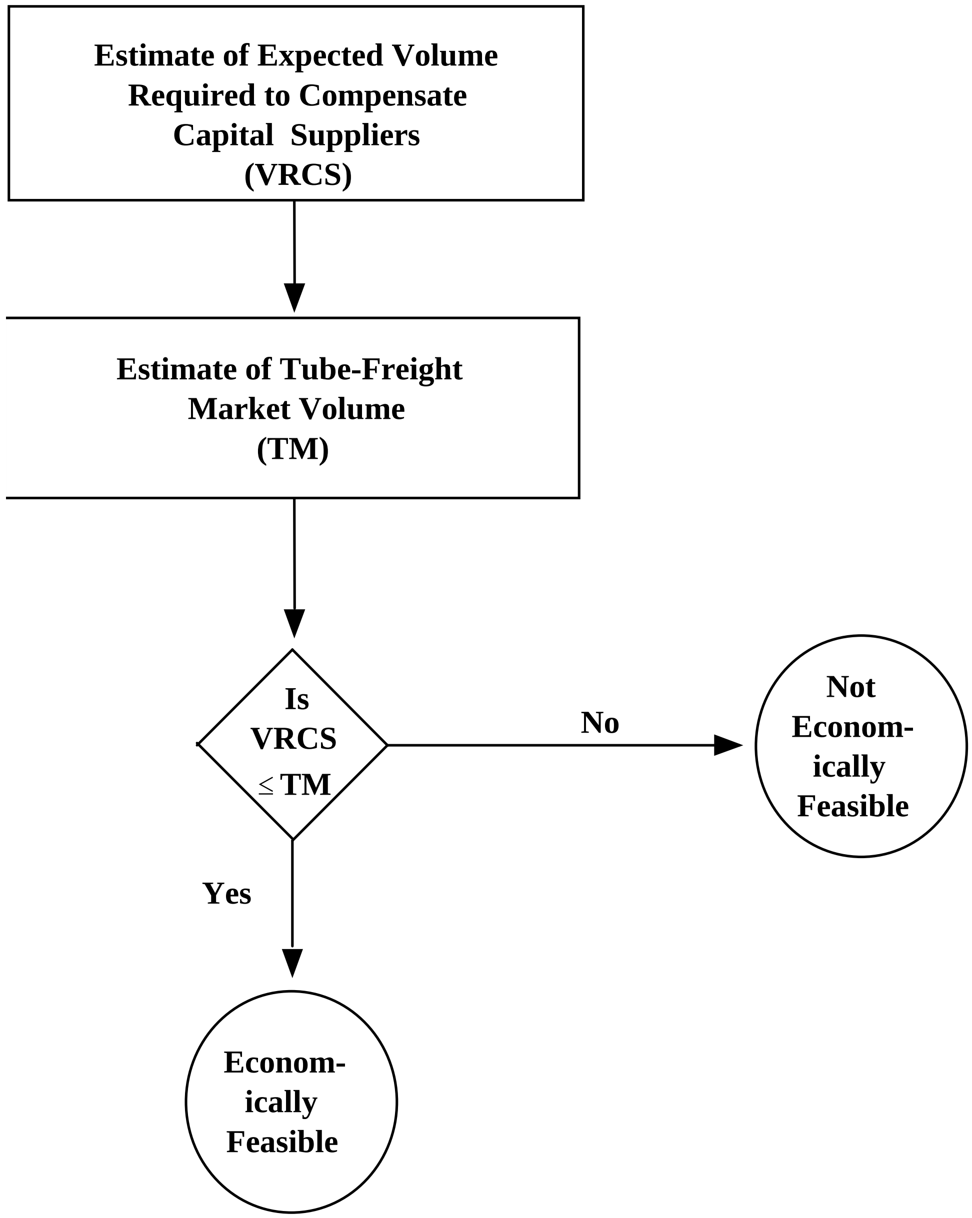

Figure 4.1 Economic Feasibility Paradigm.

In this report, all of the above variables are calculated on an annualized basis and for a one-direction distance of the tube-freight system. In addition, the variables, *VRCS*, *RCF*, *IVS*, and *E*, are estimated for a distance of one kilometer. Since truck-traffic, and hence freight, for the San Antonio–D/FW I-35 corridor is essentially evenly split, the assumption of one-directional traffic is reasonable. The value of *VRCS* is in terms of Mg-km (per km).

Equation 4.1 is nothing more than the break-even point for a firm–a concept typically presented in an introductory accounting text–that has been adjusted for the requirements of capital-market suppliers. The engineering community refers to the variable *RCF* as the annualized capital recovery, discounted by an appropriate capital recovery factor; economists would call *RCF* an opportunity cost. The other variables inside the brackets are adjustments made to convert the bracketed part of the equation to a pre-tax basis, while the constant *c* is in dollars per Mg-km and is needed to convert the right-hand side of the equation to volumetric terms.

