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FEASIBILITY OF TUBE TRANSPORTATION TO RELIEVE HIGHWAY CONGESTION

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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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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

IMPLEMENTTION RECOMMENDATIONS

The information contained in this project will aid TxDOT administrators and decisions makers in assessing the capabilities of tube or freight pipeline transportation in terms of institutional, technological, and economic feasibility. Additionally, this research provides a framework for evaluating alternative solutions to reducing congestion caused by heavy trucks.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND AND SIGNIFICANCE OF PROJECT

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 Texas appear to be rooted in the dual role of highways: transporting both people and freight. Unfortunately, this causes financial, environmental, and safety difficulties as well. For example, to increase the capacity of highways due to congestion, the number of lane-miles must be increased. Because heavy trucks are allowed on these same thoroughfares, the thickness of pavement must be increased from between three to six times greater than that required for passenger cars alone. As a result, the fiscal realities are that:

- highway freight transportation is heavily subsidized by passenger-car drivers (i.e., in Texas, combination trucks pay only about 70 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 materials testing system (MTS) 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 (Research Report 1326-2, Table B.5 McCullough et. al, 1996), assuming trucks account for 85 percent of maintenance costs, assuming 4 percent annual traffic growth rate.

1.2 PROBLEM FACING TXDOT

As stipulated in the Intermodal Surface Transportation Efficiency Act (ISTEA), the United States mobility must be maintained while the increasingly aggravated congestion on our roadways must be relieved without sacrifice to either personal safety or the environment. This, 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, a fully automated freight transport system can be developed. 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:

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

1.4 RESEARCH APPROACH

Figure 1 presents the research approach used in this project. It is easy to see that the key components are the three feasibilities. 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.

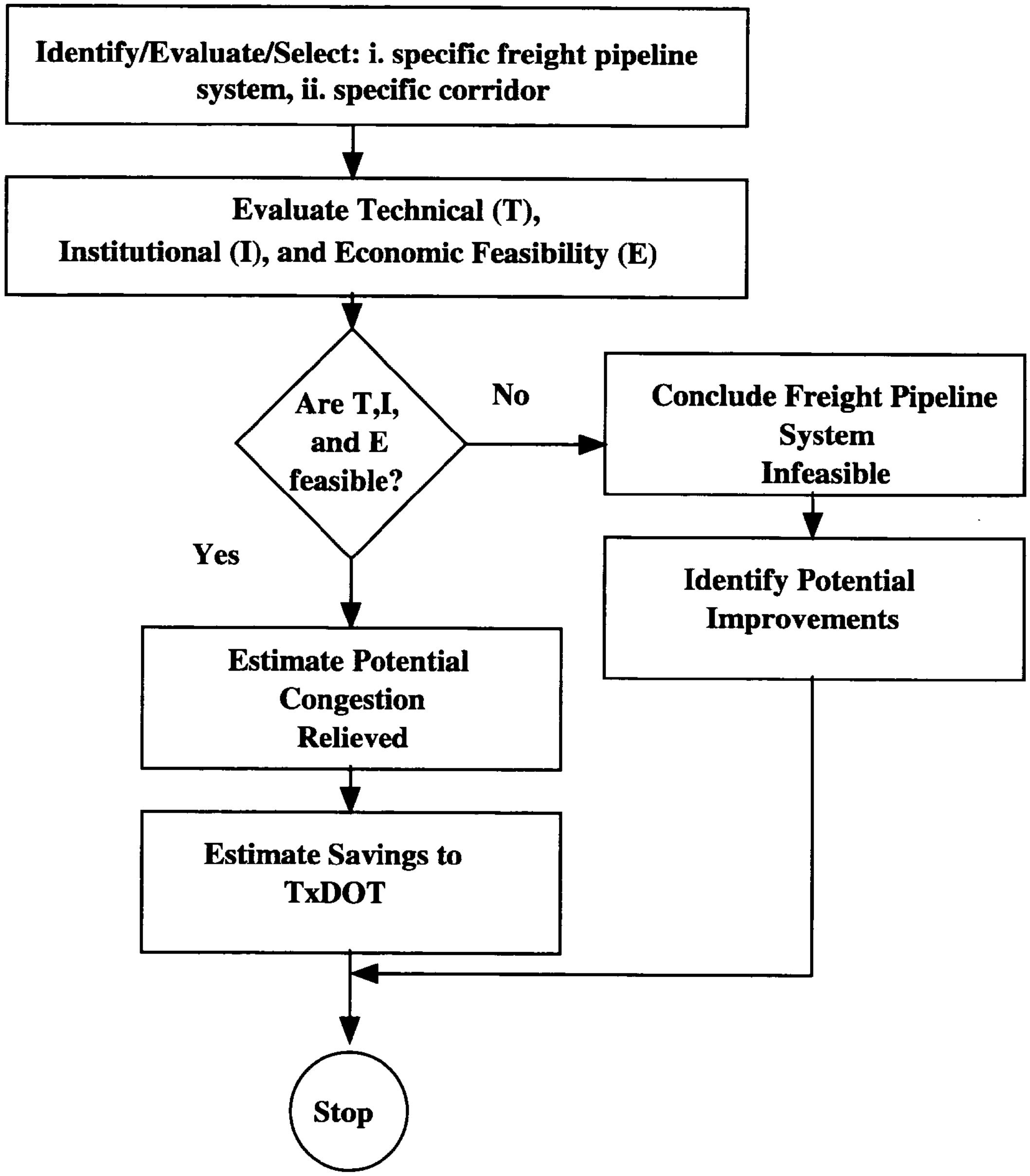

Figure 1. Research Approach.

CHAPTER 2. SELECTION PROCESS AND QUALITATIVE FEASIBILITY ANALYSES

2.1 THE SELECTION PROCESS

2.1.1 Corridor Selection

Eight corridors were evaluated on their relative advantages and disadvantages. Advantages were limited to the following: desirable existing congestion; high potential for a pipeline market; and high conductivity potential. Disadvantages were limited to estimated pipeline infrastructure installation costs and whether or not a change in pipe diameter would require an increase above 2 m.

Table 1 presents an evaluation of the eight 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).

Table 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

Based on the analysis in Table 1, the San Antonio-D/FW-I-35 corridor was selected.

2.1.2 Propulsion System Selection

There exists two basic choices regarding the propulsion system for the subsurface freight-pipelines system under study: pneumatic blowers (PB) or linear electric motors. Pneumatic capsule pipelines (PCP) systems have shown operational feasibility. According to the John A. Volpe Transportation Systems Center (1994), there are nine PCP systems in operations since 1971. Of these nine systems most of them were built in Russia and Japan. Linear electric motors can either be linear synchronous motors (LSM) or linear induction motors (LIM). According to Zhao and Lundgren (1996) 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 study, a comparison between LIMs and PBs is made in Table 2.

Table 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

The analysis shown in Table 2 reveals that LIMs are a superior propulsion system.

2.2 INSTITUTIONAL FEASIBILITY

Institutional feasibility for the subsurface tube-freight system was evaluated for environmental effects and availability of personnel. It was believed 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 the LIM powered tube transportation system was evaluated with respect to trucks and rail mode. Among the 12 criteria used, the tube transportation system ranks better (i.e., least environmental effect) than either the truck or train mode in 10 of the criteria and is ranked second in the other two criteria. Table 3 presents these results.

Table 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

2.2.2 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, mechanical, electrical, and computer engineers;
- inspectors;
- technicians; and
- quality assurance and reliability.

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

- legal;
- accounting, finance, and record keeping;
- marketing and sales;
- investor relations, employee relations, and public relations; and
- consolidation and freight labor.