The variable *IVS* is the amount of cash invested by the firm to bring their fixed assets back to their original productivity. It is the same concept behind pavement rehabilitation–bringing the pavement back to its original, or nearly original, serviceability. Accountants would refer to it as "economic" depreciation. For estimation purposes, *IVS* is equivalent to *D*, the depreciation.

This project used the corporate tax rate experienced by gas transmission and water works companies as a proxy for the corporate tax rate, *t*, of the proposed tube transportation "corporation." Analysis of these 29 companies reveals that the corporate tax rate ranged from 30 percent to 50 percent. The median of this rate, 40 percent, was used in the calculation in Equation 4.1.

4.2.1 Discount Rate Factors

Capital-market suppliers fall into two basic groups: debt suppliers (bond holders) and equity suppliers (stock holders). Debt suppliers, notwithstanding creditors and bank lenders, have the highest legal claim on a firm's financial assets and require a nearly immediate, certain or nearly certain, specific return of and on their investment (i.e., interest payments and principal re-payments). Because of this lower risk, bond holders are satisfied with a lower return than the capital-market rate (e.g., the Standard and Poor's index of 500 firms is a proxy for the capital market).

In contrast, equity suppliers have the lowest legal claim on the firm's financial assets and their long-run compensation is based on whether or not the firm can generate uncertain economic profits. To compensate stock holders for this higher degree of risk, they require returns higher than bond holders.

Thus, the discount rate used in this project is much different than the discount rate employed by TxDOT, which discounts a project with respect to TxDOT's opportunity cost (i.e., in turn, TxDOT's discount rate is a proxy for the Texas taxpayer's opportunity cost). Figure 4.2 illustrates the relationship between risk and return for capital-market suppliers.

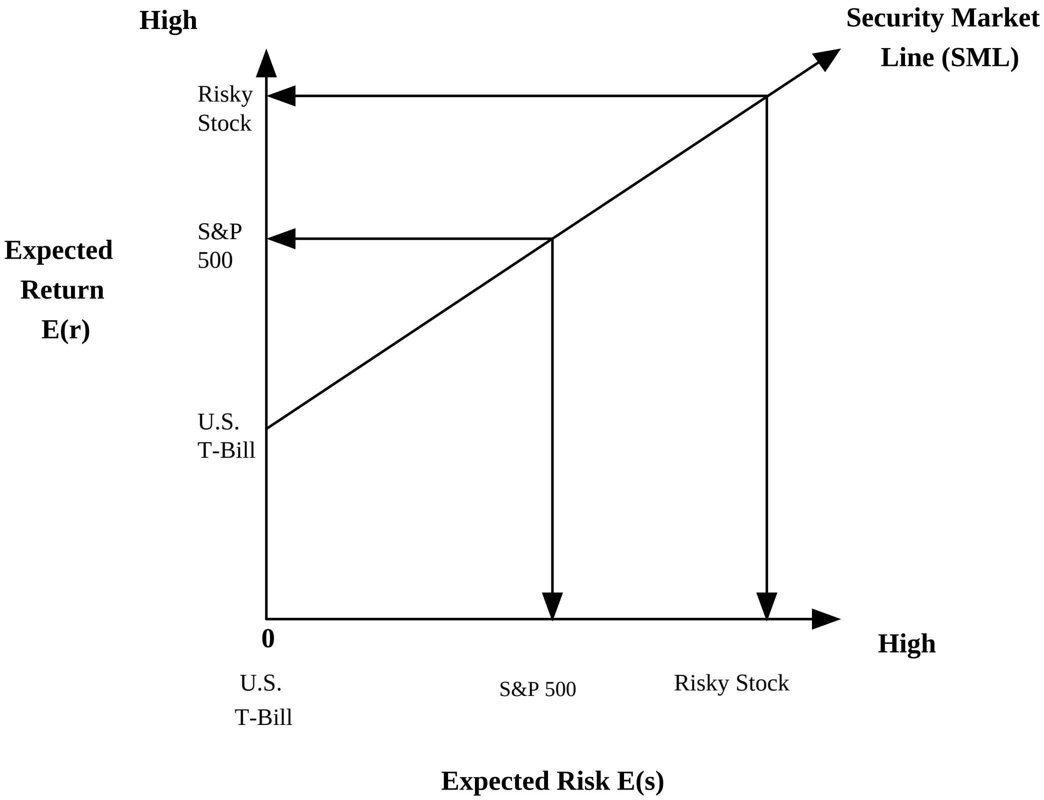

Figure 4.2 Risk-Return Relationship.

. The obvious problem in estimating the appropriate discount rate for this project is determining where on the SML the requisite E(r) and E(s) for debt and equity suppliers of this potential tube-freight system fall. For this system, the research team knows that:

- The system is untested operationally;
- Market participants may erroneously view the system as "space-age" technology;
- The system has an unproved market;
- The market has competitors (trucks and rail);
- System operational costs are more uncertain than those for other modes of freight transportation; and

- Past experience with light rail and commuter rail would suggest that market and information costs are uncertain (e.g., these costs have been overestimated in excess of 46 percent (Pickerell, 1989).

All of these facts indicate high uncertainty; hence, the capital-market would raise its E(s) and corresponding E(r). As a proxy for E(r) for debt suppliers, the research team assumes that their E(s) is at least that of a Standard and Poor’s rating of BB to B-. For 10-year bonds, the historical bond spread premium on U.S. Treasury securities of similar duration is 235 to 575 basis points, for an average rate of 4.05 percent. When added to the current U.S. Treasury 10-year note rate of 5.45 percent, this rate yields an E(r) of 9.5 percent (Bondsonline, 1998).

On the other hand, equity market participants (stock holders) have the opportunity to invest in stocks that have an above average market risk via growth oriented mutual funds, such as those managed by Fidelity Investments. The 10-year average annualized return of Fidelity’s seven growth-funds is 18.5 percent (Fidelity Investments, 1997–1998).

The capital-market suppliers’ overall discount rate would be the weighted-average discount rate of debt suppliers E(r) and equity suppliers E(r). The weighted-average is calculated by

$$k = \Omega \bullet k_d + (1-\Omega)k_e \tag{4.2}$$

where k = *weighted average discount rate*
Ω = *the fraction of the tube-freight system that is financed by debt*
k_d = *discount rate for debt holders*
k_e = *discount rate for equity holders*

Based on an analysis of the financial statements of both gas transmission companies and water works companies, the value Ω is estimated to be 51 percent. Substituting the values of 51 percent for Ω,, 9.5 percent for k_d , and 18.5 percent for k_e into equation 4.2, respectively, the research team obtains k, the discount rate, equaling 13.9 percent. Table 4.1 presents estimates of the useful life of the tube-freight system’s components and the appropriate discount factor.

Table 4.1 Estimated Useful Lives of Infrastructure Components & Applicable Discount Factors.

Component	Useful Life (years)	Discount Factor @13.9%	Comments
Tube	30	0.1419	Life estimated from annual reports of gas transmission & water works companies
Track	25	0.1446	Life estimated, in part, from annual reports of rail companies
LIMs & Control	20	0.1501	Life estimated from annual reports of electrical companies & amusement parks
Stations	40	0.1398	Estimated life derived from engineering judgment
Capsules	15	0.1620	Estimated life derived from engineering judgment

4.2.2 Estimation of RCF

Riggs (1981) provides the general formula for determining the discounted, annualized cash flow required by capital suppliers (RFC) on their investment as

$$A = I \bullet f \tag{4.3}$$

where A = *annualized cash flow*
I = *investment amount in a particular asset*
f = *discount of capital recovery factor.*

The discount factor *f*, in turn, depends upon an interest rate (*k*) from Equation 4.2 and the number of useful years of an asset (*n*). Since the tube-freight transposition system comprises an infrastructure of many different asset types with different useful lives, the calculation of RCF becomes

$$RCF = \Sigma_j \; I_j f_{j,} \quad j=1,\ldots 6 \tag{4.4}$$

where I_j = *investment amount in asset j*
f_j = *capital recovery factor associated with set j.*

Using the data in Table 4.1 and the cost information provided in Chapter 3, the research team uses Equation 4.4 to obtain the total RCF presented in Table 4.2.

Table 4.2 Estimation of RCF (per km basis).

Component	[1] Initial Cost/km	[2] Cost of Contingencies at 25%	[3] Total Initial Cost	[4] Discount Factor, f	[5]=[3]x[4] RCR for each Component
Tube	$1,478,960	$369,740	$1,848,700	0.1419	$262,331
ROW	$40,629	$10,157	$50,786	0.1390	$7,059
Track	$327,000	$81,750	$408,750	0.1446	$59,105
LIMs & Control	$470,000	$117,500	$587,500	0.1501	$88,184
Stations	$333,333	$83,333	$416,667	0.1398	$58,250
Capsules	$17,813	$4,453	$22,266	0.1620	$3,607
Totals	$2,667,735	$666,934	$3,334,669	-	$478,536

4.2.3 Estimated Annual Interest Expense

The annual interest expenses are estimated by

$$I = TC \bullet \Omega \bullet k_d \tag{4.5}$$

where I = *annual interest expenses per km*
TC = *total infrastructure cost per km*
Ω = *fraction of infrastructure cost financed by debt*
k_d = *interest rate on debt.*

Substituting the values $3,334,669 for *TC* (from Table 3.7), 0.51 for Ω and 0.095 for k_d from Section 4.2.1) into Equation 4.5, I equals $164,574 per one-way kilometer.