As one can see, the tube system would not require many new skills, except those that would require the integration of mechanical, electrical, and concrete components. However, the attainment of this new knowledge is foreseeable in the near future. Thus, the availability of trained personnel and requisite new knowledge is likely to be accomplished in the near term (4-6 years).

2.3 TECHNOLOGICAL FEASIBILITY

Technological feasibility was evaluated on the safety and reliability of the tube-freight system with respect to truck and rail modes.

2.3.1 Safety Effects

Table 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-type transportation.

Table 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, we observe 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, 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.

Potential hazards involving earthquakes, flooding, and drought could affect the integrity of the tube system. Earthquakes could 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.

Droughts are commonplace in Texas and could also cause misalignment since the soil could separate and move a tube section. However, this is not an insolvable problem with the proper reinforcement. Therefore, the risk associated with this particular hazard is acceptable.

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

For all of these reasons, the 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.

2.3.1 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 is presented in Table 5, in terms of mean time between failures.

Table 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.

CHAPTER 3. COST ESTIMATE 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, from the center of the city of Dallas to the center of the city of San Antonio. The diameter of the tube tunnel is proposed to be 2 m. Offloading stations 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 an infrastructure would primarily include the following major cost components:

- cost of right-of-way;
- cost of tunneling/tube installation;
- cost of linear induction motors;
- cost of offloading stations;
- cost of containers/capsules; and
- cost of design, project management, and contingencies.

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 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.

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. Approximately 24 percent of this land is in urban areas.

Additional land acquisition would also be necessary for the offloading stations/terminals. It is estimated 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 6.

Table 6. Land Acquisition Costs for 450 km.

Component	Land (m^2) Required	Land Unit Cost/m^2	Total Cost
Access Shafts/ Ventilation ducts			
• Rural Areas	213,000	\$ 12	\$ 2,556,000
• Urban Areas	67,000	\$ 140	\$ 9,380,000
Offloading stations/terminals	45,000	\$ 140	\$ 6,300,000
Grand Total			\$ 18,282,880

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, oil, and gas pipelines, the tube would be installed at a depth slightly greater than 6 m in urban areas and within city limits, based on the findings in an interview with a utility specialist from TxDOT (1998b).

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).

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 detailed information for the Nast Tunnel, built between 1970 and 1973 in Pitkin County, Colorado. Updating the 1973 cost to 1997 and adjusting for diameter size and geographical region (Dallas), the estimated cost per meter is $2,155.

Another estimate of tunneling costs is provided by research conducted at Massachusetts Institute of Technology (MIT) (Sinfield and Einstein 1998). Using this data set of 52 tunnels (Sinfield and Einstein 1998), the best-fit tunnel cost is $2,625 (national average) for a 2 m diameter tunnel. For the Dallas region, this is $2,267 per meter with an upper bound of $4,111. The upper bound relationship agrees with a Houston-based contractor, who estimated the cost of a 2 m tunnel to be $3,937 per meter. Thus, we have three estimates for tunneling costs: $2,155 per meter, $2,267 per meter, and $3,937 per meter.

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

(RCC) pipes of up to 1.5 m diameter was estimated by 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 7.

Table 7. 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

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 first three estimates given in Table 8 date back to the construction of the Arctic Oil and Gas railroads in early to mid-1970s (Ministry of Transport 1974). The fourth estimate is from the reported cost of construction for the Kennedy Rail Road (Logan 1998).

Table 8. 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

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[1]: $3,937
- Average per meter cost (Low+4[Most Likely]+High)/6 $2,527

[1] This estimate is consistent with the upper bound estimate from the MIT research on past projects

Table 9 provides a summary of tube construction area.

Table 9. 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 km)	2,527	$272,916,000
Tube tunnel installation outside city limits (76% of length) using cut and cover (0.76 x 450 = 342 km)	1,148	$392,616,000
Track structure material and construction	327	$147,150,000
Total Cost:	—	$812,682,000

3.1.7 Linear Induction Motors

Table 10 presents estimates of the cost and installation of the LIM and controls.