4.2.4 Estimated Annual Depreciation Expenses, D

The annual depreciation expenses assume a straight-line depreciation schedule and no salvage value. Annual depreciation expenses, per one-way kilometer, are estimated to be $ 119,249, as shown in Table 4.3.

Table 4.3 Estimated Annual Depreciation Expense per km (one-direction).

[1] Component	[2] Estimated Useful Life (years)	[3] Initial Cost ($/km)	[4]=[3]÷[2] Annual Depreciation Expenses ($/km)
Tube	0	1,848,700	61,623
Track	5	408,750	16,350
LIMs & Control	0	587,500	29,375
Stations	0	416,667	10,417
Capsules	5	22,266	1,484
Totals		3,283,883	119,249

4.2.5 Estimating the Contribution Margin (c)

The for-hire segment of the trucking industry is bifurcated into less-than-truckload (LTL) carriers and truckload (TL) carriers. LTL carriers haul shipments that range from about 0.7 Mg to 4.5 Mg, while TL carriers have average shipments of about 14.7 Mg. Additionally, LTL carriers have 22 percent of the for-hire market, based on an analysis of data contained in Bearth (1997) and the Transportation Energy Data Book (Davis, 1995).

Further research and analysis reveal that the average revenue per Mg-km for LTL carriers is $0.171. For TL carriers the revenue rate is $0.056 per Mg-km. A market survey of 1000 Texas manufacturers (51 responses) demonstrated that if tube transportation would charge 20 percent less than current trucking rates, it would gain 15 percent of the for-hire trucking market.

It is assumed that the tube transportation system could have both LTL and TL customers in the same proportion as the for-hire market. Thus the revenue per Mg-km for tube transportation is calculated by

$$\begin{aligned}\$\text{ revenue} &= 0.8[0.22\bullet\$0.171+0.78\bullet\$0.056]\\ &= \$0.065.\end{aligned}$$

By definition, the contribution margin, *c*, is the revenue per unit less all variable costs per unit. From Table 3.9, the variable costs per Mg-km are $0.014, and subtracting this value from $0.065 gives the contribution margin, c, a value of $0.051 per Mg-km.

4.2.6 Estimation of VRCS

In estimating VRCS, the research team used the following values of the variables of Equation 4.1:

- RCF = \$478,536;
- t = 0.4;
- I = \$164,574;
- D = \$119,249;
- E = \$412,888; and
- c = \$0.051.

By substituting the above values into Equation 4.1 and letting *IVS* equal *D*, the research team estimates *VRCS* to be 23,921,196 Mg-km.

4.3 ESTIMATION OF TUBE TRANSPORTATION MARKET (TM)

In this section, the research team estimates a baseline tube market along with near-term, intermediate-term, and long-term estimates of the tube transportation market.

4.3.1 Baseline Estimate of Tube Market (in Mg-km)

Estimating the size of the annual market available for tube-freight usage is calculated by the following formula

$$TM = 300 \bullet N \bullet Mg \bullet P \bullet H \bullet S \qquad (4.6)$$

where

TM = *tube transportation market, in Mg-km*

N = *average annual daily trucks traveling in one direction*

Mg = *average number of megagrams carried by each truck*

P = *fraction of trucks whose goods can be palletized*

H = *fraction of for-hire trucks*

S = *market share of tube transportation (fraction).*

The numerical value 300 represents the number of days of tube-freight operation in a year (John A. Volpe National Transportation Systems Center, 1994).

From TxDOT's 1996 Roadway Inventory Log (RI2-T Log), a random sample of 40 traffic points along I-35 in Bell, Comal, Falls, Hays, Hill, McLennan, Travis, and Williamson counties was collected to estimate *N*, the average annual daily trucks traveling in one-direction. The research team excluded Bexar and Tarrant counties because the traffic between these counties was thought to be more representative of the actual traffic traveling between San Antonio and Dallas/Ft. Worth. Accordingly, *N* equals 4923.

The for-hire truck market is divided into two groups of carriers who haul vastly different masses. These groups are LTL and TL haulers. The average number of megagrams carried by each truck is the weighted average of the mean mass carried by LTL and TL traffic. An analysis of the Pace Report (Truck Fleet Management, 1997) reveals that LTL carriers have a mean haul of 4.535 Mg, and TL carriers have a mean haul of 14.659 Mg. Since LTL carriers comprise 22.2 percent of the for-hire market, and TL carriers make up the remainder (Davis, 1998), Mg equals 12.4 (i.e., 4.535•0.222+14.659•0.778).

We assume that privately operated trucks would not switch to tube-transportation, at least not within a 10–15 year time horizon. Hence, the fraction of privately operated trucks should be removed from the estimated tube freight market. Using data from Bearth (1997), the research team estimates that the fraction of private trucks operating long-distance is about 0.17. Subtracting this fraction from one, *H* equals 0.83 (i.e., 1 – 0.17).