Table 10. 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

Since Messrs. 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 infrastructures 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 km segment to be $25 million.

3.1.9 Containers/Capsules

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 researchers estimate that the cost of the capsule is $9,500, with 1.875 per kilometer (50 percent capacity of the tube-freight system).

3.2 ANNUAL OPERATIONAL EXPENSES (1997 DOLLARS)

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 nine water works companies were analyzed.

The estimation process involved the following steps:

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

$$GSA_i = b_{0i} + b_{1i}(NFA),\ i = 1, 2$$

where i = 1 refers to gas pipeline transmission companies

i = 2 refers to water works companies.

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

Step 2. Calculate p according to

$$p = 0.5^* b_{11} + 0.5^* b_{12}.$$

The regression estimates for b_{11} and b_{12}, gas pipeline transmission companies, and water works companies, respectively, are 0.096 and 0.145. They demonstrated a high degree of "goodness-of fit," having coefficients of determination of 0.88 and 0.98 (1.0 is a perfect fit).

Thus, the estimate for p is

$$p = (0.5^*0.096 = 0.5^*0.145)$$
$$= 0.12$$

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.

Since the cost of the tube-freight infrastructure is $3,334,668 per kilometer the annual GSA expense would be $401,160 per kilometer.

3.2.2 Annual Energy Expenditures

Energy expenses are variable costs. Three estimates are provided: two by William Vandersteel and one by the Texas Transportation Institute (TTI). Vandersteel's were derived from estimating energy expenses from similarly powered electric motors, while the TTI estimate is based on the actual characteristics of an LIM.

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

$$\$\text{ per min} = \frac{32\text{ LIMs}}{1\text{ km}} \times \frac{1.609\text{ km}}{1\text{ min}} \times \frac{575\text{ kw}}{\text{LIM}} \times 9.11\text{E-5 h} \times \frac{\$0.053}{\text{kwh}}$$

$$= \$0.143$$

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.

The two estimates provided by Mr. 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 study.

3.2.2 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 system, the LIMs, the capsules, and stations. Table 11 displays the estimate for these annual expenses.

Table 11. 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, Dun and Bradstreet (1990) reports 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, maintenance and repair expenses for the transportation industry range from 0.8 percent to 2.3 percent of net fixed assets; this range includes the above estimate of $11,728.

3.3 Summary of Capital Costs and Operational Expenses

All the base estimates given previously are order of magnitude estimates of the cost of construction. Hence it is imperative to add an allowance which 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 12.

Table 12. Summary of Estimated 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 %)	$ 300,120,126
Total:	$1,500,600,631
per one-way km (rounded)	$3,334,668

The total estimated cost of approximately *$1.5 billion translates to a unit cost of $3,360,000 per one-way km 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 analyses.

Table 13 presents a summary of operational expenses.

Table 13. Summary of Estimated 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	-

CHAPTER 4. ECONOMIC FEASIBILITY OF TUBE-FREIGHT TRANSPORTATION

4.1 METHODOLOGY

Since this project assumes the tube-freight system is financed by the private sector, the determination of the economic feasibility of a tube-freight system is performed with respect to the requirements of capital-market suppliers. Figure 2 provides an overview of the paradigm used to determine economic feasibility.

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

4.2 ESTIMATING VRCS

The value of VRCS, can be determined by

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

where	*VRCS*	=	*as defined in Figure 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.*

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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 1 km. 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 given in terms of Mg-km (per km).

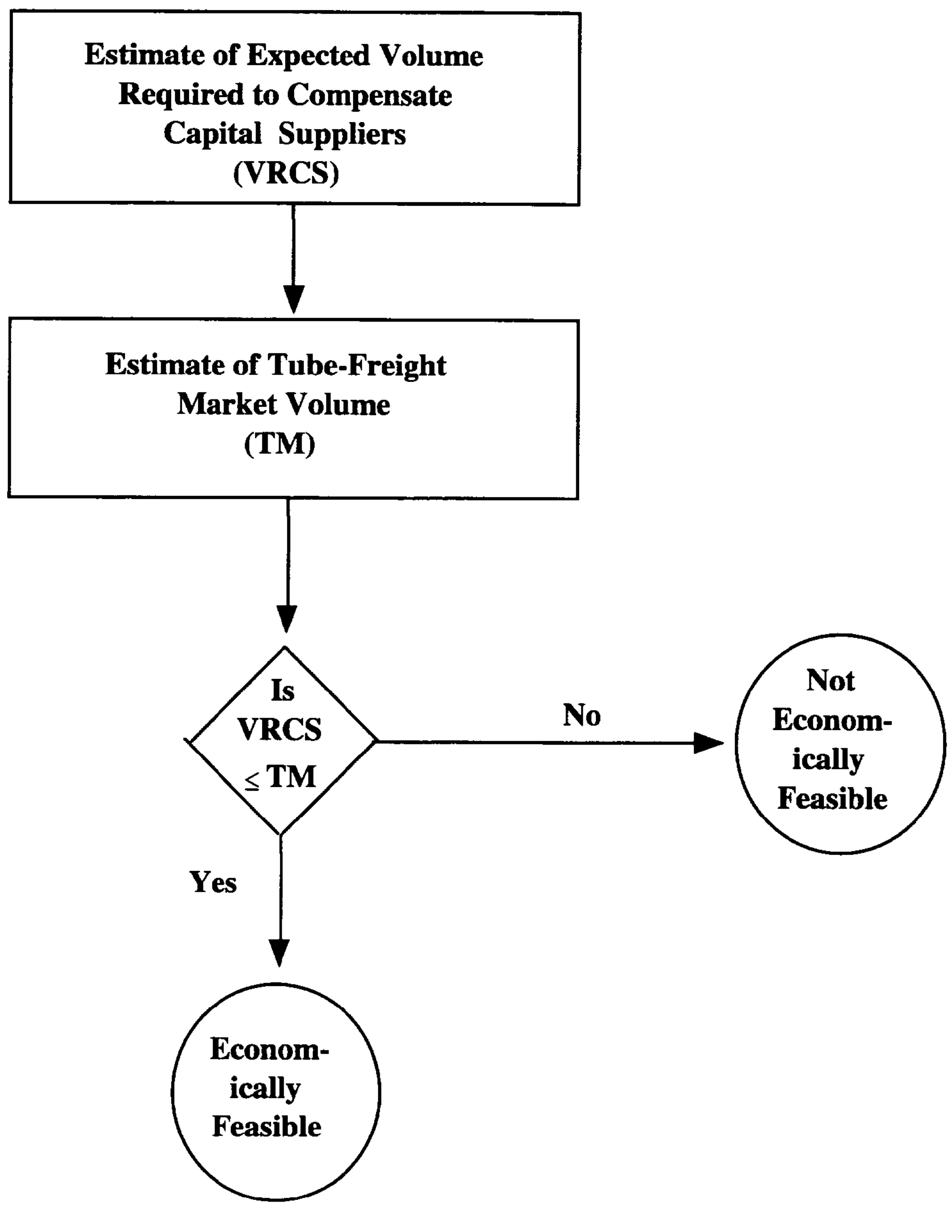

Figure 2. Economic Feasibility Paradigm.

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.

4.2.1 Discount Rate Factors

Capital-market suppliers fall into two basic groups: debt suppliers (bond holders) and equity suppliers (stockholders). Debt suppliers 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 stockholders for this higher degree of risk, they require returns higher than bondholders.

We know that a new firm with unproven market ability is inherently more risky than ongoing firms. Therefore, both debt and equity holders would demand a higher rate of return.