From a survey of Texas manufacturers, the value of *P*, the percentage of goods that can be palletized, equaled 0.68. The 51 respondents also revealed that 15 percent of the Mg-km could be diverted to tube transportation if it would charge 20 percent less than the current trucking prices. Hence, *S* equals 0.15.

Substituting these values for *N, Mg, P, H,* and *S* into Equation 4.4 yields an estimated current market for tube-freight transportation of

$$\begin{aligned} TM &= 300\,(4923) \bullet 12.4 \bullet 0.68 \bullet 0.83 \bullet 0.15 \\ &= 1{,}550{,}426 \text{ Mg-km}. \end{aligned}$$

4.3.2 Estimating Near-term, Intermediate-term, and Long-term Tube Market

Table 4.4 shows how the tube market would reasonably change for the near, intermediate, and long-terms.

Table 4.4 Near to Long-Term Tube Market (in Mg-km).

Eq. 4.6 Variable	Baseline Values	Near-term (5 years)	Intermediate-term (10 years)	Long-term (20 years)
N	4923	6600	7300	8100
Mg	12.4	13.4	14.4	16.4
P	0.68	0.71	0.75	0.83
H	0.83	0.85	0.86	0.88
S	0.15	0.20	0.25	0.35
TM (million Mg-km)	1.6	3.2	5.1	10.2

The assumptions behind Table 4.4 estimates are the following:

- *N* grows at annual rates of 6 percent for the years 0–5, 4 percent for years 0–10 and 2.5 percent (current rate of economic growth) for 0–20 years;
- *Mg* increases by 1 Mg every 5 years;
- *P* grows steadily at 1.0 percent per year as shippers and carriers grow;
- *H* increases by about 3 percent every 10 years (Bearth, 1997); and
- *S* grows 5 percent every five years.

4.4 EVALUATION OF ECONOMIC FEASIBILITY

In all of the time scenarios–near, intermediate, and long-term–the volume required by capital-market suppliers exceeds the market volume for the tube market. However, research conducted to reduce the costs of the tube infrastructure and related expenses concluded that costs could conceivably be reduced by 3 percent per year. Even so, tube transportation is not economically feasible for the near or intermediate term. It may be feasible in the long-term, perhaps 30 years from now.

Since the tube transportation system is not feasible in Texas in the 10–20 year range, the research team concludes that it cannot reduce congestion in Texas along the San Antonio–Dallas corridor parallel to I-35.

4.5 CHAPTER SUMMARY

The research team based economic feasibility on the assumption that the tube transportation system as proposed in this project would be undertaken by the private sector rather than the public sector. Hence, economic feasibility is from the capital-market supplier frame of reference. Tube transportation economic feasibility was defined as occurring when the volume, in terms of Mg-km, required to meet capital-market suppliers demand was less than or equal to the estimated tube market volume.

The analysis contained in this chapter demonstrated that VRCS exceeded TM in the near (5 years) and intermediate term (10 years), even after reducing costs by 3 percent per year. Long-term economic feasibility is a possibility. Nonetheless, the tube transportation system as proposed in this project would not reduce congestion in Texas along the San Antonio–Dallas corridor.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The objective of this project was to determine if freight pipelines (tube transportation) offer a viable means to counteract Texas highway congestion by removing heavy-truck traffic. To achieve this objective, this research consisted of evaluating whether or not tube transportation could meet three necessary thresholds:

- Institutional feasibility;
- Technical feasibility; and
- Economic feasibility.

In evaluating these thresholds, the research team selected a specific corridor (San Antonio–Dallas I-35) and a specific propulsion system (LIMs–linear induction motors).

Institutional feasibility consisted of an evaluation of the governmental regulations, the environmental consequences, and the availability of personnel required for successful operation of a tube transportation system. The tube transportation system would not be subject to the same governmental regulations to which all pipelines must comply. The research team did not believe that the local, state, or federal regulations would pose serious impediments to tube transportation. Environmentally, the LIM-powered tube system is superior to either the truck or rail modes. Additionally, the tube system would not require additional expertise of personnel that would prohibit its successful operation. (Though they certainly would have to develop a technical expertise regarding the manner in which the tube system integrates civil, mechanical, electrical, and computer engineering aspects. However, it would not be an insurmountable hurdle.)

Technological feasibility dealt with the safety and reliability aspects regarding tube transportation; it was concluded that the safety of the tube system was sufficient compared to truck and rail modes. The researchers demonstrated that the reliability of the system compared to trucks would be superior. However, the research team noted that the tube system would involve 14,400 LIMs along the 450 km proposed route. In this case, the reliability of the LIM system would be significantly lower than a single LIM. Overall, the tube system was evaluated to be technologically feasible.

The cost of the tube infrastructure was estimated to be about \$3.3 million per one-direction kilometer. Also, the operational expenses were estimated to be over \$400,000 per kilometer.

The researchers assessed economic feasibility within the context of the system being financed by the capital market. In this context, the tube transportation system would be feasible if the volume necessary to meet the capital-market suppliers' expectations was less than the expected tube transportation system market volume. The volume required to satisfy the capital market exceeded that of the tube transportation's market for the near and intermediate terms (i.e., 5 years and 10 years), though the tube system may have economic feasibility in the long-term (i.e., in excess of 20 years).

Hence, this project concluded that tube transportation could not reduce congestion by removing trucks from the Texas highways, at least not within the next 20 years.

5.2 RECOMMENDATIONS

The tube transportation system proposed in this report suffers critically from high infrastructure costs. Therefore, further research should concentrate on both reducing these costs and finding corridors that have sufficiently high truck-traffic volumes to sustain the return on investment that capital suppliers require.

The following is a list of recommended research:

- Investigation of best corridor with respect to high density of truck traffic in which the cut and cover method of tube installation can be used almost exclusively;
- Research to reduce costs of tunneling;
- Research to develop new installation techniques and improve cut and cover;
- Educate shippers on tube-freight transportation;
- Extensive market research (10,000+ survey instruments);
- Research on feasibility of federal tax abatement;

- Research on public-private partnerships; and
- Study the reliability of the tube-freight system.

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APPENDIX A—ANCILLARY TABLES

Table A3.1 Installed Cost per Meter for (1.8 meter) Pipeline Using Pipe Jacking.*

Project	Original Cost	1997 Cost/meter
White Rock Dixon Branch Interceptor Phase I-a	1994 cost - 1135	4022
White Rock Dixon Branch Interceptor Phase I-b	1994 cost - 757	2684
White Rock Dixon Branch Interceptor Phase III – Part I-a	1995 cost – 882	3127
White Rock Dixon Branch Interceptor Phase III – Part I-b	1995 cost – 886	3140
White Rock Dixon Branch Interceptor Phase III – Part I-c	1995 cost – 990	3507
White Rock Dixon Branch Interceptor Phase III – Part II-a	1996 cost – 921	3081
White Rock Dixon Branch Interceptor Phase III – Part II-b	1996 cost – 861	2881
White Rock Dixon Branch Interceptor Phase III – Part II-c	1996 cost – 884	2959
White Rock Dixon Branch Interceptor Phase III – Part II-d	1996 cost 1009	3376
	Average cost:	3199

* Bid Tab Sheets. “White Rock/Dixon Branch Relief Project,” The City of Dallas, 1994–1996.

Table A3.2 Relationship Between PPE (net) and Operating Costs of Pipelines.

Company	PPE (net) ($ Millions)	Operating Costs ($ Millions)	Operating Costs as % of PPE (net)
Kern River Gas Trans	1082.3	47.2	4.4
Kaneb Pipeline	248.4	14.0	5.6
Transcanada Pipeline	9865.7	933.4	9.5
El Paso Nat. Gas	6527.0	711.2	10.9
Northwest Pipeline	1157.6	147.0	12.7
Laclede	459.9	61.7	13.4
Aquila Gas	399.1	63.6	15.9
Transcontinental Gas Pipeline	3359.7	553.4	16.5
Central Pipeline	779.9	130.5	16.7
Colonial Gas	250.8	43.7	17.4
North Carolina Nat. Gas	195.8	36.0	18.4
Southwest Gas Corp.	1387.5	259.5	18.7
Texas Gas Transmission	1132.2	213.2	18.8
Questar Corp.	1504.3	291.2	19.4
Piedmont Nat. Gas	915.4	182.1	19.9
AGL	1456.0	308.7	21.2
KN Energy	1225.1	270.7	22.1
National Fuel Gas	1764.5	428.1	24.3
NUI	479.1	119.8	25.0
Totals	34190.3	4815.0	
		Average	14.0

Note: PPE (net) refers to Plant, Property, and Equipment after deducting accumulated depreciation.

Table A3.3 Relationship Between PPE (net) and Operating Costs of Gas Water Works Distributors.

Company	PPE (net) ($ Millions)	Operating Costs ($Millions)	Operating Costs as % of PPE (net)
Aquarion	331.6	32.2	9.7
American Water Works	3671.4	511.9	13.9
California Water Works	432.9	37.8	8.7
Consumer Water Works	393.0	13.9	3.5
Dominquez	38.2	7.5	19.6
Middlesex Water Co.	114.8	4.8	4.2
Philadelphia Suburban Co	469.9	59.2	12.6
Southwest Water Co.	76.2	9.9	13.0
United Water Works	1176.2	213.3	18.1
Totals	6704.2	890.5	
		Average	13.3

Note: PPE (net) refers to Plant, Property, and Equipment after deducting accumulated depreciation.

Table A3.4 Estimated Life of Pipelines.