As a proxy for the expected return for debt suppliers we assume that their risk 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 2.35 percent to 5.75 percent 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, it yields an expected return of 9.5 percent (BondsOnline 1998).

On the other hand, equity market participants (stockholders) 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 1998).

The capital-market suppliers' overall discount rate would be the weighted-average discount rate of debt suppliers', and equity suppliers' returns. The weighted-average is calculated by

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

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, 9.5 percent, and 18.5 percent into Equation 4.2 for Ω, k_d, k_e, respectively, we obtain k, the discount rate, equaling 13.9 percent.

Table 14 presents estimates of the useful life of the tube-freight system's components and the appropriate discount factor.

Table 14. 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

RCF is the discounted annualized cash flow required by capital suppliers. It estimates the annualized cash flows required by capital suppliers of and on their investment. The discount factor, in turn, depends upon an interest rate, k, and n, the number of useful years of an asset. Since the tube-freight transportation system comprises an infrastructure of many different asset types with different useful lives, the calculation of RCF becomes:

$$RCF \quad = \quad \sum_j I_j f_j, \quad j=1,\ldots 6 \qquad (4.3)$$

where I_j = *investment amount in asset j*

f_j = *capital recovery factor associated with set j.*

Using the data in Table 14 and the cost information provided in chapter 3, we use Equation 4.3 to obtain the total RCF presented in Table 15.

Table 15. 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 Corporate Tax Rate, t

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 reveal 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.

4.2.4 Estimated Annual Interest Expense

The annual interest expenses are estimated by

$$I = TC*\Omega*k_d \tag{4.4}$$

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 (Table 12), 0.51, and 0.095 (section 4.2.2) into equation 4.4, I equals \$164,574 per one-way km.

4.2.5 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 calculated in Table 16. *The annual depreciation expenses, per one way km, are estimated to be \$119,249.*

Table 16. 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	30	1,848,700	61,623
Track	25	408,750	16,350
LIMs & Control	20	587,500	29,375
Stations	40	416,667	10,417
Capsules	15	22,266	1,484
Totals		3,283,883	119,249

4.2.6 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. Additionally, LTL carriers have 22 percent of the for-hire market, based on an analysis of data contained in report by 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 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:

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

By definition, the contribution margin, *c*, is the revenue per unit less all variable costs per unit. From Table 13 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.

4.2.7 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, *VRCS is estimated to be 23,921,196 Mg-km.*

4.3 ESTIMATION OF TUBE TRANSPORTATION MARKET

In this section, a baseline tube market is estimated 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:

$$TM = 300N \bullet Mg \bullet P \bullet H \bullet S \qquad (4.5)$$

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

N = *average annual daily trucks traveling in 1*-direction,

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

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

H = *fraction of for-hire trucks, and*

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 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 sample 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 (Bearth 1997; Davis 1998), Mg equals 12.4 (i.e., 4.535*0.222+14.659*0.778).

It is assumed 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 respondents (N=51) 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 values *N, Mg, P, H,* and *S* into Equation 4.5 yields an estimated current market for tube-freight transportation of:

$$TM = 300\,(4923)*12.4*0.68*0.83*0.15$$
$$= 1{,}550{,}426\ Mg\text{-}km$$

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

Table 17 shows how the tube market, TM, would reasonably change for the near-, intermediate-, and long-term market. The assumptions behind Table 17 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.

Table 17. Near-to-Long-Term Tube Market (in Mg-km).

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

4.4 EVALUATION OF ECONOMIC FEASIBILITY

In all of the time scenarios—near-, intermediate-, and long-term—the volume required by capital-market suppliers (VCRS) 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, we conclude that it cannot reduce congestion in Texas along the San Antonio–Dallas corridor parallel to I-35.

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).

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. It was not believed 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.

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 reliability of the system, compared to trucks, demonstrated that the LIM-powered tube system would be superior.

The costs of the tube infrastructure were estimated to be about $3.3 million per one-direction km. 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 the 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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