Company	Years
AGL	23
Questar Corp.	13
National Fuel Gas	17
NUI	22
Laclede	18
El Paso Nat. Gas	39
Aquila Gas	16
Piedmont Nat. Gas	24
Colonial Gas	23
Transcanada Pipeline	28
Kaneb Pipeline	21
Central Pipeline	28
Kern River Gas. Trans.	65
Northwest Pipeline	24
Texas Gas Transmission	27
Transcontinental Gas Pipeline	28
KN Energy	23
North Carolina Nat. Gas	20
Southwest Gas Corp.	18
Average	25

Table A3.5 Estimated Life of Water Pipes.

Company	Years
Aquarion	28
American Water Works	37
California Water Works	36
Consumer Water Works	35
Dominquez	28
Middlesex Water Company	40
Philadelphia Suburban Co.	37
Southwest Water Co.	22
United Water Works	36
Average	33

Table A4.1 10-Year Average Annual Returns of Fidelity Growth Funds.

Fund Name	Returns
Contafund	22.60%
Blue Chip	21.20%
Capital Appreciation	14.40%
Growth Company	19.60%
Magellan	18.40%
Over-The-Counter	17.10%
Retirement Growth	16.10%
Total	129.40%
Average	18.50%

Table A4.2 10-Year Corporate Bond (rated BB/B-) Spreads Above 10-Year Treasury Bonds.

	Low	High	Midrange
Bond Spreads	2.5%	5.75%	4.14%
10-Year Treasury Notes Rate			5.4%
Estimated Bond Interest Rate			9.5%

Source: www.bonds-online.com

Table A4.3 Gas Pipeline Gas Companies Long-Term Debt.

Company	Long-Term Debt as % of Total Capitalization
National Fuel Gas	40
AGL	48
NUI	54
Laclede	43
El Paso Nat. Gas	55
Aquila Gas	54
Piedmont Nat. Gas	49
Colonial Gas	44
Transcanada Pipeline	67
Kaneb Pipeline	57
Central Pipeline	56
Kern River Gas. Trans.	56
Northwest Pipeline	56
Texas Gas Transmission	56
Transcontinental Gas Pipeline	56
KN Energy	46
North Carolina Nat. Gas	37
Southwest Gas Corp.	65
Questar Corp.	40
Total	979
Average	52

Table A4.4 Water Works Companies Long-Term Debt.

Company	Long-Term Debt as % of Total Capitalization
Aquarion	54
American Water Works	60
California Water Works	48
Consumer Water Works	61
Dominquez	32
Middlesex Water Company	51
Philadelphia Suburban Co.	53
Southwest Water Co.	41
United Water Works	54
Total	454
Average	50

Table A4.5 1996 Average Daily Trucks (One-Direction) I-35 San Antonio–Dallas.

Data Point	Trucks
1	477
2	5237
3	5110
4	4358
5	3615
6	4358
7	4285
8	4034
9	4528
10	4039
11	5526
12	5526
13	4414
14	4294
15	4628
16	4265
17	4470
18	4181
19	4000
20	3971
21	4181
22	4000
23	5175
24	4074
25	4212
26	4212
27	5327
28	5462
29	6716
30	7589
31	5630
32	4302
33	7535
34	5791
35	5214
36	5458
37	8149
38	4378
39	4200
40	5724
Average	4923

APPENDIX B—SURVEY

TEXAS TRANSPORTATION INSTITUTE
FREIGHT PIPELINE SURVEY

In answering the following questions please assume the following:

(1) the freight pipeline system has less down time than the highway system; and
(2) the freight pipeline network would run parallel to the U.S. Interstate System.

1. Please print name, address, and location of company:
____

2. Please print the name of the person filling out this survey:
____

3. Approximately, how many tons of freight do you **ship by truck** to your customers each year?
____

4. Approximately what is the average distance your product is shipped by truck?
____

5. Approximately what percentage of this freight goes by LTL (less-than-truckload) carrier?
____________%

6. Approximately what percentage of this freight goes by TL (truckload) carrier?
____________%

7. Approximately what percentage of your freight can be put on pallets? ________________
______%

8. If the **freight pipeline** would **CHARGE you 20% MORE** than you are charged now by trucking firms, what percentage of your freight would you **move by freight pipeline?**
____________%

9. If the **freight pipeline** would **CHARGE you the SAME** as you are charged now by trucking firms, what percentage of your freight would you **move by freight pipeline?**
____________%

10. If the **freight pipeline** would **CHARGE you 20% LESS** than you are charged now by trucking firms, what percentage of your freight would you **move by freight pipeline?**
____________%

APPENDIX C—SPECIAL APPRECIATION

SPECIAL APPRECIATION

Due to format policies, this section must be included in an appendix. However, no one should construe that placement equates with importance or worth.

This section is dedicated to those individuals who played a small but very significant part in this research. Many of them were just voices at the end of a telephone line who took time away from their job to assist us. This is a small attempt to recognize these individuls.

In this particular case, the authors express our sincere appreciation to those who responded to our *Survey of Texas Manufacturers* and their companies as well as those unkown workers. The following is a list of respondents:

Harold Draper, Cowtown Spa Covers, Inc., Fort Worth, TX

Terrific Trophies, Wautauga, TX

Jean Astle, Gaby's Shoppe, Dallas, TX

Robert Vest, Alamo Paper Tube Co., Inc., San Antonio, TX

Scott McGinney, Texas Industries, Dallas, TX

Karen Koon, Texas Pottery Supply and Clay, Fort Worth, TX

David Maxwell, Beckette Corp., Irving, TX

K.J. McCarthy, G.W. Plastics, San Antonio, TX

C.L. Werner, Cherin Valley Gardens, Fort Worth, TX

B. Iveragap, X-O Corp., Dallas, TX

Dave Bishop, Jaderloon Southwest, Inc., Fort Worth, TX

Bruce Montgomery, Pharmafab, Inc., Fort Worth, TX

Lowell Gwaltney, Jr., L.G. Machine & Mfg., Inc., Arlington, TX

Brad Cox, Protech Coatings, Inc., Arlington, TX

Steven Buyers, Buyers Co., Fort Worth, TX

Robert J. Hieckarz, Diamond Urethane, Arlington, TX

Charles Scarborough, Aircraft Products, Inc., Dallas, TX

Warren Casteel, Casteel & Associates, Dallas, TX

J.M. Garrison, Sr., Garrison/NAEC, Fort Worth, TX

Melinda Daniels, Kline Engraving, Fort Worth, TX

Mike Havel, Metro Custom Plastics, Arlington, TX

James Sullivan, Architectural Cap Stone Corp., Fort Worth, TX

Stuart Cole, Flow-Dyne Engineering, Inc., Fort Worth, TX

Kay Witt, Whalin Printing Co., Inc., Fort Worth, TX

P.J. Spoor, H.L. Electronics., Arlington, TX

Antje Caffey, Holzschuh America, Fort Worth, TX

Robert Hinderliter, Delco Cleaning Systems of Ft. Worth, Fort Worth, TX

Mark Hull, C&R Engravers, Inc., Fort Worth, TX

J.W. Line, Line Printing Co., Fort Worth, TX

Joe Rodriguez, Leggett & Platt Inc., Fort Worth, TX

Georgia Linam, American Ostrich & Tanning & Mfg.

Thomas Forrest, Texas Foam Inc., Austin, TX

Tim Haugh, Evergreen Paper Recycling, Fort Worth, TX

S.J. Mason III, Star Paper Tube Inc., Arlington, TX

David Milroy, GND Foods, Inc., Arlington, TX

Susan Easterling, Alliance Plastics, Inc., Fort Worth, TX

J.R. Holacka, Nortex Industrial Fan Co., Garland, TX

John Cooper, Texas Leather Trim, Inc., Fort Worth, TX

Virginia Madewell, Carruthers Cut Stone Co., Inc., Fort Worth, TX

M.P. Long, MPL Industries Inc., Dallas, TX

O.J. Garza, Regal Plastics, San Antonio, TX

J.W. Stewart, Datapoint Corp., San Antonio, TX

Mark Naukam, Plastomer, Inc., San Antonio, TX

Dusty Baker, Tuesday Welders Metalworks, Pale, TX

Jim Rollins, Equipto, Dallas, TX

Joe B. Hodges, Sheet Metal Technology Inc., Dallas, TX

Liz Corn, The Knot Hole Cabinet Shop, Killeen, TX

Linda Busteo, Gold Creations, Austin, TX

Adil Said, Money Systems Tech, Inc., Garland, TX

Joe B. Allen, US Single Ply Co., Fort Worth, TX

Ann M. Nycz, Nice Tool Mfg. Co., Inc., Fort Worth, TX

Russell Rodriguez, All-Quality Sign & Mfg. Co., Dallas, TX

Mark Matson, ACF Tarp & Awning, Fort Worth, TX

Shellay Dougherty, Nutrena Feed, Fort Worth, TX

Mike Edgmon, Grinding Specialties, Dallas, TX

Darla Ellis, Creative Fragrances, Dallas, TX

Michael Riffkind, Kittrell/Riffkind Art Glass, Dallas, TX

Chris Corby, Suntex Communications, Inc., Waco, TX

Ronita De Cordova, Tripple "D" Pump Co., Waco, TX

Dunae Brandt, Brandt Precision Machining, Austin, TX

Andy Edgerton, Pure Castings Co., Austin, TX

Alvarado Soto, Abels Copies, Austin, TX

R. J. Penshorn, Alamo Concrete Tiles, Inc., San Antonio, TX

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Frank Chenettem Padgett Printing Co., Dallas, TX

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Dennis Barber, Dennis D. Barber Electronics, Dallas, TX

Della Newman, Speedy's Printing, Austin, TX

Michael E. Cruz, BLD Medical Products, Dallas, TX